

**INDOOR AIR QUALITY: A STUDY ON VOC
EMISSIONS FROM OFFSET PRINTING
SHOPS IN KOTA BHARU, KELANTAN**

by

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LIST OF ABBREVIATIONS AND SYMBOLS

C	Ceiling Limit
CDC	Centers for Disease Control and Prevention
CO	Carbon monoxide
CO ₂	Carbon dioxide
cfu/m ³	Colony forming units per cubic meter
DCI	Development Composite Index
DOSH	Department of Occupational Safety and Health
df	Degree of Freedom
EPA	Environmental Protection Agency
EPU	Economic Planning Unit
etc	Et cetera
<i>et al.</i>	Et alii
FP	Fine Particles
H ₀	Null hypothesis
H _A	Alternative hypothesis
HP	Hewlett-Packard
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IARC	International Agency for Research on Cancer
Ibid	Ibidem
ICOP	Industry Code of Practice
IPA	Isopropyl alcohol
LED	Light Emitting Diode
m ²	meter per square
m ³ /h	cubic meters per hour
m/s	metre per second
MDH	Minnesota Department of Health
MPKB	Majlis Perbandaran Kota Bharu
MVAC	Motor Vehicle Air Conditioning
NEI	National Emissions Inventories

NIOSH	National Institute for Occupational Safety and Health
NO _x	Nitrogen oxides
O ₃	Ozone
OH	Hydroxide
OSHA	Occupational Safety and Health Administration
pH	Potential of hydrogen
PID	Photo Ionization Detection
PM	Particulate matter
PNMB	Percetakan Nasional Malaysia Berhad
ppm	parts per million
PEL	Permissible Exposure Limit
SBS	Sick Building Syndrome
SOA	Secondary Organic Aerosol
SPSS	Statistical Package for Social Sciences
STEL	Short Term Exposure Limit
SVOC	Semivolatile organic compounds
TLV	Treshold Limit Value
TSP	Total Suspended particles
TVOC	Total Volatile Organic Compounds
TWA	Time weighted average
UFP	Ultrafine Particles
UPM	Universiti Putra Malaysia
USEPA	United States Environmental Protection Agency
µm	Micrometer
VOCs	Volatile Organic Compounds
WHO	World Health Organization
%	Percent
°C	Degree Celcius

NIOSH	National Institute for Occupational Safety and Health
NO _x	Nitrogen oxides
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KUALITI UDARA DALAMAN: KAJIAN PELEPASAN *VOC* DARI KEDAI PERCETAKAN OFSET DI KOTA BHARU, KELANTAN

ABSTRAK

Industri percetakan menghasilkan kuantiti yang besar sebatian organik meruap (*VOC*) yang memberi impak kepada kualiti udara di tempat kerja dan kawasan persekitaran. Sumber *VOC* adalah pelbagai dan meluas semasa proses percetakan. Dua kedai percetakan ofset yang dipilih terlibat dalam pemantauan kepekatan *VOC* termasuklah aktiviti mereka. Kadar pelepasan kepekatan *VOC* diukur menggunakan *Multi Photoionization Detector (PID)* selama empat minggu. Kepekatan *VOC* melawan masa persampelan (pagi, tengah hari dan petang) dianalisis menggunakan ujian Kruskal Wallis. Purata pelepasan *VOC* adalah di antara 0.615 ppm hingga 8.259 ppm di Kedai A, manakala, purata bacaan bagi kedai B direkodkan daripada 0.070 ppm hingga 2.852 ppm. Purata *VOC* di kedua-dua kedai menunjukkan bacaan kepekatan *VOC* adalah yang tertinggi pada waktu pagi. Fenomena ini juga berlaku disebabkan oleh kehadiran pelbagai sumber *VOC* lain, bukan sahaja hasil daripada operasi mencetak. Ia juga disebabkan oleh kesan daripada pengumpulan semalaman ke atas kepekatan *VOC*. Ujian Kruskal Wallis menunjukkan nilai p untuk kedua-dua kedai adalah kurang daripada 0.05 iaitu 0.034 (Kedai A) dan 0.001 (Kedai B). Hal ini menunjukkan bahawa keputusan ini signifikan dan hipotesis null ditolak. Di samping itu, proses percetakan, pembersihan sarung atau gelung dakwat (larutan pencuci) dan dakwat percetakan dikenalpasti sebagai sumber yang berpotensi menjadi bahan pencemar udara di kedai percetakan. Kesimpulannya, percetakan ofset menyumbang kepada kepekatan *VOC* yang tinggi terutamanya bagi udara dalaman di kedai percetakan.

INDOOR AIR QUALITY: A STUDY ON VOC EMISSIONS FROM OFFSET PRINTING SHOPS IN KOTA BHARU, KELANTAN

ABSTRACT

Printing industry emits large quantities of volatile organic compounds (VOCs) that impact to the air quality of the workplace and ambient of air quality. The sources of VOCs are numerous and widespread through the printing process. Two selected offset printing shops were involved for monitoring of VOC concentration including their activities. Emission rates of VOC concentration were measured by using Multi Photoionization detector (PID) for four weeks. The VOC concentration against time of sampling (morning, afternoon and evening) was analyzed by using Kruskal Wallis test. The VOC emission, ranged from 0.615 ppm to 8.259 ppm at Shop A, while, the average reading for Shop B were recorded from 0.070 ppm to 2.852 ppm. Average VOC concentration at both shops shows the VOC concentration reading was the highest in the morning. This phenomenon also occurred because of various sources of VOC presence, not only came from the photocopier operation. It also because of the effect from overnight accumulation of the VOC concentrations. Kruskal Wallis test shows that the p -values for both shops are less than 0.05 which are 0.034 (Shop A) and 0.001 (Shop B). This indicates that the result were significant and null hypothesis were rejected. Besides, printing process, blanket or ink roller cleaning (cleaning solvents) and putting inks were found as a potential sources of air pollutants at printing shops. It was concluded that offset printing contribute to high concentration of VOCs especially to the indoor air at printing shops.

CHAPTER 1 .

INTRODUCTION

1.1 Background of The Study

Currently, indoor air quality (IAQ) is one of the health issues among the workers or occupants. This is because IAQ is very complex and occupants are potentially exposed to various contaminants. Moreover, the contaminants are in the form of gas and particles such as from office machines, cleaning products, construction activity, carpets and furniture, perfumes, smoke, water damaged building materials, the growth of microbes (fungi and bacteria), insects, and external pollutants. Besides that, temperature, relative humidity, and ventilation levels are the other factors of IAQ that affect the way individuals respond to an indoor air (Centers for Disease Control and Prevention (CDC^a), 2013).

The average person spends 90% of time inside the buildings. Unfortunately, indoor air is much more polluted than outdoor air. According to the Environmental Protection Agency (EPA), indoor air contains two to five times more contaminants and on occasion, as much as 100 times more. The one of the most serious environmental threats to the health is indoor air pollution but nobody can control it, and few studies have been done about its effects on the health (USEPA, 2014).

There are various emission sources of chemical contaminants in indoor air, such as volatile organic compounds (VOCs). In fact, VOCs are easily evaporated into air at room temperature. VOCs are often regarded as one of the main indoor pollutant, because of their continued emission from a variety of sources and their

diffusion properties. VOCs are defined as a large group of carbon-based chemicals or hydrocarbons including acetone, benzene, ethylene glycol, formaldehyde, methylene chloride, perchlorethylene, toluene, xylene and 1,3-butadiene (Minnesota Department of Health (MDH), 2013).

VOCs are emitted from the use and application of solvents (DOSH, 2010). Photocopiers are sources of office indoor air pollution. Toner and dispersant from photocopiers contain heavy-treated naphtha, a mixture consisting primarily of decane, which is known to be toxic to humans (Posudin, 2010).

In addition, irritating fumes are produced from copying and printing machines. A copier is a photocopying device that allows users to create duplicate copies of a document or an image, which is too cheap. Photocopiers are used in many work places, a good source of employment and common machines (refer Appendix A (Figure A1)). The machine works on simple electronics. It just projects light on the document placed on the glass plate, the ink in the roller blade clings to the image area as per the alignment of electrically charged particles on the paper and reproduces or photocopies the original document. Toner is the main component of photocopying machine that mainly consists of carbon black (7%), polycyclic aromatic hydrocarbons (PAHs), styrene, magnetite, nitropyrenes, benzene, toluene, other volatile substances (Gadhia *et al.*, 2005).

Printer also emit the chemical around the shops. A solid copy of the digital data that is represented on the computer screen is created by peripheral device known as printer (refer Appendix A (Figure A2)). A peripheral device is a device that connects to a computer system to add functionality. For examples are a mouse,

keyboard, monitor, printer and scanner. Generally, the printing offices perform the maintenance duties with staff small in number (Csaba & Zoltan, 2008).

A number of industrial activities make use of chemical products containing volatile organic compounds (VOCs), which are widely used mainly due to their high volatility. Among the activities that can result in the emission of such compounds in its working environments are the offset printing processes. The offset printing which is the most commonly used as a printing method today (refer Appendix A (Figure A3)). Over 40% of all print jobs are carried out using offset printing. Offset printing invades every aspect of the lives from influencing education through the printing of books, periodicals and other reading material to the packaging industry by creative printing of packages for consumer goods. Furthermore, offset printing is the printing technique that has made newspapers possible and books affordable (Maja *et al.*, 2011).

Photocopiers use toner, an extremely fine powder, as part of the printing process. Toner may cause respiratory tract irritation resulting in coughing and sneezing in substantial quantities. Furthermore, it can also be an irritant to those with respiratory conditions such as asthma or bronchitis. There are a few situations where one could be accidentally exposed to toner dust. The example is toner dust spilled inside the machine could become airborne after passing through the ventilation fans into the room. Another example is there could be a spillage when one is replacing the toner cartridge. Toners may contain up to 7% carbon black. Carbon black becomes a cause for concern when a group of Swedish scientists noticed that certain toners caused genetic changes in bacterial test systems, and it was later regarded as a possible carcinogen for humans (Cormier *et al.*, 2006)

This study was involved two selected printing shops in Kota Bharu as a sampling area. According to Development Composite Index (DCI), Kelantan was listed as one of the least developed regions in Malaysia. Figure 1.1 shows the chart of the level of urbanisation by state, Malaysia which its proven by census 2010. It revealed that the states with lower urbanisation levels were Kelantan (42.4%), Pahang (50.5%) and Perlis (51.4%) (Department of Statistics, 2010). Government was planned to develop new growth area in Kelantan as first step for development plan (Economic Planning Unit (EPU), 2012). Therefore, it started with Kota Bharu which is the most developing areas in Kelantan and this is the reason for

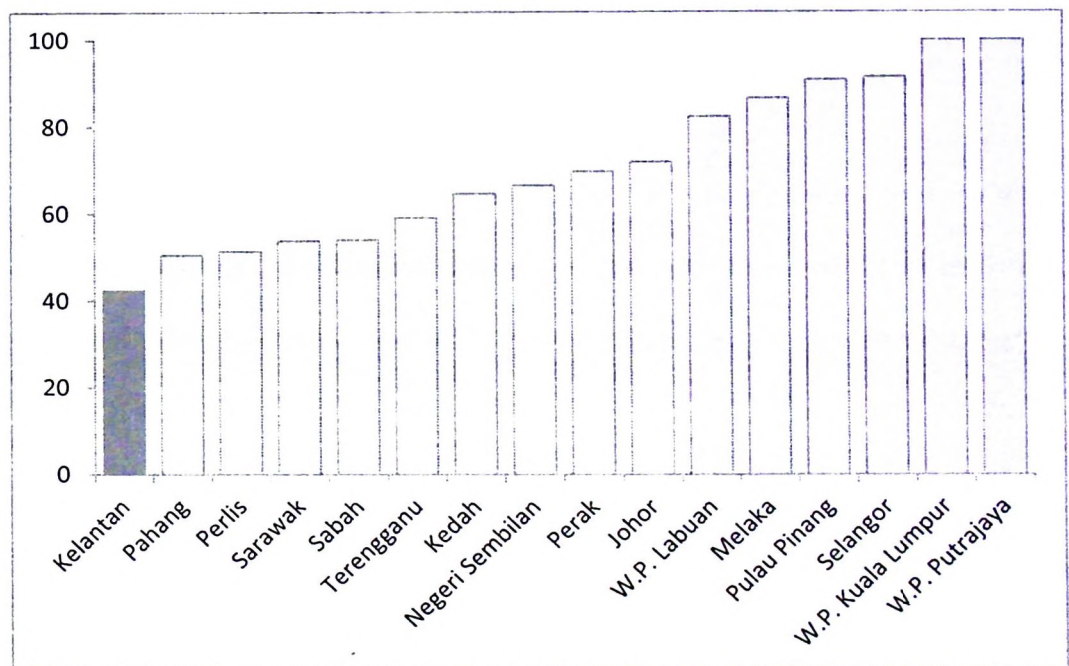


Figure 1.1: The chart of the level of urbanisation by state, Malaysia, 2010.
(Source: Department of Statistics, 2010)

1.2 Problem statement

The problems of exposure to indoor air pollutants is indoor air in the buildings. A growing body of scientific evidence was indicated in the last several years, that the air within homes and other buildings can be more seriously polluted than the outdoor air in even the largest and most industrialized city. Approximately 90% of their time people use in indoor environments such as residences, public buildings and offices. The concentrations of many pollutants are frequently higher than in outdoor urban air. For example, office workers would occupy their offices or other buildings for about eight hours per day and for five days per week. Hence, the quality of the indoor air they breathe is critical for their health and well-being (Jalaludin *et al.*, 2014).

VOCs are one of the chemical sources that affect indoor air pollutants. VOCs that commonly exist in high concentrations indoors are classified as hazardous chemicals. VOCs are released from consumer products, such as aerosol sprays, solvents, glues and adhesives, cleaning products, paint, air fresheners, building materials, furnishings, office equipment, carpet, craft supplies and dry cleaning chemicals on recently treated clothing. Photocopiers not only produce VOCs from their process but they emit small dust. Laser printers and photocopiers may be substantial sources of gaseous emissions as well as emitters of fine and ultrafine particles (Bake & Moriske, 2006). The symptoms of this emission include asthma and pseudo allergic inflammations of the respiratory tracts, irritations of the skin and eyes, headache and sick building syndrome (Kagi *et al.*, 2007; Jaakkola *et al.*, 2007).

According to EPA's National Emissions Inventories (NEI), the domestic printing industry ranks fifth in VOC's emissions among major industries. The

automobile industry ranks sixth that was behind printing industry which are put this ranking in perspective. In the United States (US) printing industry, pollution was emitted from this industry is dispersed among 34,146 firms, with 70% of them employing less than 10 employees (Bureau of Labor Statistics, 2006).

In Malaysia, the printing industry is probably also among the top five largest industries in the manufacturing sector. The domestic printing and publishing industry consists mainly of small and medium-scale domestic-oriented manufacturers. There are many companies involved in this sector such as Percetakan Nasional Malaysia Berhad (PNMB), Utusan Printcorp Sdn Bhd, The New Straits Times Press Bhd and Kumpulan Karangraf (Department of Skills Development Ministry of Human Resources, Malaysia, 2012).

There are four primary components of printing inks including varnish, solvent, colorant (may include heavy metals), and additives. During the heating and cooling processes of the varnish, odorous emission from printing process are released, which includes resins, drying oils, petroleum oils, and solvents. The example of common solvents include butanol, ethanol, glycol ethers, heptane, hexane, methanol, mineral spirits, toluene, and xylene (refer Table 1.1) (USEPA, 1995).

Table 1.1: Common solvents used in commercial inks.

Butanol (butyl alcohol)	Ethanol (ethyl alcohol)	Ethyl acetate
Ethylene glycol	Glycol esters	Glycol ethers
Glycol ether esters	Heptane	Hexane
Isocetanol (isooctyl alcohol)	Isopropanol	Isopropyl acetate
Methanol (methyl alcohol)	Methyl chloroform	Methyl isobutyl ketone
Methyl ethyl ketone	Mineral spirits	Normal propyl acetate
Napthas	Propanol (propyl alcohol)	Stoddard solvent
Toluene	Xylene	

(Source: USEPA, 1995)

In the printing industry, most conventional solvents was used by VOC's, and account for the majority of the 101.537 tons of VOC's emitted per year by the printing industry. According to EPA, VOCs emissions from the printing industry are the fifth largest of 18 industrial sectors, placing it just below the fabricated metals industry and ahead of the motor vehicles, bodies, parts, and accessories industry. For a complete list of industries and their associated emissions factors was shown in the Table 1.2 (USEPA, 1995).

Table 1.2: VOC release by industry sector (short tons/year).

Industry sector	VOC emissions
1) Petroleum refining	369,058
2) Organic chemicals	201,888
3) Rubber/plastics	140,741
4) Fabricated metal	102,186
5) Printing	101,537
6) Motor vehicles	101,275
7) Pulp and paper	96,875
8) Iron and steel	82,292
9) Furniture/fixtures	59,426
10) Inorganic chemicals	52,091
11) Lumber production	41,423
12) Stone/clay/concentrate	30,262
13) Nonferrous metals	27,375
14) Dry cleaning	7,310
15) Electronic components	4,854
16) Non-metal mining	1,736
17) Metal mining	1,283

(Source: USEPA, 2007)

The primary causes of indoor air quality problems in homes or offices are from release of gases or particles into the air. Increased indoor pollutant levels

caused by inadequate ventilation which are not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the home or offices. High temperature and humidity levels can also increase concentrations of some pollutants (USEPA^a, 2013).

The duration of working hours is related to concentration of VOCs. The working time of worker is commonly from 8.30 am until 5 pm and the time to rest from 1 to 2 pm. Yet, the duration of working hours for most of printing shops is more than eight hours per day. Besides that, the size of the room was influenced the accumulated of VOCs around in the rooms. This is because the size of the room is related to the physical parameters. There are standard range for all physical parameters that must be met as stated in Table 1.3.

Table 1.3: Acceptable range for specific physical parameters.

Parameter	Acceptable range
(a) Air temperature	23 – 26 °C
(b) Relative humidity	40-70%
(c) Air movement	0.15 – 0.50 m/s

(Source: Department of Occupational Safety and Health (DOSH), 2014).

From health perspective, the exposure of occupants to pollutants such as VOCs, can cause various diseases, including Sick Building Syndrome (SBS). SBS does occur on the workers and customers due to poor ventilation in the printing shop. The term SBS is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified. Generally, the symptoms that experienced by the occupants are cough, chest tightness, fever, chills and muscle aches. The causes of SBS come from chemical contaminants from indoor sources

such as copying machines may emits VOCs. Many researches shows that some VOCs can cause chronic and acute health effects at high concentrations, and some are known carcinogens (USEPA, 1991).

Therefore, clean air is considered to be a basic requirement of human health and well-being. However, current global environment issues are the big concern for the printing industry. Various problems continuously arise, such as global warming issues, waste and recycling, and chemicals controls. Through the evaluation of previous studies on indoor air quality, especially on the used of printers, there are some problems that arise consistently. These problems should be given special emphasis to reduce the impact on human health. In order to ensure this problem does not persist, the study of indoor air pollutants, particularly VOCs was emphasized by this study.

1.3 Research Objectives

There were two types of objectives in this study which are general and specific objectives.

1.3.1 General objective:

To identify the pattern of VOCs accumulated at two selected printing shops in Kota Bharu, Kelantan.

1.3.2 Specific objectives:

1. To compare the concentration of VOCs between two selected printing shops with permissible exposure limit (PEL).
2. To identify the potential sources of VOC concentration at two selected printing shops.

1.4 Hypothesis

Hypothesis were divided into null and alternate hypotheses.

1.4.1 Null Hypothesis

1. There is no significant association the concentration of VOCs between two selected printing shops with permissible exposure limit (PEL).
2. There is no significant association between the potential sources of VOC concentration at two selected printing shops.

1.4.2 Alternate Hypothesis

1. There is significant association the concentration of VOCs between two selected printing shops with permissible exposure limit (PEL).
2. There is significant association between the potential sources of VOC concentration at two selected printing shops.

1.5 Significance of The Study

Determination of the pattern of VOCs at selected printing shops as well as the factors that contribute to poor IAQ were important. There are also important to measure the level of concentration of VOCs at selected printing shops and compared with PEL. A Permissible Exposure Limit (PEL) is the maximum amount or concentration of hazardous substances that a worker may be exposed to under Occupational Safety and Health Administration (OSHA) regulations (Centers for Disease Control and Prevention (CDC), 2011).

However, maintaining and improving health is the key objective of risk management. The risk of health effects from inhaling any chemical or gases depends on how much is in the air, how long and how often a person breathes it in. This is because breathing low levels of chemical and gases for long periods of time may increase some people's risk of health problems especially eldest and children. The findings of the VOCs concentration are very useful to the people especially the workers of the printing shops.

The current condition of IAQ problem causes from emitted VOCs, can be monitored in order to fully utilize for future planning of the condition of the printing shops efficiently. It is important to identify the potential sources of indoor air problems to know the VOC concentration at the printing shops. This can help authorities to monitor activities that affected more frequently to ensure the VOC concentration can be overcome.

CHAPTER 2

LITERATURE REVIEW

2.1 Indoor Air Quality (IAQ)

Environmental Protection Agency (EPA) defines an indoor air quality (IAQ) as the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants (USEPA, 2012). It is now known that indoor air pollution likely has equal or even greater impact on occupant's health when compared to that of outdoor pollutants where it may be vulnerable to pollutants including particulate matters and VOCs (Sousa *et al.*, 2012).

The various health issues such as asthma and allergy symptoms, irritation of the airways, decreased lung function and other respiratory symptoms, the cause of indoor air pollutants, either infiltrated from outside or produced by internal sources (Mitchell *et al.*, 2007). Some of the common causes of indoor air problems give rise to poor air quality are the presence of indoor sources of pollution such as poorly designed, maintained or operated air conditioning and mechanical ventilation systems, and uses of buildings that are unplanned for what the buildings were designed or renovated for (Cheong & Chong, 2001).

Indoor air quality has an important issue that affects the comfort, health and productivity of office workers (Graudenz *et al.*, 2005). Due to this matter and an increased awareness regarding poor indoor air quality, it is not surprising that the number of reported employee complaints of discomforts and illnesses in non-industrial workplaces are increasing (Mui *et al.*, 2008). One of the examples of non-industrial workplaces is the photocopy centers or shops.

According to Lee *et al.* (2006), the main difference between the photocopy centers in Taiwan and in other developed countries is the centers are generally small and simultaneously serve as both businesses and residences. The daily operating time of photocopy centers generally exceeds 12 hours, and the workforce is primarily female. Due to the climate in Taiwan, the doors and windows of photocopy centers are usually closed in winter for warmth and are also closed in summer because of the use of air conditioning. Thus, the climate in Taiwan may exacerbate IAQ problems in photocopy centers and potentially increase the health risks of employees. Considering the number of photocopiers employed, IAQ in photocopy centers might be worse than in general office environments. As a result, occupational exposure is a concern for employees in photocopy centers, despite this industry employing only a relatively small number of people.

In Malaysia, several research were done on exposures to indoor air pollutants and respiratory health symptoms among office workers in old and new building at Universiti Putra Malaysia (UPM). It was done to investigate the association between high level of indoor air pollutants in the buildings that influence the prevalence of respiratory health symptoms. They found that the level of ultrafine particles (UFP) was significantly higher in old building compared to new buildings which may contribute to health effects to human (Jalaludin *et al.*, 2014).

2.2 Sources of Indoor Air Pollutants

The sources of internal pollution is associated with the ventilation and air-conditioning systems. This includes the microbiological contamination of any segment of such systems, the materials used to build and decorate the building, and

the occupants of the building. Tobacco smoke, photocopiers, photographic labs and printing presses are specific sources of indoor pollution. All these sources should have a general ventilation system and air extracted from these areas should not be recycled through the building (Hernández & Liébana, 2011).

Furthermore, the measurement and evaluation of contaminants of indoor air quality were evaluated in the building. Several indicators were used to ascertain the quality of air inside a building. It was included the concentrations of carbon monoxide and carbon dioxide, total volatile organic compounds (TVOC), total suspended particles (TSP) and the rate of ventilation. Various criteria or recommended target values exist for the evaluation of some of the substances found in interior spaces (Hernández & Liébana, 2011).

In the printing industry, the main indoor sources for VOCs are solvents, inks, fountain solution and cleaning agents due to their low vapor pressure, significant amounts of toluene, xylenes, and other volatile compounds. They were emitted during the printing process and polluting the workplace environment. The inks used in the offset process are made basically of a mixture of resins, vegetal or mineral oils, pigments, and solvents. The main ingredients of the conventional inks are pigments, binders, carriers and additives (Maja *et al.*, 2011; Michael *et al.*, 2005).

Other printing processes and operations that caused serious hazardous emissions include ink preparing, varnishing, and cleaning. Cleaning operation in screen printing implies the removal of residual ink with a solvent, usually sprayed directly on the mesh. Some common ink removal solvents are d-limonene-based products, glycol ether and dibasic ester blends, mineral spirits, methyl ethyl ketone, acetone, butyl celusol, cyclohexane, toluene, and methyl isobutyl ketone. Thus,

cleaning operation can result in solvent exposure up to ten times that of other operations and the level of daily exposure is mainly dependent on the number of cleaning episodes (Jelena *et al.*, 2011).

2.3 VOCs

Volatile organic compounds (VOCs) are present in indoors from outdoors and are emitted from buildings, furnishings and consumer products. In renovated or completely new buildings, levels of indoor air pollutants, especially VOCs resulting from the emissions during constructions and building materials are higher than the VOC levels in buildings with normal use. The VOCs concentration in indoor air is typically ten times higher than outdoors (Jalaludin *et al.*, 2014). Toner and paper dust from printing devices might become airborne that can generate respirable particles, which include ultrafine aerosols (Lee *et al.*, 2001; Kagi *et al.*, 2007). Ultrafine particles (UFP) was defined as those, which are smaller than 0.1 micrometre (μm). UFP formation is also reported during operation of laser printers and copiers (Lee & Hsu, 2007).

Many studies have indicated that ozone, particulate matter (PM) and several volatile organic compounds (VOCs) are emitted during photocopier operation, causing indoor air pollution. VOCs emitted from photocopiers was suspected of causing Sick Building Syndrome (SBS) (Lee *et al.*, 2001) . Consequently, the effect of photocopiers on indoor air quality has attracted substantial interest over recent years. USEPA concluded that VOCs from photocopiers may have potential health effects and recommended more research efforts to identify emission profiles from office equipment, and specifically photocopiers (Lee & Hsu, 2007).

The formation of VOCs occurs when dry toners are fine powders that consist of synthetic resin, polyethylene wax and carbon black (Furukawa *et al.*, 2002). The fusing stage of the photocopying process provides finishing touches that cause the toner image to remain permanently on a sheet of paper. Depending on the characteristics of the toner and the fuser materials, the toners consistently emit such VOCs. VOCs may be emitted from paper that is heated in the fuser of a dry-process copier. Other materials in photocopy centers, including printed documents, cleaning solvent, office furniture, building materials, flooring materials and other office equipment, can emit chemicals into the indoor environment (Lee *et al.*, 2001).

Besides that, chamber investigations and indoor air measurements which determine emissions of laser printers and photocopiers shown that fine and ultrafine particles, gases such as ozone and various VOCs were released into indoor air. Therefore, an exposure to complex mixtures consisting of particles and chemical compounds can be assumed while operating office machines (Alessandra *et al.*, 2013).

2.4 Offset Printing

Offset printing is a commonly used printing technique in which the inked image is transferred or known as offset, from a plate to a rubber blanket, then to the printing surface. When used in combination with the lithographic process, which is based on the repulsion of oil and water, the offset technique employs a flat (planographic) image carrier on which the image to be printed obtains ink from ink rollers. The offset lithographic process is used for a broad range of printing applications, including books, magazines, catalogs, business forms, advertising

brochures, newspapers and calendars. VOC emissions from offset lithographic printing result from the evaporation of components of the inks, fountain solutions, cleaning materials and other miscellaneous materials such as varnishes, coatings and glues (USEPA, 2006). While the non-printing area attracts a water-based film, called as fountain solution, that keeping the non-printing areas ink-free (Deidre, 2014).

Offset printing technique is based on the principal that oil and water do not mix (hydrophilic and hydrophobic process). Lithographic plates undergo chemical treatment that render the image area of the plate oleophilic (oil-loving) and therefore ink-receptive and the non-image area hydrophilic (waterloving). During printing, fountain (dampening) solution, which consists primarily of water with small quantities of isopropyl alcohol and other additives to lower surface tension and control pH, is first applied in a thin layer to the printing plate and migrates to the hydrophilic non-image areas of the printing plate. Ink is then applied to the plate and migrates to the oleophilic image areas (Maja *et al.*, 2011).

Since the ink and water essentially do not mix, the fountain solution prevents ink from migrating to the non-image areas of the plate. Traditionally, isopropyl alcohol was used to control surface tension in the fountain solution, but in recent years its use has been reduced, and in many cases eliminated by using alcohol substitutes. The reason for this shift is due to the VOC emissions attributed to the evaporation of isopropyl alcohol and the level of environmental regulation this lead to (Maja *et al.*, 2011).

The article reported by the Queensland Institute of Technology determined that nearly 30% of 62 printers they tested emitted high levels of ultrafine toner particles. Among the manufacturers of the printers were Canon, Hewlett-Packard,

Toshiba and Ricoh. The emitted high levels of particles made the air potentially as hazardous as cigarette smoke and were five times higher during working hours than non-working hours. The one additional contributor to polluted indoor air are combined with the fumes, vapors and fumes emitted by photocopiers, (Hao, 2011).

The VOCs are present in powdered copier toner that can pose significant health risks with prolonged exposure that is according to the EPA. The example of health risks are headaches, throat irritation, nausea, irritation and hyperresponsiveness of the upper and lower respiratory tract and chronic fatigue (Kurt & Michael, 2013). The United States Environmental Protection Agency (USEPA) has found concentrations of VOCs in indoor air commonly to be two to five times greater than in outdoor air and sometimes far greater (John, 2009).

In the exposure measurements were carried out at printing process in Norway as part of a project to study the impact of organic solvent exposure on the health of printing press operators. The use of organic solvents in the printing industry has been linked to acute intoxication and decreased performance in behavioural tests. Workers in this industry are also represented in statistics of patients with the diagnosis chronic brain dysfunction (Ewers & Nowak, 2006).

2.5 Available IAQ Standard and Guidelines

The concentrations of formaldehyde, volatile organic compounds, suspended particulate matter and other contaminants such as carbon dioxide (CO₂) in room air must be within the limits were specified in Table 2.1. By referring to Industry Code of Practice Indoor Air Quality (ICOP) 2010 by DOSH (2014), the maximum limit of VOCs that can be exposed by the occupants for eight hours is 3 ppm. The VOCs

product are released when in use or even while stored. Indoor air pollutant levels can be anywhere between 25% to 62% greater than outside levels according to the World Health Organization (WHO). The people in industrialized nations spend as much as 90% of their time indoors estimated by the Environmental Protection Agency (EPA). For some parts of the population, such as infants and the elderly, the time spent indoors can be even greater. Exposure to some pollutants, such as tobacco smoke and radon, occurs almost exclusively indoors (Eisenbraun, 2013).

Table 2.1: List of indoor air contaminants and the acceptable limits

Indoor air contaminants	Acceptable limits		
	ppm	mg/m ³	cfu/m ³
<u>Chemical contaminants</u>			
Carbon monoxide	10	-	-
Formaldehyde	0.1	-	-
Ozone	0.05	-	-
Respirable particulates	-	0.15	-
Total volatile organic compounds (TVOC)	3	-	-
<u>Biological contaminants</u>			
Total bacterial counts	-	-	500*
Total fungal counts	-	-	1000*
<u>Ventilation performance indicator</u>			
Carbon dioxide	C1000	-	-

Notes:

- *For chemical contaminants, the limits are eight-hour time-weighted average airborne concentrations.*
- *mg/m³ is milligrams per cubic meter of air at 25° Celsius and one atmosphere pressure.*
- *ppm is parts of vapour or gas per million parts of contaminated air by volume.*
- *cfu/m³ is colony forming units per cubic meter.*
- *C is the ceiling limit that shall not be exceeded at any time. Readings above 1000ppm are indication of inadequate ventilation.*
- **excess of bacterial counts does not necessarily imply health risk but serve as an indicator for further investigation.*

(Source: Department of Occupational Safety and Health (DOSH), 2014).

2.6 Health Effects

There are symptoms associated with pollutants emitted from building materials. The health symptoms associated with environmental condition such as headache, dizziness, fatigue, dry throat, shortness of breath and nasal problems. Studies were linked such symptoms with materials in the offices, office equipment and heating, ventilation and air conditioning (HVAC) systems that can contribute to indoor air pollution (Myers & Maynard, 2005). Moreover, office equipment were also found to be a source of ozone, particulate matters, VOCs and particles (Jones, 1999).

VOCs was related to Sick Building syndrome (SBS) towards human health. SBS was describe as a situation in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be spread throughout the building. Some of these buildings may be inadequately ventilated. People generally have less control over the indoor environment in their offices than they do in their home. As a result, there were an increase in the incidence of reported health problems (DOSH, 2014).

From the previous study by Brinke *et al.* (2004), occupants in office buildings were exposed to low concentrations of complex mixtures of VOCs that encompassed a number of chemical classes and a broad range of irritancies. SBS is suspected to be related to these exposures. Using data from 22 office areas in 12 California buildings, seven VOC exposure metrics were developed and their ability to predict self-reported SBS irritant symptoms of office workers were tested. The VOC metrics were

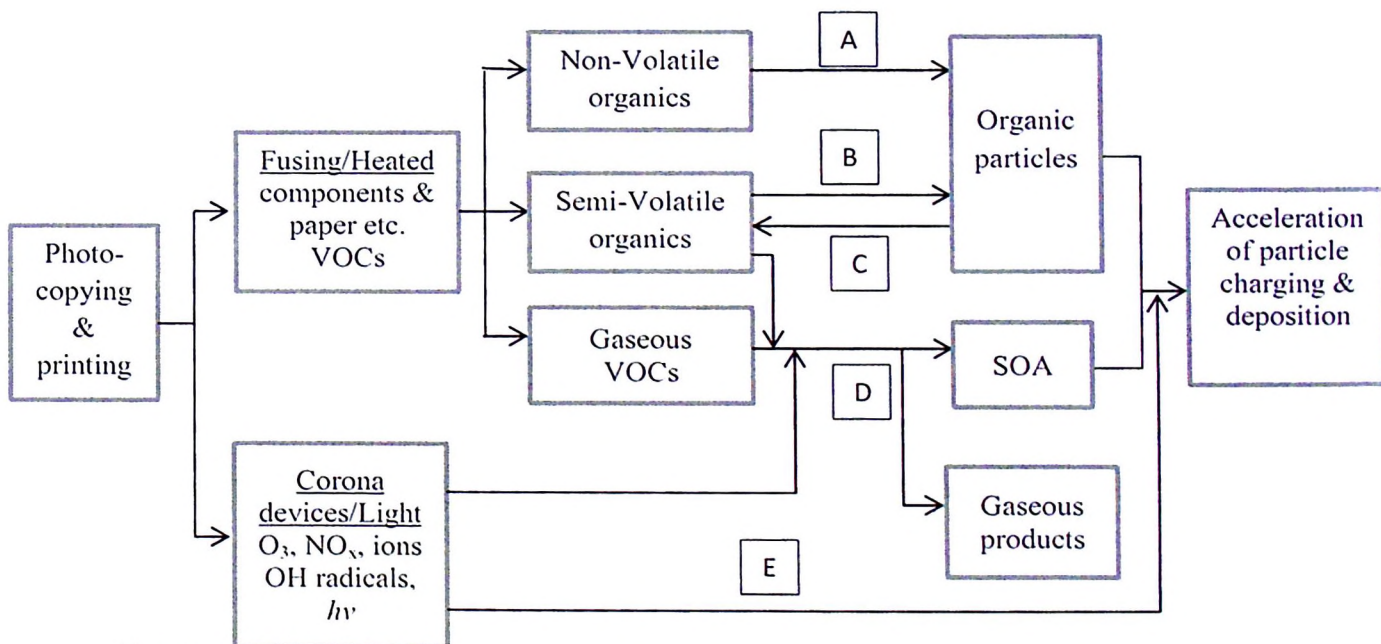
evaluated in a multivariate logistic regression analysis model adjusted for other risk factors or confounders. As a result, they found a link between low level VOC exposures from specific types of indoor sources to SBS symptoms and it was confirmed by using data sets from other buildings.

In the Department of Environmental and Occupational Health UPM, they found that the level of VOCs was higher in the old building compared to the new buildings. The VOC concentrations in the breathing zone of the building occupants are good predictors of mucous membrane irritation and central nervous system complaints. Besides that, irritation of the eyes and respiratory tract are the health effects from exposure to VOC, and cause sensitization reactions involving the eyes, skin, and lungs. Because of the similarity of these symptoms, exposure to VOCs has frequently been attributed as a cause of sick building syndrome among office workers (Jalaludin *et al.*, 2014).

Other than that, exposure to solvents can lead to a variety of adverse health effects. Many of them were considered hazardous materials since the early 1970s, when the first environmental laws were enacted and they may produce health effects if humans are exposed to high enough concentrations. In general, long-term exposure to low concentrations of VOCs in water or air, at or above regulatory standards may result in liver or kidney effects. Breathing some of these contaminants may cause irritation of the respiratory tract. These chemicals might produce cancer, especially benzene which has been placed in the first group of carcinogens by International Agency for Research on Cancer (IARC) Environmental emissions of printing solvents may cause ground level ozone formation and some may contribute to stratospheric ozone depletion (Maja *et al.*, 2011).

2.7 Conceptual Model

Many studies were focused on the emission rates of photocopier-emitted pollutants. One of them is shown in the Figure 2.1. In the photocopying process, the fusing stage provides finishing touches that cause the toner image to remain permanently on sheet of paper. The toners consistently emitted such VOCs, depending on the characteristics of the toner and the fuser materials. The study is showed the particle size distribution that ultrafine particles (UFP) dominated the photocopier emitted particles. Different mechanisms might contribute to the formation of UFP during photocopying. The possible formation mechanism of UFP is the nucleation/condensation of low vapor pressure substances. It were vaporized at high temperature and condensed at low temperature to form particles (Lee & Hsu, 2007).



Note:

A - Nucleation/Condensation

B - Nucleation/Condensation

C - Evaporation

D - Oxidation/Ion Induced Nucleation

E - Ion Diffusion Charging

Figure 2.1: Conceptual model of indoor air chemistry and particle formation and removal during photocopying.

(Source: Lee & Hsu, 2007)

The second possible mechanism of UFP formation during photocopying is the oxidation of indoor VOCs. The byproducts of corona charging during photocopying, such as ozone, NO_x and OH-radicals, are both strong oxidants for the oxidations of emitted VOCs. Many studies have demonstrated that photo-oxidation products of aromatic hydrocarbons can undergo various reactions to produce secondary organic aerosols (SOA) in the presence of O₃, OH radicals, and Nox (Lee & Hsu, 2007). Therefore, SOA formation inside photocopiers might be an important source of indoor UFP and FP during photocopying. Furthermore, many studies have confirmed that ozone may react with unsaturated VOCs (such as terpenes and styrene), causing secondary emission of UFP and FP in an indoor environment (David & Ajay, 2011).

In Lee & Hsu (2007), they concludes that ozone and UFP concentrations in photocopy centers should be concerned in view of indoor air quality and human health. The corona devices in photocopiers and photocopier-emitted VOCs have the potential to initiate indoor air chemistry during photocopying and result in the formation of UFP.

2.8 Statistics

Investigating the patterns and trends in the data is the core feature of Statistical Packages for Social Sciences (SPSS). It can produce basic descriptive statistics, such as averages and frequencies. Descriptive analysis was used to obtain frequency and percentage of all data (Zar, 1999).

Statistical tests were used to analyze some aspect of a sample. The results of the test to be generalizable to the population from which that sample was drawn or the sample to represent the parameters of the population. The example of test that can be used were Mann Whitney U test, regression, Kruskal Wallis test (Bruin, 2006).

Jaluludin *et al.* (2014) was used Mann Whitney-U test to make a comparison of concentration of indoor air pollutant between old and new buildings. Only UFP were shown a significant difference with $p < 0.05$ for the old building compared to the new buildings, while other indoor air pollutants (formaldehyde and VOCs) did not significantly differ in comparing these buildings. However, the level of VOCs was still higher in the old building compared to the new buildings.

Besides that, multivariable regression also commonly used in determination of multiple source VOC emission factors. Multivariable regression is an effective technique to separate emission factors from multiple sources in indoor industrial air spaces. This approach provides a means of describing emissions in an air space with complex processes. While this multivariable approach, using multiple descriptions of solvent use as independent variables, is not easily graphed, it does more accurately reflect the mechanisms that result in emissions (Keil *et al.*, 1997).

The one of study about Kruskal Wallis test in indoor air was done by researchers from Georgia. The study is about the profiles of airborne fungi in