A Study of Indoor Air Quality in UTP's Academic Buildings No.18 Level 3

by

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Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified source or persons.

NURUFIRIN BINTI NORSHAM

ABSTRACT

Indoor air quality (IAQ) is a term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. Research shows that people spend approximately 90 percent of their time indoor, therefore, for many people, the risks to health may be greater due to exposure to air pollution indoors than outdoors. Universiti Teknologi PETRONAS, a place where education takes place, has been build for more than 10 years. In addition, the location is in Malaysia, a hot and humid country. Academic building 18, level 3 is an office for lecturers. The growth of mold, and fungi can be seen at the back of the chairs. This situation indicates that there is something wrong with surrounding environment. Thus, a study is conduct to determine the current status of IAQ inside the building. Next, when the culprit is found, root cause analysis is done by listing all the possible causes and the main reason is selected. Finally, improvement study is done based on how to solve the problem detected before. The temperature, humidity, carbon dioxide (CO_2) content, ventilation rate and the PM10 content are being recorded. When all the results gains are compared to standard, only PM10 concentration is not complying with it. In the root cause diagram, the four main possible causes for high PM10 concentrations are manpower, machines (which refer to HVAC system), materials and design. After an analysis on all 4 main factors, filtration is chosen as the main cause of this problem. In order to perform improvement study, another set of data collection of PM10 on the upstream of the filter is recorded to find its efficiency. From the calculation, the efficiency of current used filter is only 33.91% compared to its original, 80%. Also, the filter has been used for up to 6 years now, since 2006, exceeding its original life cycle, which is 1 year. Suggestion on changing to new filter is made to over come this problem.

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ABBREVIATIONS

IAQ	: Indoor air quality
HVAC	: Heating, Ventilation and Cooling
IDPH	: Illinois Department of Public Health
UTP	: Universiti Teknologi PETRONAS
RCA	: Root cause analysis
NAAQS	: National Ambient Air Quality Standard
AIHA	: American Industrial Hygiene Association
ASHRAE	: American Society of Heating, Refrigerating and Air Conditioning Engineers
NIOSH	: National Institute of Safety and Health

CHAPTER 1
INTRODUCTION

1.1 Background of study

Through the year, man had been trying to build boxes to protect themselves from rain and heat, warm them during cold time and cool them during summer. Almost 90 percent of the their time are being spend to work and lives inside those boxes. However, buildings do not always protect their occupant from pollutions. The molds, fungi, dust and toxic gases entered might trapped on the inside may well exceed those outdoors. By shielding ourselves from the outside environment, we have created an inside environment with a whole new set of problems.

This complex IAQ ecosystem model, therefore consist of the occupants, their activities, the air pathway and the heating, ventilation and cooling (HVAC) system, the building envelope, and its environment setting. One additional component undergrids this matrix, is time. Time is essential to our understanding of the cause and prevention of poor indoor air quality. System, situations, load, usage, efficiencies, and cost of all change over time. As buildings age, they wear, deteriorate, leak, break and fail. This process of continuous degradation makes maintenance and operating practices a major component of this IAQ model.

A healthy indoor environment provide comfort, health, and well being of the building users. As temperature and humidity are the main factors of determining the level of comfort zone, the concentrations of respiratory gas such as carbon dioxide must be maintained and not exceed the standard (R.Ganick, 1995, p.1). When there are needs for comfort, health, and well being to be satisfied, building user might experience the effect of poor IAQ. Syndromes like headache, burning and itching eyes, respiratory difficulties, skin irritation, and fatigue are something common experience by them.

This health effects, due to poor air quality are dependent upon several factors, for example air contaminant, concentration, duration of exposure and individual sensitivity. The air contaminant may be an allergen, or a carcinogenic chemical. The allergen will cause an immediate reaction with minimal long term effects. A carcinogenic chemical may not have any warning signs of exposure but may cause cancer years after exposure. It may be an irritant with passing health effects, or it may be a sensitizing chemical (e.g. isocyanates) whereby future exposure may result in extreme immune response (Kosa, 2002, p.3).

As the public recognizes the importance of healthy, comfortable, and productive indoor environments, their awareness and demand for good indoor air quality (IAQ) increases. This demand has resulted in IAQ emerging as a major concern in office buildings. Many office buildings have significant indoor air pollution sources. These sources include furnishings, occupant activities, housekeeping practices, pesticide applications, and microbial contamination (Hansen, 1999).

1.2 Problem statement

Academic building number is a part of academic complex in Universiti Teknologi PETRONAS (UTP) and it has been build for more than a decade. As a prestige institution of higher learning, it comes with facilities like classrooms, toilets, office for lectures and laboratories.

Located in Malaysia, a tropical climate country, the average of temperature is 86°F (30°C) throughout the year. Hence, the level of humidity is very high. With regards of these factors, symptoms like strange smells, stuffy and stale air, appearance of mold and mildew, corrosion, headache and irritation toward eyes, nose and throat can be seen.

Figure 1.1 Corrosions on cardboard and fungi growth on the back of the chair

Since academic building is a place where educational process is take place, a comfortable place should be provided in order to increase its efficiency. Therefore, a comprehensive study should be conduct in order to determine the real culprit and preventing it from getting worst, and resulting into bigger problems.

1.3 Objectives

There are three objectives to achieve in this study. The first one is to establish the current status of IAQ in academic building, level 3. Next is to conduct root cause analysis (RCA) to find the cause of poor indoor air quality. Finally, improvement study will be done as recommendations on enhancing the current condition of the environment.

1.4 Scope of study

In this project the area of study is level 3 of academic building 18, both on the left and right wings. In order to find what is wrong with the IAQ of this building, data collected will be compared to standard and regulations. Anything that is not complying with both will then be investigated deeper.

All possible causes are then list out to conduct the root cause analysis in order to find the main reason for this problem. The tool selected to perform this task is root cause diagram, which has been created by Kaoru Ishikawa in 1990. The common uses of the root cause diagram are product design and quality defect prevention, to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation (www.wikipedia.com, last access on 18 April 2011)

When the main cause is found, study on how the problem can be solves is conduct. A brief explanations on the why the problems occur will be explain and the best ways of preventing it will then be recommend.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Overview of IAQ

The indoor environment is currently considered to be one of the most important health concerns. The major changes in the indoor environment begin with an attempt to control the indoor air temperature and at early theories about the impact of the indoor environment on occupants. Then the significant changes in the indoor environment began after World War II with a dramatic increase in the use of synthetic materials and chemicals that produced potentially harmful indoor contaminants.

Pahwa (1996) defined Indoor Air Quality (IAQ) as the ability to provide the acceptable comfort level to 80% of the people exposed to it. It is an important component of Heating, Ventilation & Air Conditioning (HVAC) and has become one the primary concerns in HVAC system design, manufacturing, installation and operation because of these reasons:

1. IAQ is closely related to the health of the occupants inside a building, whether a building is a healthy building or a sick building (causes Sick Building Syndrome).
2. IAQ and thermal control (zone temperature and relatively humidity control) indicate primarily the quality of the indoor environment in a building.
3. IAQ and thermal control represent mainly the functional performance of an HVAC system.

IAQ deals with the content of interior air that could affect health and comfort of building occupants and it compromises of microbial pollutants such as asbestos, CO_2, CO, NO_2, O_3, formaldehyde, radon, particulates and volatile organic compound. According to the ASHRAE HVAC 2005 fundamental handbook, there are several of diseases that can be related to the contaminated air in the building.

IAQ problems can be due to indoor air pollutants/contaminants or to inadequate pollution controls despite otherwise normal or baseline rates of ventilation. Sources of indoor air pollutions are from different origins:

i. The occupants themselves (such as exhaled carbon dioxide gas);
ii. Inadequate materials or materials with technical defects used in the construction of the building;
iii. The work performed within (such as cleaning of carpet);
iv. Excessive or improper use of normal products (pesticides, disinfectants, products used for cleaning and polishing);
v. Combustion gases (such as smoking); and
vi. Cross-contamination coming from other poorly ventilated zones

2.1.1 Sick Building Syndrome (SBS)

The term "sick building syndrome" (SBS) is used to describe situations in which building occupants experience acute health and discomfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be widespread throughout the building. In contrast, the term "building related illness" (BRI) is used when symptoms of diagnosable illness are identified and can be attributed directly to airborne building contaminants (Brooks. et al., 1991).

2.2 Generic aspect

According to Phillips J. (Indoor air quality,1990) understanding the quality of indoor air quality requires the perspectives of physic, chemistry and biology.

From a physical perspective, the concentration of any substance within an enclosed space depends on interior sources and sinks, cracks in the boundaries, temperature and pressure difference and the time dependence of these and other parameters. The physicist seeks to develop a theory, which accurately reflects quantitative relationships among these parameters.

From a chemical perspective, the concentration of many chemicals must be measured in the indoor environment. The chemist seeks to accurately measure these chemicals despite problems due to simultaneous presence of several chemicals and very low measurement levels.

From a biological perspective, the concentrations of chemical must be evaluated for hazard potential. The biologist seeks to accurately predict human health effects from exposure to these chemical concentrations.

2.3 Cause of indoor air pollutions

Bradford O. Brooks, in his book understanding indoor air quality (2006), said that, indoor air quality pollution is contribute by various factors like building concentration materials and interior furnishings, appliance, office equipment and supplies, human activities, biological agents, and the chemical element of atomic number 86, radon. These factors contribute to more than 1000 compound of air pollutant agent and it continues to grow.

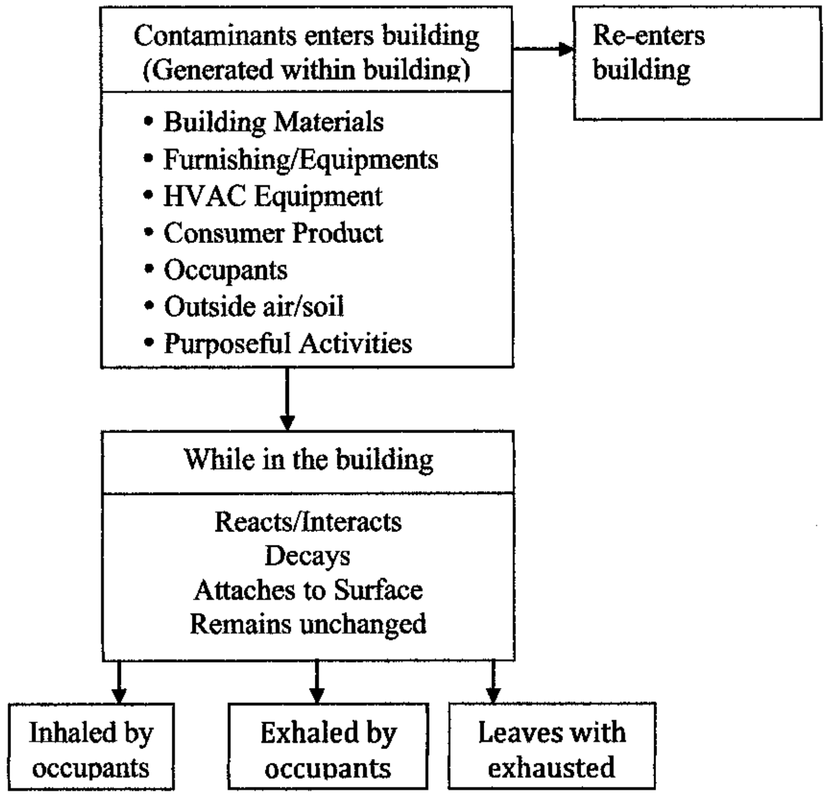

Figure 2.1 Indoor Pollutant Flow

Illinois Department of Public Health (IDPH) in their website conclude that there are 6 major indoor air quality problems, by referring to one of NIOSH method in their publication, *Guidance for Indoor Air Quality Investigations.* This NIOSH technique is best described as one of exclusion. The investigation tries to narrow the range of possible problem causes. The six major sources are:

i. *Inadequate Ventilation* -These problems involve lack of adequate fresh air uneven distribution of fresh air within a building

ii. *Humidity and temperature* –these problems involve with levels of these parameter outside of normal range.

iii. *Inside Contamination* -Copy machines, office products, and chemicals stored indoors have been identified as significant sources of indoor air problems in some investigations.

iv. *Outside Contamination* - This is caused by the re-entrainment of previously exhausted contaminants, generally caused by improper air intake placement or by periodic changes in the wind conditions. A common problem is vehicle exhaust fumes from parking garages or loading docks being drawn into a building ventilation system.

v. *Microbial Contamination* - This type of problem is usually associated with water leaks, water infiltration, elevated indoor humidity, humidifiers, and contaminated ventilation ductwork.

vi. *Building Materials* - This results from building materials (including carpeting) releasing gasses into the air during and shortly after the materials are first installed. Increased ventilation after installation will enhance the dissipation of these chemicals. These problems usually resolve with time.

2.4 Preliminary assessments of IAQ

The preliminary assessment is design as the first response to reports of indoor air problems. It is data gathering and observation effort without any measurement taken. The purpose of this are to get a better understanding of the extent of the problem and related condition, the nature and scope of complaints and as the preliminary audit of facility conditions, systems, maintenance and operational procedure.

Process like interview and questionnaires will be conducted as talking to people who had been using the building can be a valuable means of securing information about nature and the scope of problems. The National Institute of Occupational Safety and Health (NIOSH) has found that when the questionnaire is conducted, the finding enable the NIOSH team to develop more effective strategies in dealing with the problem and their time is used more efficiently.

For background assessment, it is best to check whether operational conditions in the area are normal or not. The basic purpose is to assess the overall conditions of the building. Original construction information, such as construction dates, square footage, ventilation system design, and materials used, is gathered.

2.4.1 Qualitative Walk Through (WT) Inspection

The WT inspection involves a more thorough and detail visual examination of the facility and the HVAC system. It usually involves the use of simple temperature, humidity and air flow measurement and monitoring, humidity gauges, and smoke pencil to check the airflow. CO_2 measurements are sometimes taken to assess the effectiveness of the ventilation system.

2.4.2 Simple Quantitative Sampling and Assessment Techniques

In this stage of assessment, the characteristic of the building can be easily and economically diagnosed and analyzed. The resulting data aids in the understanding of the general performance of the building and its various systems. The simple tests consist of temperature and humidity test, measuring airflow, and also measuring the CO_2 level. Along with the WT inspection more information is gained.

2.4.3 Interpreting Result From Simple Test

Therefore, from the result obtained, the current status of academic building number 18 can be determine. If humidity or airflow readings compare unfavorably with the guidelines, the root cause analysis must be done to determine the possibilities for its occurrence.

2.5 Assessment and method used

2.5.1 Thermal comfort

Human thermal comfort is defined by ASHRAE as the state of mind that expresses satisfaction with the surrounding environment (ASHRAE Standard 55, 2006). Maintaining thermal comfort for occupants of buildings or other enclosures is one of the important goals of HVAC design engineers.

Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Any heat gain or loss beyond this generates a sensation of discomfort. It has been long recognized that the sensation of feeling hot or cold is not just dependent on air temperature alone.

Thermal comfort is very important to many work-related factors. It can affect the distraction levels of the workers, and in turn affect their performance and productivity of their work. Also, thermal discomfort has been known to lead to Sick Building Syndrome symptoms. The combination of high temperature and high relative humidity serves to reduce thermal comfort and indoor air quality. The occurrence of symptoms increased much more with raised indoor temperatures in the winter than in the summer due to the larger difference created between indoor and outdoor temperatures.

- **Temperature humidity index (THI)**

Anisha Noori Kakon, from department of Architecture and Civil Engineering, Saga University, Japan in her paper work entitle "Assessement of thermal comfort in respect to building height in a high-density city in tropics" (2010) conduct a research by evaluating the temperature humidity index (THI) in the city of Dhaka, Bangladesh.

THI or also known as Discomfort Index (DI) is one of the variants of Effective Temperature (ET), developed by Thom (1959). Following is the equation used:

$$THI = 0.8Ta + \frac{RH \times Ta}{500}$$

Where:

Ta = The air temperature (°C)

RH = The relative humidity (%)

By empirically testing the THI values on human objects, the comfort limits are defined as:

$21 < THI < 24$ = 100% of the subject felt comfortable

$24 < THI < 26$ = 50% of the subject felt uncomfortable

$THI < 26$ = 100% of the subject felt uncomfortable

- **ASHRAE 55-2004**

According to Ashrae 55-2004, Thermal comfort is a condition of mind, which expresses satisfaction with the thermal environment. There are 6 factors contributing into determining human thermal comfort. They are air temperature, radiant temperature relative humidity, air velocity, activity and also clothing. There are few ways that can be use in knowing the status of a place thermal comfort.

Due to individual difference, it is impossible to satisfy everyone. In their research, it will ensure that 80% or more of the occupants will find the environment thermally acceptable. The conditions of comfort were found by studies of North American and European subjects. Recent studies with Japanese subjects led basically to the same results. Therefore, it can be assumed that these conditions of comfort can be applied in most parts of the world.

- **Ashrae Comfort Zone (Psychometric Chart)**

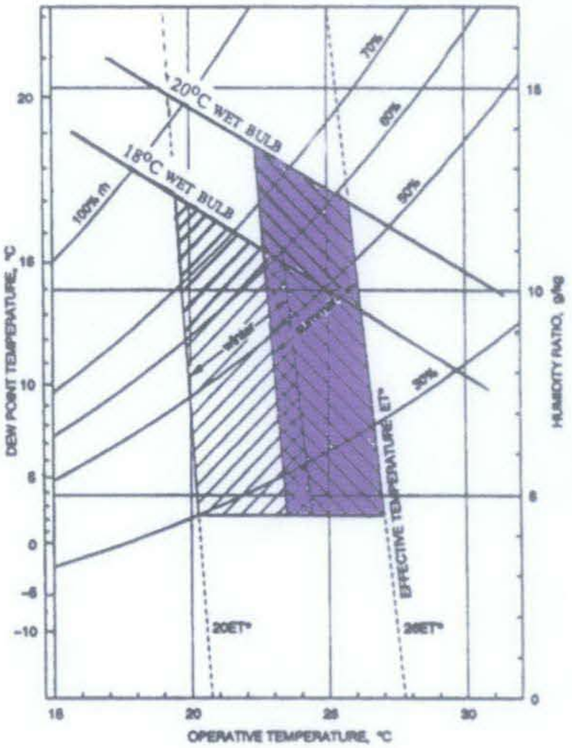

Figure 2.1 Relative humidity (RH) / temperature (T) diagram based on comfort zone according to ASHRAE 55-2004

ASHRAE has developed an industry consensus standard to describe comfort requirements in buildings. The standard is known as ASHRAE Standard 55-2004 Thermal Environmental Conditions for Human Occupancy. The purpose of this standard is to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space. One of the most recognizable features of Standard 55 is the ASHRAE Comfort Zone as portrayed on a modified psychometric chart above. The Standard allows the comfort charts to be applied to spaces where the occupants have activity levels that result in metabolic rates between 1.0 met (human body heat production, in which it calculate as, 1 Met = 58 W/m^2 (356 Btu/hr)) and 1.3 met and where clothing is worn that provides between 0.5 clo (use to measure cloth thermal insulation, in which it is calculated as 1 Clo = 0.155 m^2K/W) and 1.0 clo of thermal insulation.

• **ISO7730**

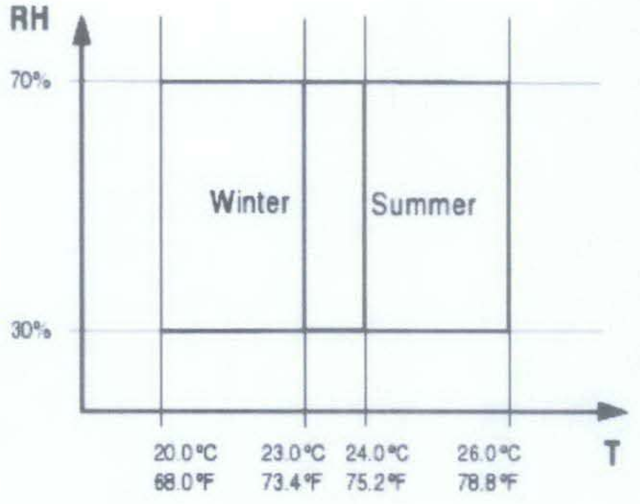

Figure 2.2 RH/T diagram showing the comfort zone according to ISO7730

Another approach for defining the comfort zone is done by the standard ISO77302. It neglects the fact that higher temperatures can be borne at low humidity. Therefore its upper and lower temperature limits are vertical. This approach can be used in less demanding applications for simpler implementation of air-conditioning algorithms. While simple temperature ranges are given per season the relative humidity is set between 30%RH and 70%RH in winter and summer time, respectively. The limits are set to decrease the risk of unpleasantly wet or dry skin, eye irritation, static electricity, microbial growth and respiratory diseases.

- **Heat Index**

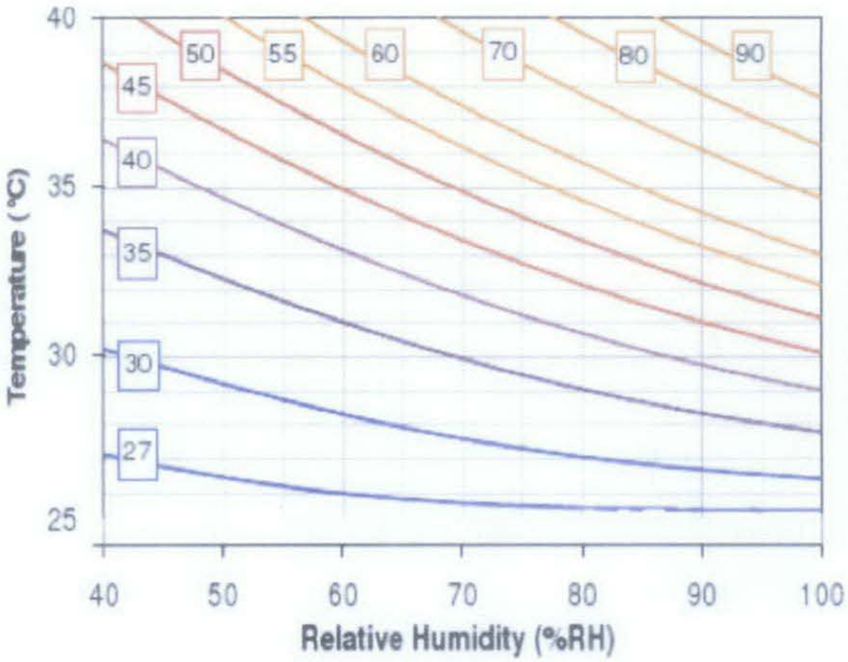

Figure 2.3 Heat Index Graph

At high humidity, high temperature conditions, the well- being may be controlled with the concept of Heat Index. Heat Index indicates how the human body feels temperature. The heat index is based on subjective. The most popular definition of the Heat Index is the one of the *National Weather Service and Weather Forecast Office* of the *National Oceanic and Atmospheric Administration* (NOAA). The Heat Index in °C is given by

$$HI= C_{00} + C_{10}t + C_{01}U_w + C_{11}tU_w + C_{20}t^2 + C_{02}U^2{}_w + C_{21}t^2U_w + C_{12}t^2U^2{}_w + C_{22}t^2U^2{}_w$$

Coefficient:

C_{00}	-8.7847	C_{02}	-0.0164
C_{10}	1.6114	C_{21}	$2.2117\text{-}10^{-3}$
C_{01}	2.3385	C_{12}	$7.2546\text{-}10^{-4}$
C_{11}	-0.1461	C_{22}	$-3.5820\text{-}10^{-6}$
C_{20}	-0.0123		

- **Past research on thermal comfort**

Since Malaysia is a tropical country, therefore they are having a very high humidity. Therefore, the figures recommended by ASHRAE are not very easy to accomplish. Based on research done by Ibrahim Hussien from UNITEN in his paper research entitle 'Thermal Comfort Zone of a Campus Building in Malaysia' proves this problems. Data was obtained from measurement of dry-bulb temperature and relative humidity of the air-conditioned campus buildings and a survey conducted on the occupant to determine the comfort classroom environment. As the result, the thermal comfort zone obtained within the study scope of the present study is in temperature range of 23°C to 24.5 and relative humidity of 74% to 83%. This is slightly different from ASHRAE standard. According to ASHRAE, temperature up till 27°C are still acceptable but with the conditions of up to 60% relative humidity.

2.5.2 Ventilation rate

- **Overviews**

Ventilation is the intentional movement of air from outside a building to the inside. Ventilation air, as defined in ASHRAE Standard 62.1 and the ASHRAE Handbook, is that air used for providing acceptable indoor air quality. Ventilation is used to remove unpleasant smells and excessive moisture, introduce outside air, to keep interior building air circulating, and to prevent stagnation of the interior air. It is one of the most important factors for maintaining acceptable indoor air quality in buildings. When people or animals are present in buildings, ventilation air is necessary to dilute odors and limit the concentration of carbon dioxide and airborne pollutants such as dust, smoke and volatile organic compounds (VOCs). Ventilation air is often delivered to spaces by mechanical systems, which may also heat, cool, humidify and dehumidify the space.

- **Ventilations units**

The ventilation rate is normally expressed by the volumetric flow rate of outside air being introduced to the building. The typical units used are cubic feet per minute (CFM) or liters per second (L/s). The ventilation rate alsoe expressed as a per person or per unit floor area basis, such as CFM/p or CFM/ft^2, or as air changes per hour.

Ventilation for Acceptable Indoor Air Quality (ASHRAE 62-2007)

Table 2. 1 Minimum Ventilation Rates In Breathing Zone for Educational Facilities and Office Building

Occupance Category	People Outdoor Air Rate RP		Area Outdoor Air Rate RA		Default Values		
					Occupant Density	Combined Outdoor Air Rate	
	Cfm /person	L /s•person	Cfm /ft2	L /s•m2	1000ft2 /100m2	Cfm /person	L s•person
Educational Facilities							
Daycare (through age 4)	10	5	0.18	0.9	25	17	8.6
Classrooms (ages 5-8)	10	5	0.12	0.6	25	15	7.4
Classrooms (age 9 plus)	10	5	0.12	0.6	35	13	6.7
Lecture classroom	7.5	3.8	0.06	0.3	65	8	4.3
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3	150	8	4
Art classroom	10	5	0.18	0.9	20	19	9.5
Science laboratories	10	5	0.18	0.9	25	17	8.6
Wood/metal shop	10	5	0.18	0.9	20	19	9.5
Computer lab	10	5	0.12	0.6	25	15	7.4
Media center	10	5	0.12	0.6	25	15	7.4
Music/theater/dance	10	5	0.06	0.3	35	12	5.9
Multi-use assembly	7.5	3.8	0.06	0.3	100	8	4.1
Office Buildings							
Office space	5	2.5	0.06	0.3	5	17	8.5
Reception areas	5	2.5	0.06	0.3	30	7	3.5
Telephone/data entry	5	2.5	0.06	0.3	60	6	3
Main entry lobbies	5	2.5	0.06	0.3	10	11	5.5

- **International standard**

This standard is based on the ASHRAE standard that can be found in the ASHRAE documents *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 62-2007).

2.5.3 Carbon dioxide content

Carbon dioxide (CO_2) is a surrogate for indoor pollutants emitted by humans and correlates with human metabolic activity. Carbon dioxide at levels that are unusually high indoors may cause occupants to grow drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor levels are an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity. Carbon dioxide itself is not responsible for the complaints; however, a high level of carbon dioxide may indicate that other contaminants in the building also may be present at elevated levels and could be responsible for occupant complaints (Quinne, 2011).

- **International standard**

NIOSH considers that indoor air concentrations of carbon dioxide that exceed 1,000 ppm are a marker suggesting inadequate ventilation. ASHRAE recommends that carbon dioxide levels not exceed 1000 ppm above outdoor ambient levels. The UK standards for schools the carbon dioxide in all teaching and learning spaces, the whole day should not exceed 1,500 ppm. European standards limit carbon dioxide to 3500 ppm.

In building areas where there are potential sources of carbon dioxide other than exhaled breath, the guidelines above cannot be used. This can include exhaust gas from kilns, internal combustion engines, dry ice, etc. Under these conditions, the Occupational Safety and Health Administration (OSHA) standard for carbon dioxide should be used. The OSHA standard is an eight-hour time-weighted average (TWA) of 5,000 ppm with a short-term 15-minute average limit of 30,000 ppm.

Organization	Maximum CO2 content
ASHRAE	1000 ppm
UK Standard	1500 ppm
European Standard	3500 ppm
** Areas where with potential sources of carbon dioxide other than exhaled breath*	
OSHA	5000 ppm
OSHA (15 minutes average)	30000 ppm

Table 2.2 Summary of Guideline for CO_2 content

2.5.4 Volatile organic compounds (VOC)

Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary, room-temperature conditions. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate from the liquid or solid form of the compound and enter the surrounding air. Many VOCs are dangerous to human health or cause harm to the environment. VOCs are numerous, varied, and ubiquitous. They include both man-made and naturally occurring chemical compounds. VOCs are typically not acutely toxic, but instead have compounding long-term health effects. Because the concentrations are usually low and the symptoms slow to develop, research into VOCs and their effects is difficult.

- **Formaldehyde**

Formaldehyde is a common constituent of adhesives used in particle board, carpeting and furniture. The use of formaldehyde has been modified in recent years to reduce its release from these products. Increased ventilation during and following renovation or new construction should reduce the level of formaldehyde. The Department of public health Illinous recommends the level of formaldehyde to not exceed 0.1 ppm for offices and 0.03 ppm for homes.

- **Particulates**

Particulates can be classified as either respirable (less than 5 microns in diameter) or nonrespirable. Respirable particles can penetrate into the lower lung and can cause damage. Nonrespirable particles are trapped in the upper respiratory system and can cause irritation. The Department of public health Illinous recommends that particulates 2.5 micrometers to 10 micrometers in diameter (PM_{10}) be maintained at less than the USEPA National Ambient Air Quality Standard (NAAQS) of 150 micrograms of particulates per cubic meter of air (ug/m^3) and particulates 2.5 micrometers in diameter or less ($PM_{2.5}$) be maintained at less than the NAAQS of 65 ug/m^3 during a 24-hour time period.

PM_{10} refers to particulate matter that is 10 μm or less in diameter. PM_{10} is generally subdivided into a fine fraction of particles 2.5 μm or less ($PM_{2.5}$), and a coarse fraction of particles larger than 2.5 μm. It is further classified as primary (emitted directly into the atmosphere) or secondary (formed in the atmosphere through chemical and physical transformations). The principal gases involved in secondary particulate formation are sulphur dioxide (SO2), nitrogen oxides (NO_x), volatile organic carbons (VOCs) and ammonia (NH_3). Primary particles are found in both the fine and coarse fractions, whereas secondary particles, such as sulphates and nitrates, are found predominantly in the fine fraction. Both primary and secondary PM can result from either natural or (human) anthropogenic sources.

- **Tobacco Smoke**

Tobacco smoke contains a mixture of irritating gases and carcinogenic tar particles. Because tobacco doesn't burn completely, other contaminants are given off, including sulfur dioxide, ammonia, nitrogen oxides, vinyl chloride, hydrogen cynide, formaldehyde, radionuclides, benxene and arsenic.

The Department of public health Illinous recommends smoking not be allowed indoors. If smoking is allowed indoors, it should be limited to a designated smoking area with adequate exhaust separate from the main heating, ventilation, and air conditioning (HVAC) system.

- **Radon**

Radon is a colorless, odorless, radioactive gas naturally produced when uranium decays in the soil. Uranium and its decay products are commonly found in soil and rock in Illinois. Radon gas enters buildings through cracks, crawlspaces, basement drains and other openings in the foundation or concrete slab. The gas decays into radioactive particles that, when inhaled, cause cell damage and potentially lung cancer. Radon gas is the second leading cause of lung cancer in the United States. and the leading cause of lung cancer among non smokers.

The Department of public health Illinous recommends that levels in homes be less than 4.0 picocuries per liter (pCi/L). If levels exceed 4.0 pCi/L, radon mitigation should be considered to reduce the risk of adverse health effects. The only way to determine the level of radon in your home is to have the air tested.

2.5.5 Microbial Contamination

Microorganisms such as bacteria and fungi are a normal and essential component of our ecosystem. They can live and grow in living organic material, or both. Saprophytic microorganisms, which include many fungi and many bacteria and protozoa, prefer non-living organic material such as dead plant material such as dead plant materials. Parasitic microorganisms need a living host to grow. Saprophytic microorganisms are the most prevalent in the indoor environment because of their ability to find nourishment from non-living matter.

Building can provide all the essentials for microbial growth because they contain many biodegradable materials (Any material that can be decayed by microorganisms and thus support microbial growth is considered biodegradable. Biodegradable materials must contain carbon, nitrogen, sulfur, and phosphorus for microbial growth).

Microbial growth can occur in the temperature range less than 10 degrees C to greater than 50 degrees C (Nevalainen 1993). Building temperatures may enhance or deter microbial growth, but most organisms can grow at temperatures either below or above their optimum growth temperature.

The presence of nutrients an acceptable temperature range are not sufficient to promote microbial growth, the most crucial prerequisite is moisture. Moisture are not only regulates microbial growth, but the amount of moisture available will determine what microbes will grow.

Building, especially with HVAC system are an excellent source of moisture. HVAC systems contains water reservoir, humidifiers, or cooling tower and they also have the potential to provide additional sources of moisture because of condensation, leaks, or floods (ASHRAE 62-2004).

- **Mold and Fungal detections in Academic building Block 17**

According to Hana Azura, (2009) mold detected at lecture rooms bin academic building no. 17 are Penicillium spp and Aspergillius spp. Penicilium fungi are versatile and opportunistic. They are post-harvest pathogens. Penicillium species are one of the most common causes of fungal spoilage in fruits and vegetables. Many species produce mycotoxins. While some Aspergillius species cause serious disease in human and animals, and can be pathogenic.Aspergillus flavus produces aflatoxin which is both a toxin and a carcinogen. The most common causing allergic disease is Aspergillius fumigatus and Aspergillius clavatus. Aspergillosis is the group of disease caused b Aspergillus. The most common subtype among paranasal sinus infection associated with aspergillosis is Aspergillus gumigatus. The symptoms include fever, cough, chest pain or breathless, which also occur in many other illnesses so diagnosis can be difficult.

Under microscope, spore for Penicillium are spherical. Penicillium growth structure appears brush-like with strings of beads coming off the ends of the brushes. While for the Aspergillus, it will look like a flower that gives off strings of beads that are the spores. The spores of Aspergillius are also spherical under the microscope view.

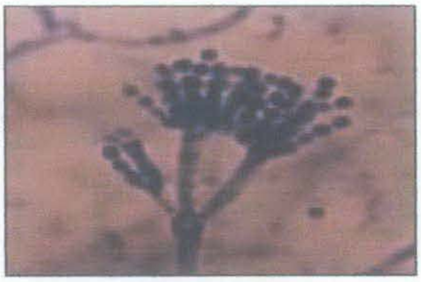

Figure 2.4
Penicillium
(Chemistry Laboratory of Natural Resources, 2009)

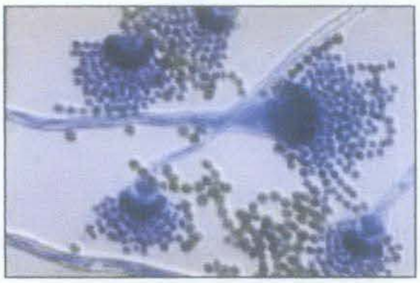

Figure 2.5
Aspergillius
(Dr Martin Huss, 2009)

2.6 Improvement study

Lots of research had been made in order to improve the IAQ. For example indoor air purification technology using ions generated by discharge plasma has been developed by Nishikawa,K. from Sharp Corp., Japan. The purpose of this paper is to report the physical background of this technology and effect to improve indoor air quality by reducing airborne particular microbial.

Another research done by Danial S.L (2003) from USA, where developments in the application of controllable air ionization processes that apply dielectric-barrier discharge devices to generate non-thermal plasmas have led to applications for chemical and biological decontamination in indoor air environments. These include significant reductions in airborne microbial, neutralization of odors, and reductions of volatile organic compounds (VOCs).

Daniel Friedman in his website, inspectapedia.com, had been designing a "Continuous HVAC Blower Fan Operation" for optimum indoor air quality. According to Daniel, this device will improved air filtration, lower indoor dust levels and improved building comfort.

Figure 2.6 Continuous HVAC Blower Fan (Daniel Friedman, inspectapedia.com)

CHAPTER 3
METHODOLOGY

3.1 Flow Chart

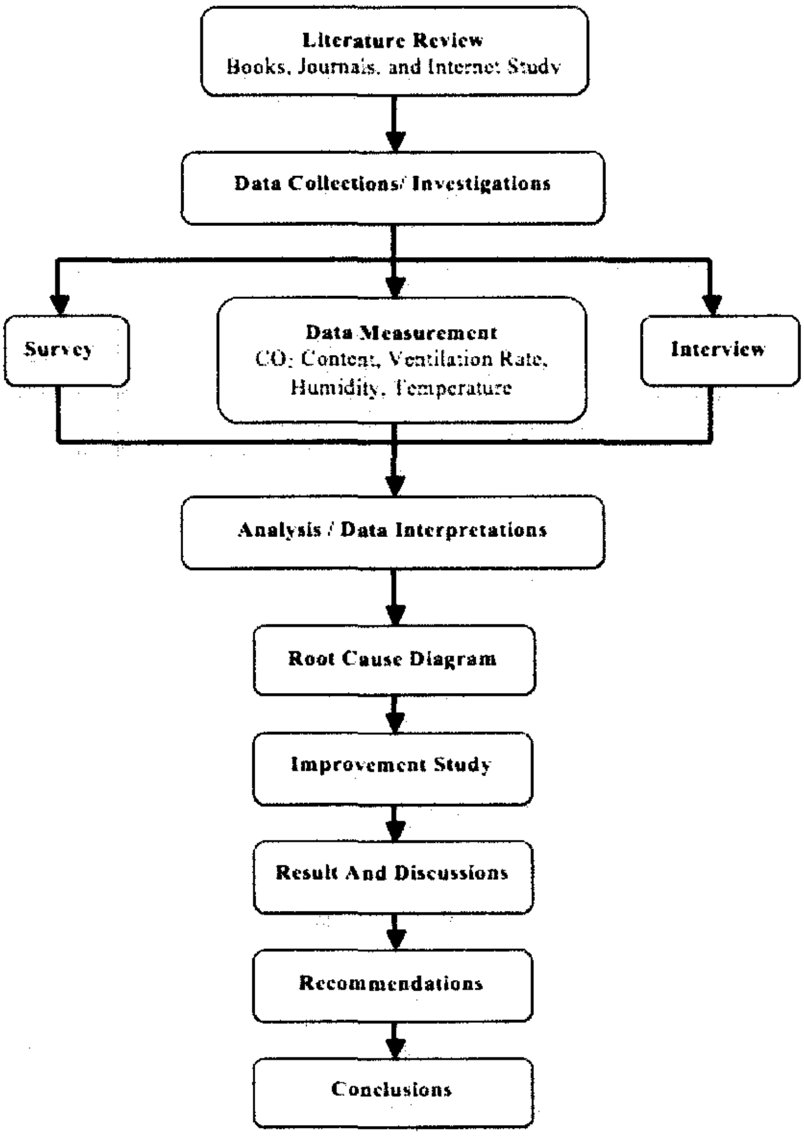

Figure 3.1 Summary of activities of the study

Based on figure 3.1, the study will start with research on books, journal and internal study with regards to indoor air quality. Later on, data like temperature and humidity, carbon dioxide content, ventilation rate, and contaminat content will be collected by using specific equipment. Result obtained will be compared to find what is wrong and what is right. Next, any possible causes will be list and transform into root cause diagram. When finally the main cause is known, the improvemnet study will take place.

3.2 Survey

3.2.1 Purpose of survey

The purpose of this survey is to identify the complaints from lectures who had their office either in building 17, 18 or 19. Therefore, from this survey, the possible problems, which lead into the real cause of indoor, air quality problems.

3.2.2 Survey's questionnaire

The questionnaires were handed into each and every mailbox of lectures in level 3 of building number 17, 18, and 19. About 12 responded participate in this survey. They were asked on the condition of their office, their health conditions and also suggestion on how the quality of indoor air can be improve.

3.3 Data Measurement

3.3.1 Relative humidity, temperature, CO_2 content and ventilation rate

The reading of relative humidity, temperature, CO_2 content and ventilation rate content of office room in level 3 is taken randomly. Equipment used are:

- IAQ Meter Model: Telaire 7001

Figure 3.2 Telaire 7001

The recorded data then being analyze to find:

- **Thermal comfort**

  This are find by using temperature humidity index (THI) and Relative humidity (RH) / temperature (T) diagram based on comfort zone according to ASHRAE 55-2004

- **CO_2 content**

  Reading taken is then compared to ASHRAE 62-2007 standard, which required that part per million (ppm) of carbon dioxide,CO_2 less than 1000 to be considered as safe.

- **Ventilation rate**

  Reading taken is the compared to ASHRAE documents *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 62-2007). The safe range should be 5 cfm/person or 2. L/s.person.

3.4.2 Particulates

The readings of particulates are measure by using MicroVol 1100 Low-Flow Air Sampler. This device provides a flexible sampling platform for PM10, PM2.5 or TSP particulates and basic meteorological parameters. The result is then compared to standard by department of Illinois public health.

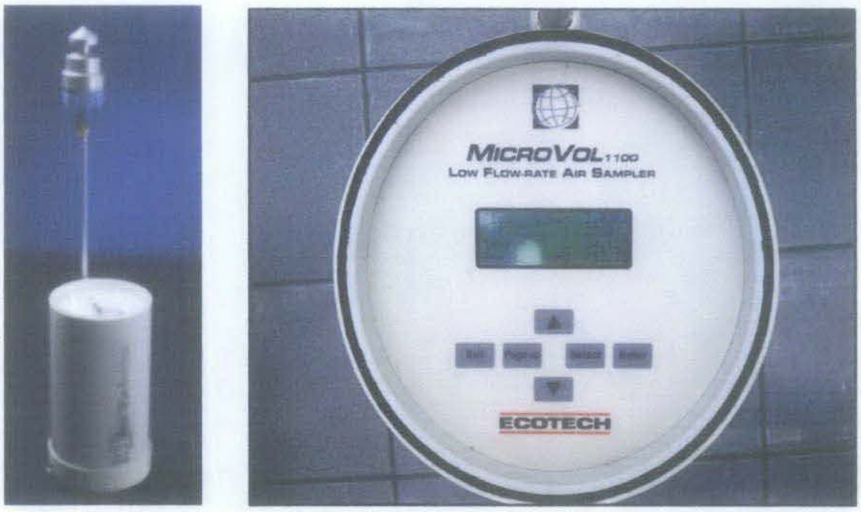

Figure 3.3 MicroVol 1100 Low-Flow Air Sampler

Step by step on how to use MicroVol 1100 Low-Flow Air Sampler.

1. Weight filter paper and put it into the equipment.
2. Searched for location with possible air pollution (parking area) within the campus area.
3. Select a spot (open space) to allocate the PM10 Analyzer .
4. Fixed necessary settings on the PM10 Analyzer (e.g. the starting and ending date), and left it at the site.
5. Obtain readings from the equipment every half an hour for 24 hours, data including flow rate of ambient, total volume of particulates present, temperature and pressure.
6. After 24 hours is finished, collected back the equipment and compose data for report writing.
7. Weight filter paper for the final weight.

3.4 Interview

Interview session was done with both Mr. Syed and Mr. Hong from maintenance department of UTP. They answer questions regarding the maintenance schedule of UTP's HVAC system and also maintenance process.

3.5 Cause and effect diagram

Cause and effect diagram are causal diagrams that show the causes of a certain event, created by Kaoru Ishikawa in the year of 1990. Common uses of the Ishikawa diagram are product design and quality defect prevention, to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to identify these sources of variation.

Cause-and-effect diagrams can reveal key relationships among various variables, and the possible causes provide additional insight into process behavior. They will typically be one of the traditional categories mentioned above but may be something unique to the application in a specific case. The categories typically include:

- **People:** Anyone involved with the process
- **Methods:** How the process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations and laws
- **Machines**: Any equipment, computers, tools etc. required to accomplish the job
- **Materials:** Raw materials, parts, pens, paper, etc. used to produce the final product
- **Measurements:** Data generated from the process that are used to evaluate its quality
- **Environment:** The conditions, such as location, time, temperature, and culture in which the process operates

3.6 Gantt Chart

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project work continues															
Root Cause Analysis															
Root cause diagram															
Improvement Study															
Progress Report															
PRE-EDX (poster)															
Draft Report Submission															
Soft Copy submission															
Oral Presentation															
Hardbound Report Submission															

Planning
Summission of Work/ Assessment
Up to date work

Table 3.1 Gantt chart for FYP II

The work continue with root cause analysis and building of root cause digram for about 6 week, however, the completion of task is delay for another 2 weeks. For the next 5 weeks , starting from week 6 until week 10, the improvement study start. Next, on week 8 is submission of progress report, week 11 is poster submission, week 12, 13, and 14 for submission of draft, soft copy and also presentation. Finally on week 15, it is the hardbound repeort submission.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Data Collection

4.1.1 Temperature and humidity data collection

A series of data measurement has been conducted in an office in one of the new academic building for a week (5 working days), which are being taken from 4th of October 2010 until 8th of October 2010. The reading are taken three times per day - on the morning, around 1000 Hrs, on the noon, around 1200 Hrs and finally on the evening, around 1530 Hrs. The measurement were done with the help of Hydro Thermo Anemometer, a device capable of reading indoor humidity and temperature.

Date	**4/10/2010**	**5/10/2010**	**6/10/2010**	**7/10/2010**	**8/10/2010**
Time	**1002 Hrs**	**1015 Hrs**	**1020 Hrs**	**10.01 Hrs**	**1005 Hrs**
Temperature (°C)	27.0	24.5	24.7	24.4	24.6
Relative Humidity (%)	65.7	70.8	72.9	73.0	71.3
Time	**1205 Hrs**	**1207 Hrs**	**1217 Hrs**	**1215 Hrs**	**1144 Hrs**
Temperature (°C)	24.4	27.8	25.3	24.7	24.1
Relative Humidity (%)	74.3	62.2	66.3	68.3	70.0
Time	**1535 Hrs**	**1532 Hrs**	**1535 Hrs**	**1517 Hrs**	**1520 Hrs**
Temperature (°C)	27.1	26.0	24.5	25.9	26.2
Relative Humidity (%)	62.7	61.6	71.4	64.2	67.3

Table 4.1 Temperature(°C) and Relative Humidity (%) reading for 5 days, 3 times per day at 18-03-10

4.1.2 Indoor air quality survey

Investigation forms (please refer to *appendix1*) that contain questionnaires regarding the indoor air quality have been distributed to block 17,18 and 19 of new academic building in UTP. The target groups are those who work at level 3 offices in each block. A total of 20 forms were distributed and 12 people had already responded. However, I am still hoping for more response. Below are the summary of answers from respondents.

No	Question	Answer			
1	How long have you worked in the building?	< 1 yr	1-5 yr	> 5 yrs	
		1	6	5	
2	Have you experience any medical problems?	Yes	No		
		4	8		
3	Symptoms experience and estimated duration	0-24 hrs	< 1 week	1-4 weeks	4 weeks
	Headache	4			
	Eye irritation	3			
	Nose Irritation	3			
	Throat Irritation	4			1
	Dry mouth	3			
	Backache	2		1	
	Short of breath	2			
	Chest pain	2			
	Nausea	2			
	Flu-like symptoms	2	1	1	1
	Fever	1	2		
	Fatigue	1		1	
	Drowsiness	1	1		
	Dizziness/ Faintness	2			
	Difficulty concentration	1	1		
	Skin dryness, rash, irritation	2			
	Too hot	1	1		
	Too cold			1	3
	None	2			
4	Symptoms Pattern	intermit-tently	Conti-nually		
		8	1		
5	Are the symptoms experienced away from work?	Yes	No		
		5	4		

6	What are whether condition when your symptoms are the worst?	Calm, mild	Windy	Cold	Rainy, Storm
				4	1
		Hot, humid	Dry	Not sure	
		1	1	3	
7	How would you describe condition around your work area?	Stuffy	Too smokey	Too dry	Feet too cold
		2		2	2
		Too Humid	Too much glare	Too bright	Poor light
				1	
		Too much noise	Back too cold	Back too hot	None
			3		4
8	Have you noticed any unpleasant odor(s)?	Yes	No		
		1	11		
9	Has there been any recent	Painting	Carpet installation	New furniture	Wall covering
			1		
		none			
		11			
10	is there any evidence of	Water leakage	Mold growth	Excessive noise	Poor lighting
		2	2	1	
		Dirt near duct	Glare	None	
			1		
11	Are you feel comfortable in your room?	Yes	No		
		10	2		
12	is your room	Too cold	Too hot	Just nice	
		4		8	

Table 4.2 No. of answers given by the respondent for investigation form

4.1.3 Carbon dioxide (CO_2), Temperature (°C), and Ventilation rate (cfm) data collection

Another data collection process was done on 4th of November 2010. This time, the CO_2 content, temperature and ventilation rates were measure. Readings were taken at 6 random office room located on level 3 block 18. The measurement was done from 1630 Hrs to 1715 Hrs. IAQ meter was used for this purpose. The table below shows the data obtained.

Room No.	CO_2 ,Ppm	Temperature,°C	VentilationRates (cfm)
18-03-20	609	26.5	46.3
18-03-23	581	26.0	53.3
18-03-26	618	25.3	44.9
18-03-09	664	25.6	36.1
18-03-05	610	25.4	46.3
18-03-10	627	25.2	45.3

Table 4.3 Measurement of CO_2 concentration, Temperature, and ventilation rates

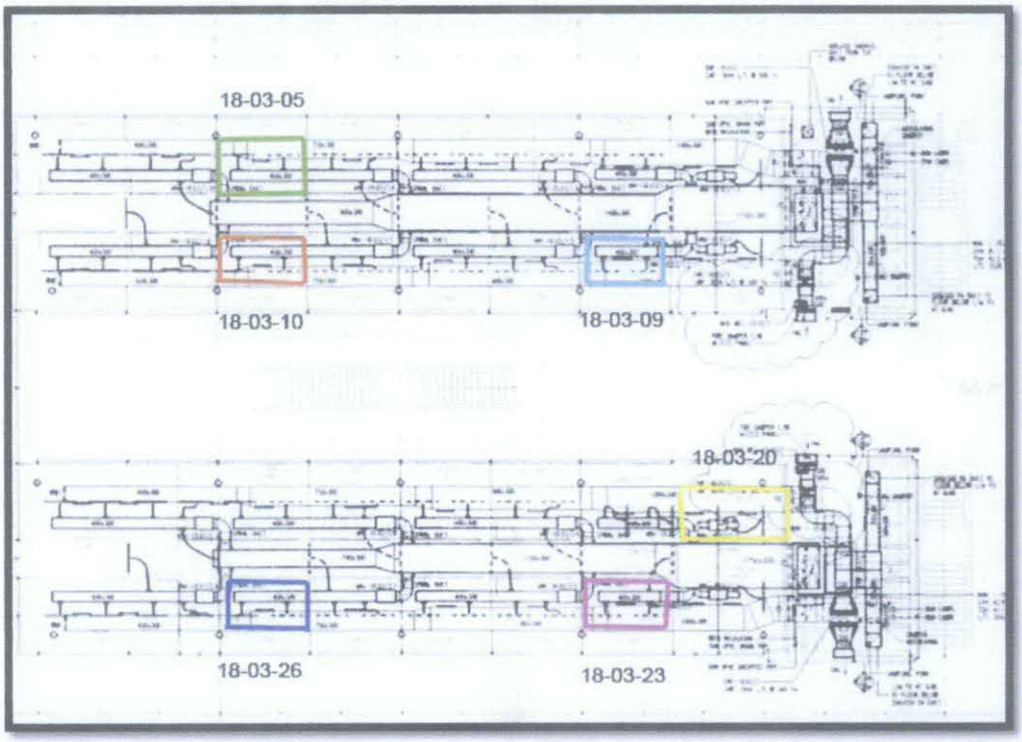

Figure 4.1 Layout of level 3 building 18

4.1.4 PM10 concentration

Data were taken from 1530 hr on 8th of November until 1530 hr, the next day. 48 readings had been taken in 30 minutes interval between each reading, for 24 hours. The filter paper is weighted before and after the experiment to calculate the weight different.

Time	Flow rate (L/min)	Filter paper (g)	Total time (hrs)
3:00:00 PM	5.2333	0.002	24
4:00:00 PM	5.1000	0.0018	24
5:00:00 PM	4.9667	0.002	24
6:00:00 PM	4.6500	0.002	24
7:00:00 PM	3.1250	0.002	24
8:00:00 PM	3.1313	0.002	24
9:00:00 PM	3.1375	0.002	24
10:00:00 PM	3.1438	0.002	24
11:00:00 PM	3.0000	0.002	24
12:00:00 AM	3.0063	0.002	24
1:00:00 AM	3.0125	0.002	24
2:00:00 AM	3.0188	0.002	24
3:00:00 AM	3.0250	0.002	24
4:00:00 AM	3.0313	0.002	24
5:00:00 AM	3.0375	0.002	24
6:00:00 AM	3.0438	0.002	24
7:00:00 AM	3.0500	0.002	24
8:00:00 AM	5.1500	0.002	24
9:00:00 AM	4.9833	0.002	24
10:00:00 AM	4.9000	0.002	24
11:00:00 AM	5.1167	0.002	24
12:00:00 PM	5.0500	0.002	24
1:00:00 PM	4.9167	0.002	24
2:00:00 PM	4.9167	0.002	24

Table 4.4 Flow rate (l/min) and weight of filter paper for PM10

4.2 Data Analysis

4.2.1 Thermal comfort

The thermal comfort level in room 18-03-10, will be determine by using 5 methods. They are temperature humidity index (THI), survey towards the residents, ASHRAE Standard 55-2004, ASHRAE comfort zone and also Heat index. Below are my analysis based on the data obtained for a week.

- **Temperature Humidity Index (THI)**

THI index are being calculated by using the formula below:

$$THI = 0.8Ta + \frac{RH \times Ta}{500}$$

Where:

Ta = The air temperature (°C)

RH = The relative humidity (%)

Comfort limits:
21<THI<24 = 100% of the subject felt comfortable
24<THI<26 = 50% of the subject felt uncomfortable
THI<26 = 100% of the subject felt uncomfortable

Date	**4 Oct 2010**	**5 Oct 2010**	**6 Oct 2010**	**7 Oct 2010**	**8 Oct 2010**
Time	1002 HR	1015 HR	1020 HR	10.01 HR	1005 HR
THI Index	25.14	23.07	23.36	23.09	23.18
Time	1205 HR	1207 HR	1217 HR	1215 HR	1144 HR
THI Index	23.15	25.07	23.60	23.13	22.65
Time	1535 HR	1532 HR	1535 HR	1517 HR	1520 HR
THI Index	25.08	24.00	23.10	24.05	24.49

Table 4.5 THI Index for room 18-03-10 from 4/10/2010-8/10/2010 in the morning, noon and evening

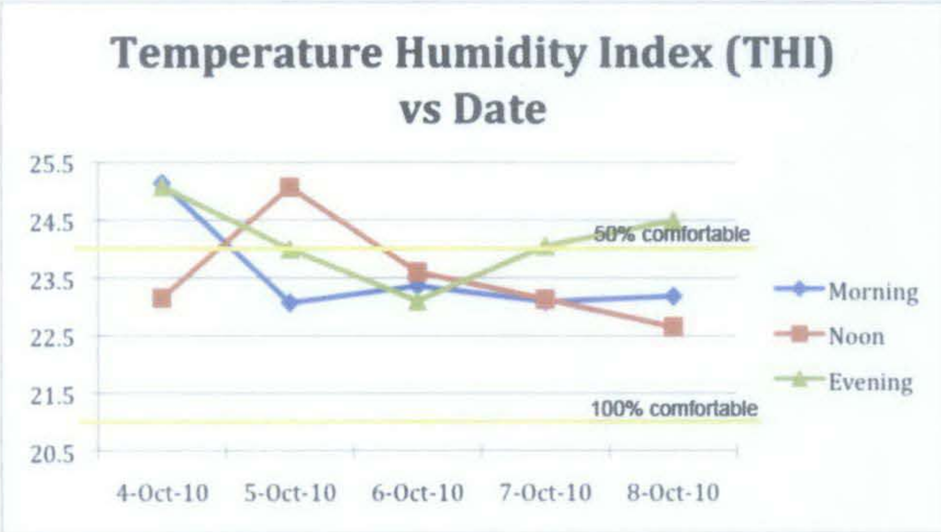

Figure 4.2 Temperature Humidity Index Graph

Based on the result obtain, 10 over 15 reading gives THI value of 21 to 24, where only 66.67% of the time that the resident felt 100% comfortable. However, there are no readings on THI value of more than 26, where it indicates than the room is 100% uncomfortable.

- **Survey towards residents**

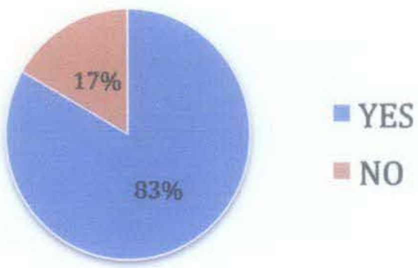

Figure 4.3 Percentages of people answer towards thermal comfort in their room

From the survey, based on question no. 12, "Are you feeling comfortable in your room?", 10 people answer yes and only 2 people answer no, which gives the percentage of 83% feel comfortable and only 17% are not. Based on As 55-2004 thermal comfort, they view thermal comfort as a specific combination of thermal conditions if 80% of the occupant feeling comfortable. Therefore, based on this data, the building is thermally comfortable.

- **Ashrae Comfort Zone (Psychometric Chart)**

Based on the plotted *Psychometric* chart below, it shows that the point is not in the thermal comfort zone. However the readings are not too far from the zone, only slightly out of the box. The range of relative humidity is from 61.6% - 73.0%. As for the temperature, the highest is 27.1°C and the lowest is 24.1°C. Based on ASHRAE standard, they state that a comfort zone for an occupied building should be following the range:

- 22°C to 27°C for dry bulb temperature and
- Relative humidity of 30% to 60%

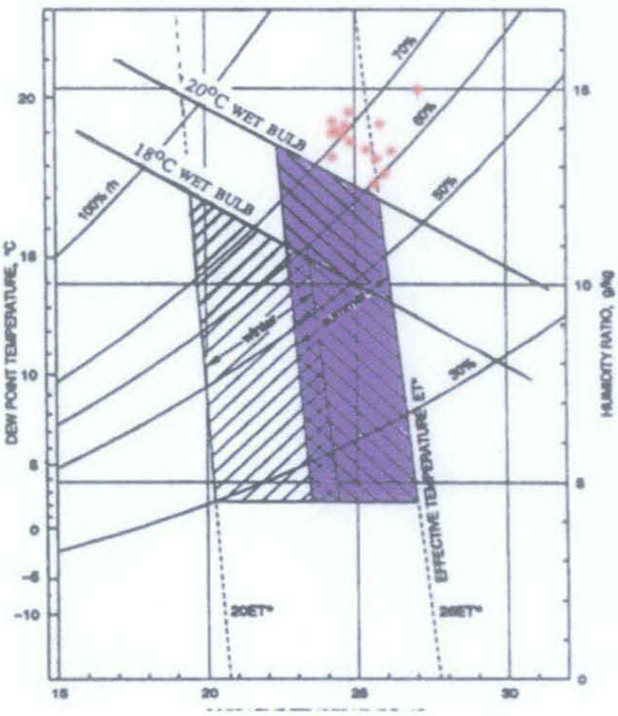

Figure 4.4 Acceptable ranges of operative temperature and humidity for people in typical winter and summer clothing during light and primary sedentary activity

- **ISO7730 Comfort Zone Standard**

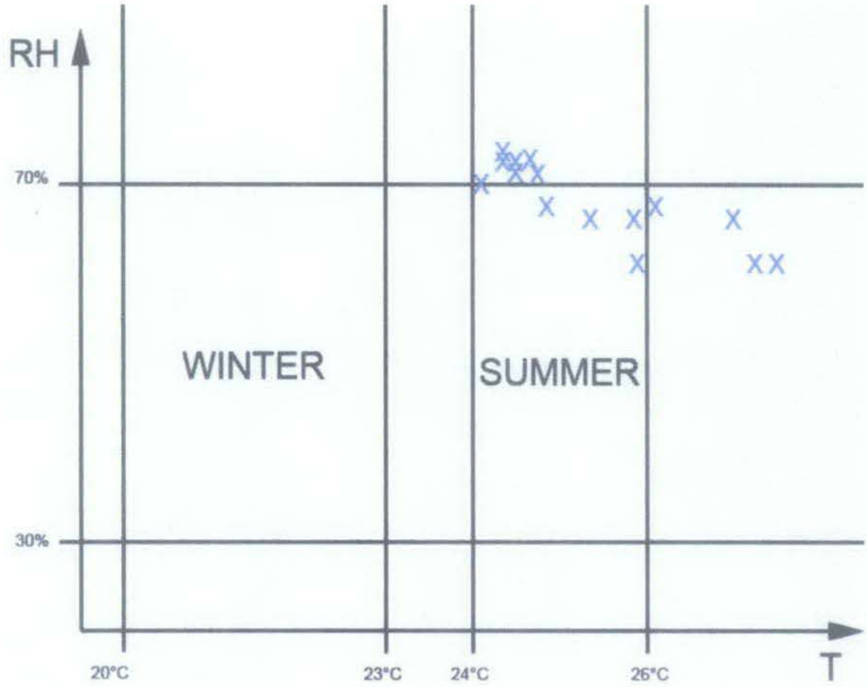

Figure 4.5 Plotted ISO7730 based on data gain for room 18-03-10

Based on the graph that had been plotted above, 5 reading are in the summer comfort zone, while the other 10 readings are slightly out from the box. This show that based on ISO7730 comfort zone standard, only 33.33% in one week time that the occupants felt comfortable.

- **Heat Index**

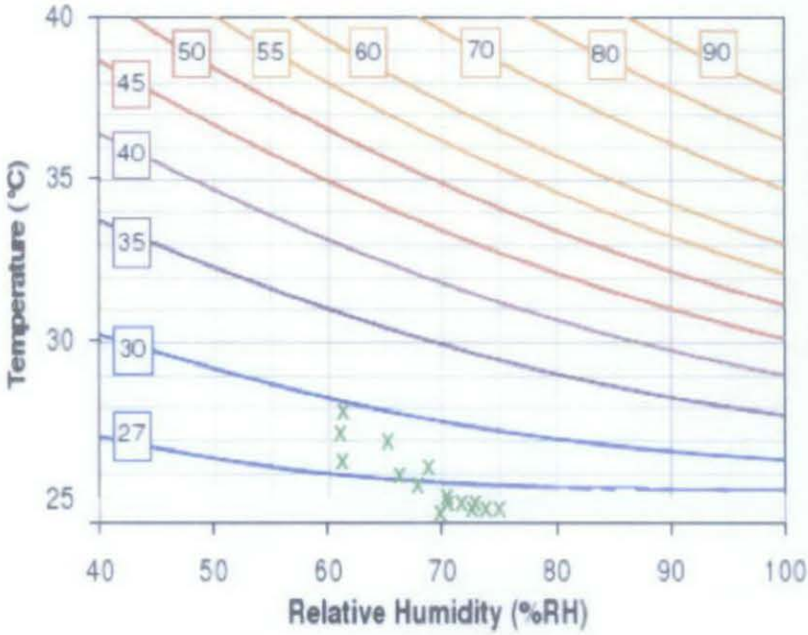

Figure 4.6 Plotted heat index based on data gain for room 18-03-10

Based on the plotted Heat Index, all reading are below 30°C. This indicates that no discomfort was felt in the room.

4.2.2 CO_2 Content

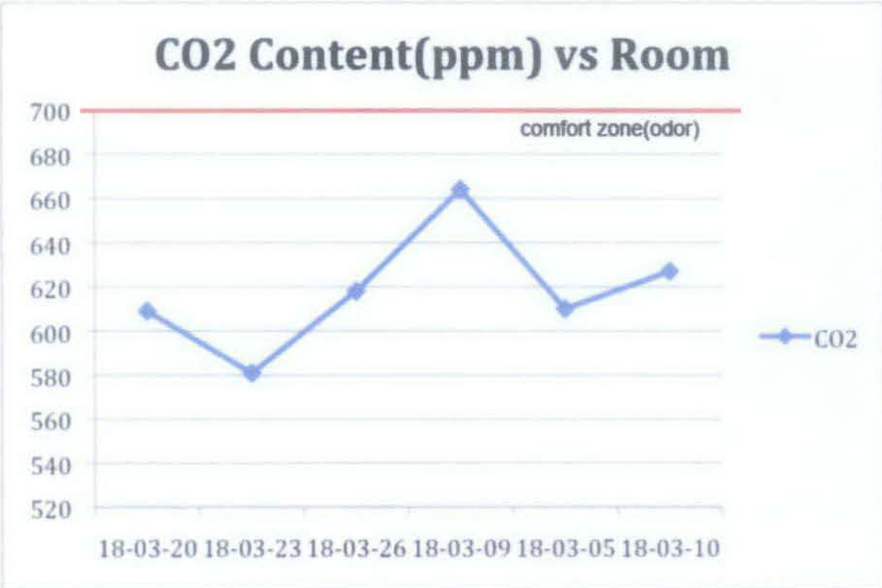

Figure 4.7 Plotted ISO7730 based on data gain for room 18-03-10

Based on the plotted graph, when compared to the ASHRAE standard, OSHA, IDPH, and ACGIH, all the room are in safe state. According to the guideline, CO_2 content in must be below that 1000ppm. Comfort (odor) criteria with respect to human bioeffluents are likely to be satisfied if the ventilation results in indoor CO2 concentrations less than 700 ppm in the air concentration (ASHRAE Section 6.1.3).

4.2.3 Ventilation rate

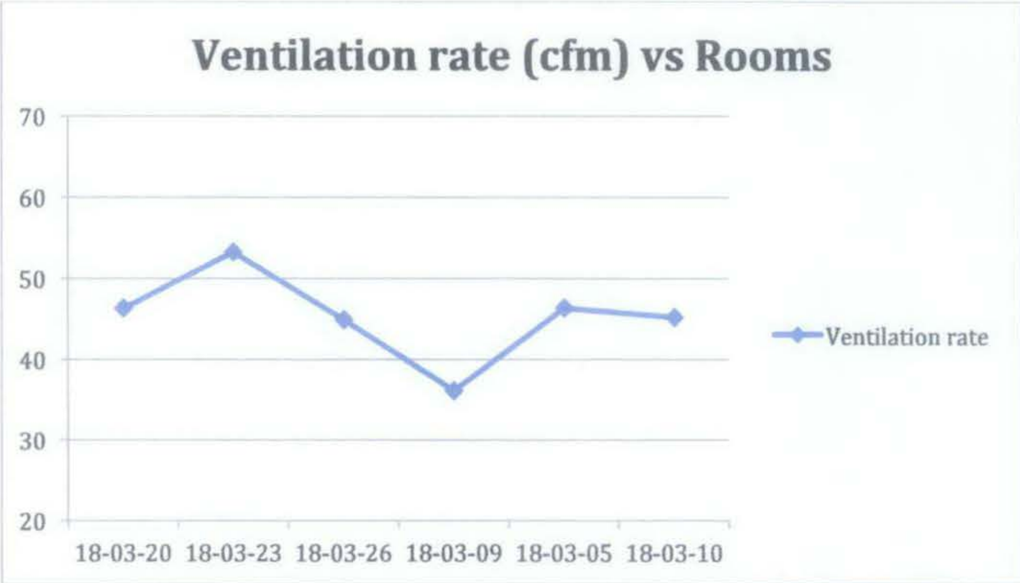

Figure 4.8 Ventilation rate graph for 6 rooms in block 18 level 3

According to ASHRAE, ventilation rate at which stated in it handbook guideline Standard 62-2007: Ventilation for Acceptable Indoor Air Quality, the minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects. The specified rates at which outdoor air must be supplied to each room within the facility range from 15 to 60 cfm/person, depending on the activities that normally occur in that room. (Table 2.1 Minimum Ventilation Rates In Breathing Zone for Educational Facilities and Office Building)

4.2.3 Temperature Distribution

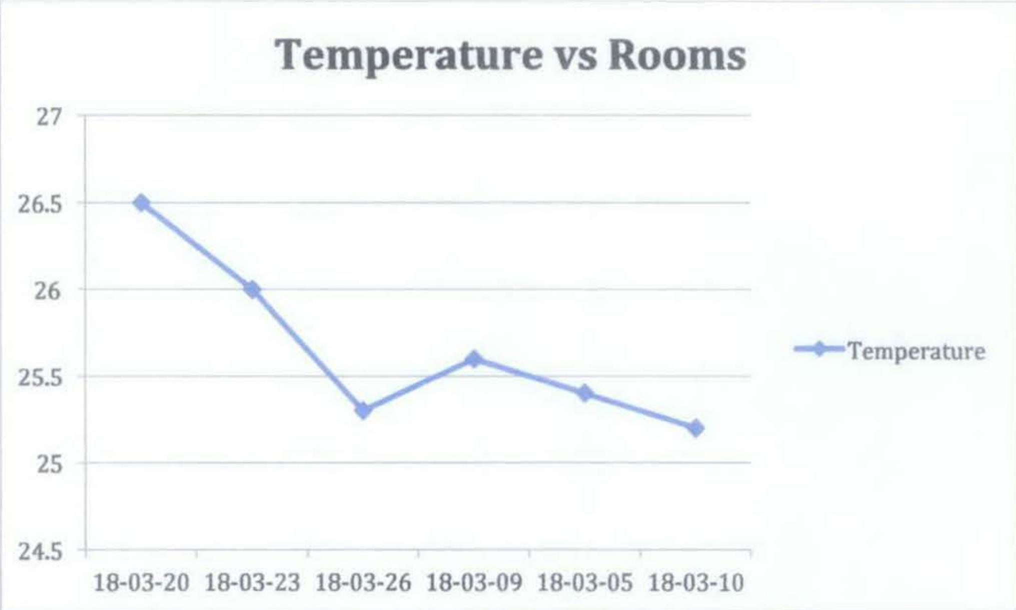

Figure 4.9 Temperature graph for 6 rooms in block 18 level 3

There has been variation in reading of temperature for the 6 rooms. The highest temperature is 26.5°C and the lowest is 25.2°C. There has been variation of reading due to the location of the room itself.

4.2.3 PM10 concentration

The calculation of the weight different of the filter paper as shown below:

Before experiment: 0.012 g

After experiment: 0.015 g

Therefore, the weight different is:

Δ *filter paper*: 0.015 g – 0.012 g = 0.002 g

To obtain the concentration of the particulate for particular reading, the concentration is calculated using the equation:

$$\text{Concentration} = \frac{(\Delta filterpaper)g}{FlowRate * Time} * \frac{h * 1000L}{60\min * m3}$$

Time	Flow rate (l/min)	Filter paper (g)	Total time (hrs)	Concentration (µg)/m³)
3:00:00 PM	5.2333	0.002	24	66.348
4:00:00 PM	5.1000	0.002	24	61.275
5:00:00 PM	4.9667	0.002	24	69.911
6:00:00 PM	4.6500	0.002	24	74.671
7:00:00 PM	3.1250	0.002	24	111.111
8:00:00 PM	3.1313	0.002	24	110.889
9:00:00 PM	3.1375	0.002	24	110.668
10:00:00 PM	3.1438	0.002	24	110.448
11:00:00 PM	3.0000	0.002	24	115.741
12:00:00 AM	3.0063	0.002	24	115.500
1:00:00 AM	3.0125	0.002	24	115.260
2:00:00 AM	3.0188	0.002	24	115.022
3:00:00 AM	3.0250	0.002	24	114.784
4:00:00 AM	3.0313	0.002	24	114.548
5:00:00 AM	3.0375	0.002	24	114.312
6:00:00 AM	3.0438	0.002	24	114.077
7:00:00 AM	3.0500	0.002	24	113.843
8:00:00 AM	5.1500	0.002	24	67.422
9:00:00 AM	4.9833	0.002	24	69.677
10:00:00 AM	4.9000	0.002	24	70.862
11:00:00 AM	5.1167	0.002	24	67.861
12:00:00 PM	5.0500	0.002	24	68.757
1:00:00 PM	4.9167	0.002	24	70.621
2:00:00 PM	4.9167	0.002	24	70.621

Table 4.6 Concentration of PM10 in level 3, academic block 18

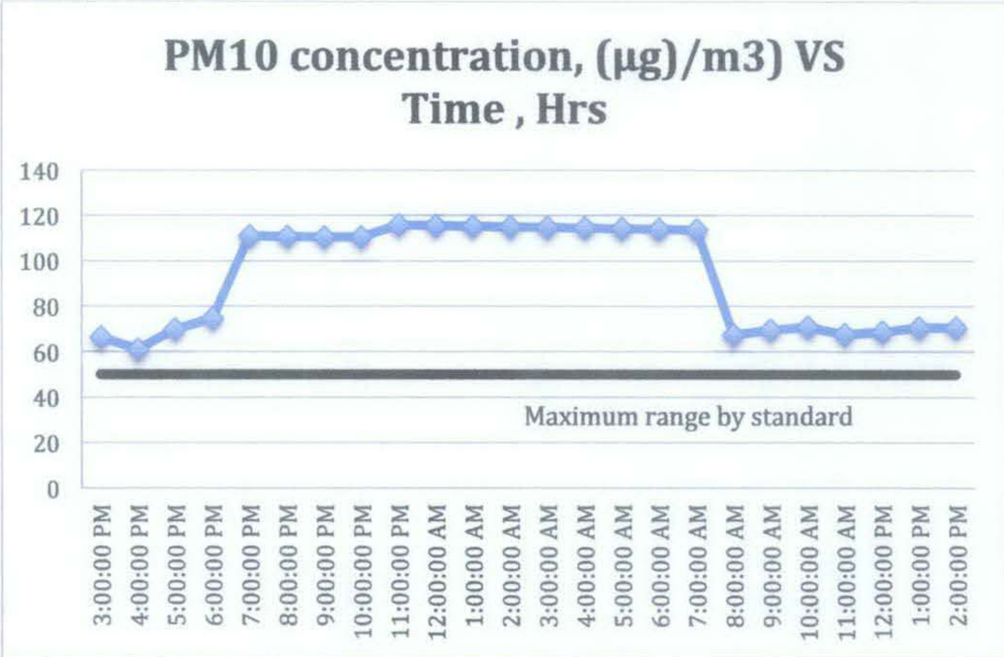

Figure 4.10 Graph of PM10 Concentration (µg/m³) over Time

Based on the result and graph obtained above, we observed that, higher concentration of PM recorded is 115.5 $\mu g/m^3$ at 12:00 am. As for the lowest concentration of PM recorded it is 61.275 $\mu g/m^3$ at 4:00 pm. Between 7:00 pm till 7:00 am on the next day the concentrations of particle recorded were closely relative with each other in range of 110.448 $\mu g/m^3$ to 115.5 $\mu g/m^3$.

4.4 Conclusion on data analysis

Based on data that had been analyzed, it shows that the carbon dioxide (CO_2) content ventilation rate, and PM10 concentration are on the safe range, when it is compared to the respective standard. However, for the temperature and humidity reading, both are too high from the standard.

4.5 Root cause analysis

From the conclusion on data analysis, only temperature and humidity are showing readings that are too high from the standard. Therefore, the root cause analysis will be done to find the possible causes of this problem.

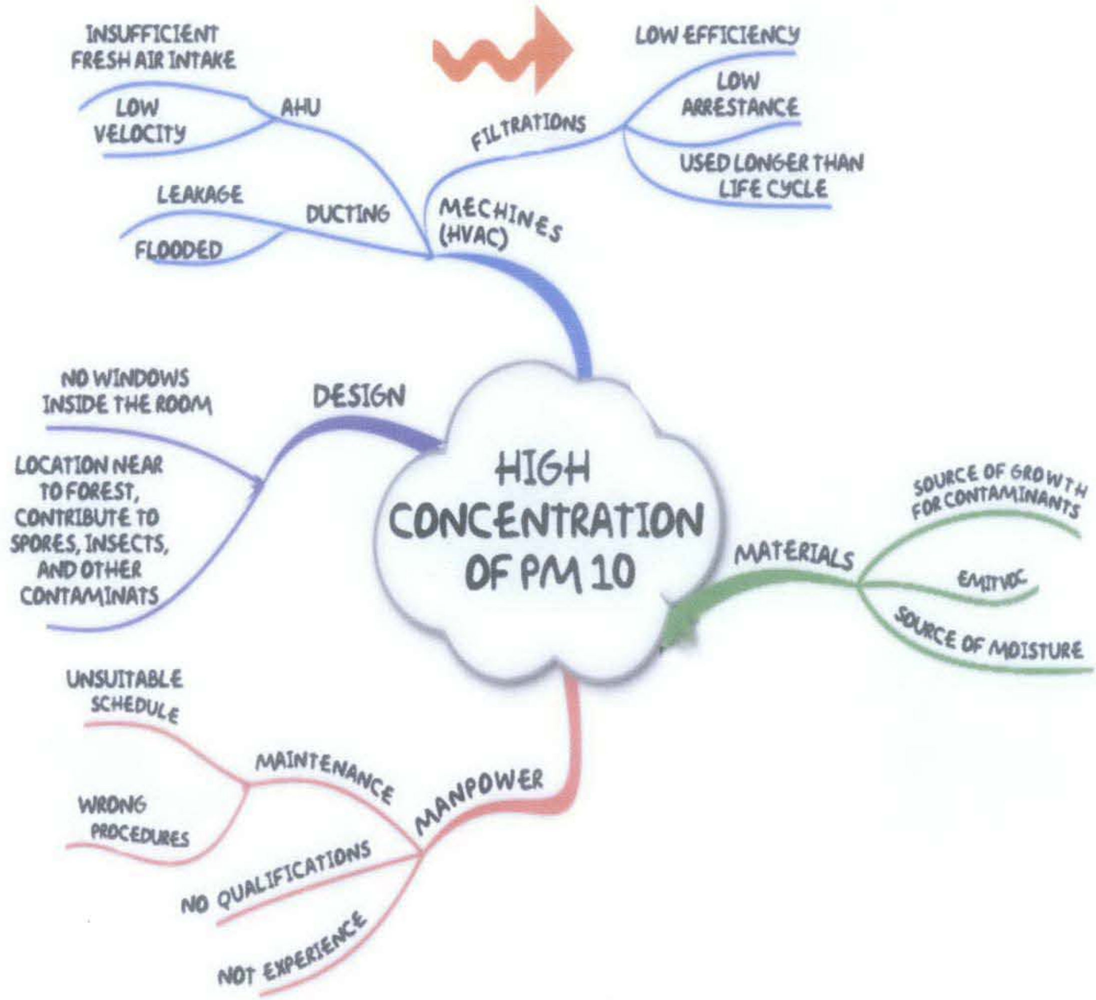

Figure 4.11 Root cause diagram for high concentration of PM10

On the root cause diagram above, there are 4 main possible causes that had been listed, as they are among the potential factors contributing toward building's poor IAQ. The four main factors are manpower, machine (which refer to HVAC system), materials and design. Also, for every main possibility, another branches of smaller topic under the main cause are stated.

4.5.1 Materials

Building can provide all the essential s for microbial growth because they contain many biodegradable materials, which are any materials that can be decay by microorganism. Biodegradable materials contains carbon, nitrogen, sulfur, phosphorus, in which helping the microbial growth. Building can be constructed of or contain biodegradable materials and/or provide sufficient nutrients through the introduction of outside dirt.

Also, the most crucial factor for microbial growth is moisture, which regulates the amount of growth as well type of microbes that will proliferate. Since most of the materials used in the building can absorb water/moisture, more place can lives by the contaminants. For microorganism such as bacteria and fungi are normal and essential component of our ecosystem. They can live and grow in living organic material, non-living organic materials or both.

4.5.2 Manpower

Manpower involvements towards the contributions of higher concentration of PM10 are especially in maintenance issues. The maintenance schedule might not be suitable as the frequency is not enough or too much. Not enough cleaning process will result into dirty environment and more contaminants i.e. PM10 present. Too much interaction through cleaning especially with equipment for example filters will reduce its efficiency.

As for the personal issues of the manpower, such as their experience and knowledge towards the right procedure while maintenance processes are done also another factors here. For example, inexperience worker might use wrong method while servicing the HVAC equipment. Also, wrong procedures practice while maintaining too could not bring any effect on reducing the PM10 concentrations.

4.5.3 Design

The design of offices in level 3 academic building 18 can also be seen as a cause of poor IAQ in the building. With no windows inside the building, ventilations is solely based on the air circulation by AHU. Therefore no natural ventilation can be done. When the occupants feel stuffy inside their office, there is nothing could be do to improve the ventilation. Insufficient ventilation mean the concentration of the PM10 cannot be lessen by air circulation.

The location of building 18 themselves is near to the forest. Due to this reason, the spores that come from the tree in the forest will be one of the sources for the fresh air. There are also incest and other contaminants can be easily entered the building.

4.5.4 Machines (HVAC Systems)

Under this topic, there are 3 possible cause that contributing to high PM10 concentration. There are filtration, AHU and ducting. For filtration, the problems with the filter are that they have low efficiency and low arrestance. When filtration efficiency and arrestance are low, the PM10 can easily pass through and flow toward the building and increase its concentration.

Also, there are issue on minimization of cost in UTP. Therefore, due to this reason, the filter might be used for more than its life cycle. Usually, a filter must atleast be change once a year. Unchanging filter are less efficient and cannot filter the particles that passing through it.

4.6 Improvement study

Improvement study is done in order to propose ways of preventing the main cause of poor air quality, filtrations. Therefore, further studies are done on filtration of academic building level 3. Data of the upstream (before filtrations) of the filter on AHU (air handling unit) were collected to find its coefficient and resistance of the current air filter. Suggestions were made on how to improve the filter's efficiency.

4.6.1 History of air filter in academic building 18

Before 2006, academic building 18 are using High-efficiency Particulates Air filters or also know as HEPA. However, later on the filters are change to fine filter with average efficiency of 80%. This type of filter are washable, in which it will be clean monthly. Since then, the filters have not been change.

4.6.2 Characteristics of current air filter

Below are the summaries of the characteristics for current air filter:

Case	Galvanized steel
Media	Knitted/ Multi layered pad
Separator	Hot-melt beads
Sealant	Polyurethane
EN 779:2002 efficiency	F7
Arrestance efficiency	65% - 80%.
Temperature	70°C maximum in continuous service.
Type of filter	Washable
Maintenance	Being wash once a month
Duration of usage	6 years (since 2006)
Life Cycle	1 year

Table 4.7 Current air filter characteristic

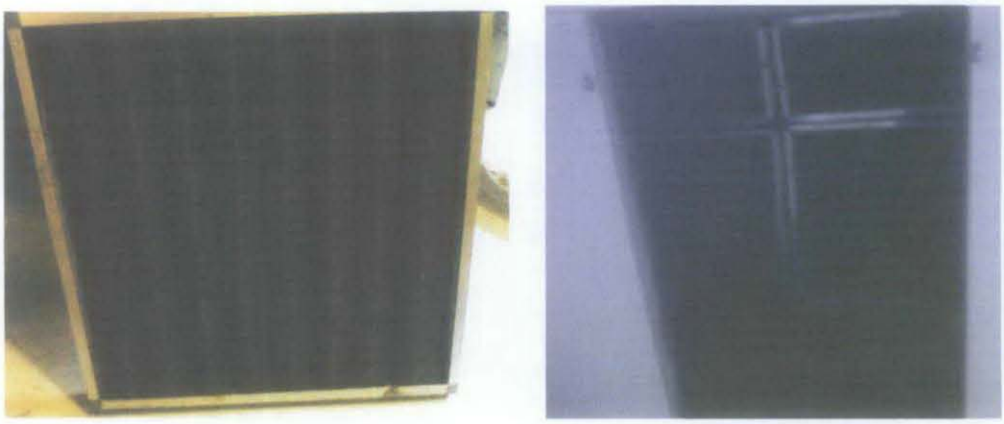

Figure 4.12 Current used filter image in AHU right wing building 18 level 3

4.6.3 Data collection on PM10 upstream

On 2 August 2011, another set of data for 24 hours are taken on the upstream of the filter. MicroVol 1100 is place in the AHU room near the filter. The recorded data are as below:

The calculation of the weight different of the filter paper as shown below:

Before experiment: 0.012 g

After experiment: 0.020 g

Therefore, the weight different is:

Δ *filter paper*: 0.020 g – 0.012 g = 0.008 g

$$\text{Concentration} = \frac{(\Delta filterpaper)g}{FlowRate * Time} * \frac{h * 1000L}{60\min * m3}$$

Time	Flow rate (L/min)	Filter paper (g)	Total time (min)	Concentration (μg/m³)
3:00:00 PM	13.9556	0.008	24	99.522
4:00:00 PM	13.6000	0.008	24	102.124
5:00:00 PM	13.2444	0.008	24	104.866
6:00:00 PM	12.4000	0.008	24	112.007
7:00:00 PM	9.0000	0.008	24	154.321
8:00:00 PM	8.0000	0.008	24	173.611
9:00:00 PM	8.0000	0.008	24	173.611
10:00:00 PM	8.0000	0.008	24	173.611
11:00:00 PM	8.0000	0.008	24	173.611
12:00:00 AM	8.0000	0.008	24	173.611
1:00:00 AM	8.0000	0.008	24	173.611
2:00:00 AM	8.0000	0.008	24	173.611
3:00:00 AM	8.0000	0.008	24	173.611
4:00:00 AM	8.0000	0.008	24	173.611
5:00:00 AM	8.0000	0.008	24	173.611
6:00:00 AM	8.0000	0.008	24	173.611
7:00:00 AM	8.0000	0.008	24	173.611
8:00:00 AM	13.7333	0.008	24	101.133
9:00:00 AM	13.2889	0.008	24	104.515
10:00:00 AM	13.0667	0.008	24	106.293
11:00:00 AM	13.6444	0.008	24	101.792
12:00:00 PM	13.4667	0.008	24	103.135
1:00:00 PM	13.1111	0.008	24	105.932
2:00:00 PM	13.6444	0.008	24	101.792

Table 4.8 Graph of PM10 Concentration (μg/m³) over Time

Based on the table above, the highest concentration, 173.611 μg/m³ was recorded on 8:00pm until 7:00 am. This is because AHU was not turn on. Since there is no mechanical force to help completing the air-conditioning cycle, the air is hardly to move. This can be seen with low air velocity are also recorded. Even though the concentration is exceeding the standard, there are no occupancies since the working hour is over. Therefore, due to issue of cost minimization, the AHU is needed to be turn off. As for the lowest data, it is recorded at 3:00pm with concentration of 99.522 μg/m³.

- **PM10 concentration at upstream and downstream of right wing filter of academic building 18, level 3**

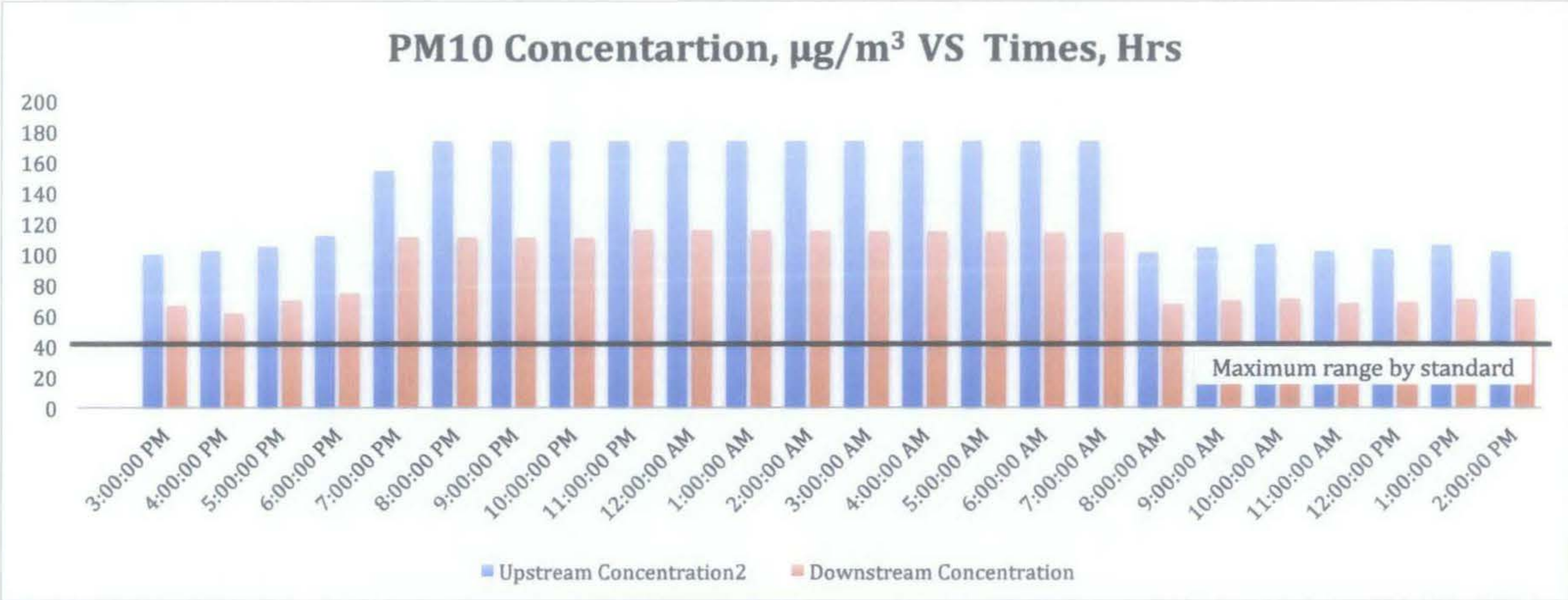

Figure 4.13 PM10 concentration at upstream and downstream of right wing filter Academic building 18, level 3

Based on the graph above, all the concentration both on upstream and down stream is not in the safe range of PM10 concentrations by standard.

4.6.4 Building 18, Level 3 Right wing filter's efficiency

Air filter efficiency is he ability of a filter to remove particulate or gaseous material from an airstream by measuring the concentration of the material upstream and downstream of the device. The efficiency describes how well of an air filter removes microscopic particles (PM10) such as dust, dust mites, pollen, mold, bacteria, and smoke (www.engineeringtoolbox.com, 15/08/2011). Air filter efficiency can be expressed as:

$$\mu_e = n_t / n_u = (n_u - n_d) / n_u$$

where:
μ_e = air filter efficiency
n_t = particles trapped
n_u = particles upstream
n_d = particles downstream

Since there are many readings were taken, the average of of PM10 concentration for both upstream and downstream are used.

Upstream average concentration :**140.865 μg/m³**
Downstream average concentration :**93.093 μg/m³**

Filter's efficiency

$$= \frac{(140.865 - 93.093)\ \mu g/m3}{140.865} \times 100\%$$

$$= \underline{33.91\ \%}$$

4.6.5 Suggestion for improvement of IAQ.

From the calculations, it shows that the current filter efficiency is only 33.91% compared to its original efficiency 80%. This is due to longer usage of 6 years, instead of 1 year of it's original life cycle. When the same filter is keep cleaned, the cavity of the filter's are getting bigger, resulting into penetration of more contaminants as more cancan pass through. Therefore, I would like to suggest on replacement of new filters as it will have higher efficiency and reduce level of concentration of PM10 and other contaminants.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study is complete with all the objective has been achieved. The first objective - the current status of indoor air quality in building 18 level 3 is determined through sets of data of relative humidity, temperature, ventilation rate, carbon dioxide (CO_2) content, and PM10 concentration. When collected data is analyze and compared to standard, only PM10 concentration is not in the safe range. The average of its concentration is about 93.1 $\mu g/m^3$ downstream, after the filtrations. This value is high and dangerous to the occupant if they are being expose for a long time.

Since only PM10 is not in the safe zone, the root cause analysis for high concentration of the particle is being done. In the root cause diagram, the four main possible causes for high PM10 concentrations are manpower, machine (which refer to HVAC system), materials and design. After an analysis on all 4 main factors, filtration is chosen as the main cause of this problem.

Further studies on filtration are done by taking the PM10 data on the upstream. Efficiency is calculated and compare to the original. However, the efficiency is only 33.91% compared to the original, 80%. This shows that the contaminant cannot be filtered and still circulated in the building.

From the overall finding, the current condition of IAQ in academic building must be enhance. The improvement study done can be implement and beneficial in term of building occupants. A good indoor air quality is indeed important for a healthy indoor environment. Poor indoor air quality can cause variety of short-term and long-term health problems. Therefore, a continuous study should be done especially in improving the IAQ.

5.2 Recommendations

The followings are the recommendations from the present study to improve the indoor air quality:

1. To change current filter used with high efficiency filter
2. To have better pre-filter and maintenance on fresh air duct (FAD)

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