# A COMPARISON OF OCCUPANT THERMAL COMFORT BETWEEN A GREEN BUILDING AND A CONVENTIONAL BUILDING IN THE TROPICS

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**FACULTY OF ENGINEERING**

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**RESEARCH REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING**

**FACULTY OF ENGINEERING**

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## UNIVERSITI MALAYA

## ORIGINAL LITERARY WORK DECLARATION

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Field of Study: HEATING, VENTILATION AND AIR CONDITIONING

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# Abstract

This research report conducts a study of comparing the thermal comfort between a green building and a conventional building in tropical climate, namely Malaysia. The green building selected for this study is the Suruhanjaya Tenaga (Energy Commission) headquarters in Putrajaya, also known as the Diamond building. For the conventional building, an electronic manufacturing company called Epson Toyocom Malaysia Sdn. Bhd. was selected. For both the buildings, specific office locations were targeted for data collection area. Field work was conducted within one day in Epson Toyocom Malaysia Sdn. Bhd. (Conventional building) consisting of physical measurements of environmental conditions and thermal survey of its occupants. The Suruhanjaya Tenaga (Green building) physical measurement and thermal survey raw data were provided by Dr.Yau. Both the results were analyzed and compared.

72% of green building occupant voted neutral or thermally satisfied compared to only 51% of conventional building despite the lower operative temperature. In the office in conventional building, the thicker clothing profile and the lack of natural air ventilation may have contributed to this results. Additionally, green building was also voted better acoustically and visually by its occupant compared to conventional building. The design characteristics of the green building compared to the enclosed space in conventional building office is significant in the outcome of the results.

It is suggested for organizations to strongly consider sustainable design for future developments.

# Abstract (Malay)

Laporan penyelidikkan ini membuat perbandingan keselesaan thermal diantara bangunan Hijau dan bangunan biasa di kawasan beriklim tropical. Bangunan hijau yang dipilih ialah ipupejabat Suruhanjaya Tenaga yang terletak di Putrajaya, manakala bangunan biasa yang dipilih ialah sebuah kilang elektronik, Epson Toyocom Malaysia Sdn. Bhd. yang terletak di Sri Damansara, KL. Kawasan pejabat tertentu dari kedua-dua bangunan tersebut diplih bagi tujuan penyelidikkan ini. Kajian yang dijalankan di bangunan biasa mengambil masa satu hari dimana bacaan parameter berkaitan keadaan sekeliling serta soal selidik pengguna pejabat tersebut di kumpulkan pada masa yang sama. Data bagi bangunan hijau pula di perolehi daripada Dr.Yau. Kedua-dua data tersebut kemudiannya dianalisa serta dibandingkan.

72% daripada pengguna bangunan hijau mengundi keadaan neutral ataupun selesa berbanding dengan hanya 51% daripada pengguna bangunan biasa yang mengundi kategori yang sama, walaupun suhu operasi bagi bangunan hijau lebih rendah daripada bangunan biasa. Tahap pakaian yang lebih tebal serta kekurangan sistem pengudaraan semulajadi adalah berberapa sebab keputusan tersebut. Selain daripada itu, bangunan hijau juga diundi sebagai lebih selesa dari segi visual dan akustik. Kelebihan dari segi rekabentuk yang mengutamakan kesinambungan tenaga bagi bangunan hijau berbandingkan bangunan biasa yang merangkumi sebuah pejabat yang tertutup menjado faktor penting dalam keputusan kajian ini.

Pembangunan masa depan dicadangkan tidak menghiraukan ciri ciri rekabentuk bangunan yang mesra alam.

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First and foremost, I would like to express my gratitude to my supervisor, Associate Professor Ir.Dr. Yau Yat Huang for all the guidance, comments and engagement through the learning process of this master research report.

Furthermore I would like to thank Dr.Chew Bee Teng for her assistance in providing support for additional data and access to measurement equipment throughout this research study. Also not forgetting Mr.Ramesh from mechanical department, UM for his assistance in the equipment as well.

Last but not the least, special thanks to all my family member and friends for their support throughout the time of this research work.

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# Chapter 1 Introduction

## 1.1 Background

Deterioration of the earth's natural resources and climates are recently being taken into notice by many. Governments all over the world have realized the impending catastrophe if effective measures are not taken from now on. One area of concern is conservation of energy and green buildings are one area where recent attention is being given. Otherwise known as sustainable building, green buildings are described as construction or structures that has considered environmental effects

United States Environmental Protection Agency (Agency) describes green buildings as a structure which throughout its lifecycle maintains an environmentally friendly existence and resource efficient operation. The whole process of materializing the building, from design level up to fabrication and construction of the building considers and minimize its effect on environment and surroundings. It however must not defeat the whole purpose of the building in maintaining its productivity and human comfort.

Green building index website ("Green Building Index," 2012) defines green building to be focused on increasing the efficiency of resource used for the reason of saving. At the same time, green building will be able to improve human health and reduce environmental impact. All this is achieved by carefully planned and innovative construction, operation, design and removal.

## 1.2 Green building developments in Malaysia

Malaysia has been lagging behind in the green industry compared to the other countries in similar or more advanced economic state. Green Market Report 2008(2008) by BCI (Building Construction industries) companies in Australia shed a lot of light on the challenges faced in the green market in Malaysia. As the report is based on empirical data collected from AEC (Architecture, Engineering and Construction) professionals from Australia, South East Asia and China, the results can be referred to as a reliable representation of the green technology stature in these countries. Malaysian professionals had very low exposure to green building projects compared to the other countries in the survey. The report also showed that the same subjects did not have the belief in the return of investment in green technology which interpreted into the lack of commitments into such projects. However the report managed to highlight main reason for this lesser penetration in Malaysia in terms of green building which is lack of awareness. In support to this cause, there were also lack of proper research and encouragement by government. The report concludes that the Malaysia AEC professionals have little experience in terms of green technology and their main worry point is the initial costs and the return of investment. However due to foreseen energy crisis looming throughout the world, they are very interested to get involved and receiver further information into this area.

This has not gone unnoticed by the Malaysian government with the establishment of the Ministry of Energy, Green technology and Water back in 2009. This shows they are concerned and looking to overcome the aforementioned problems. With the government push and supply of information throughout the nation, Malaysia looks to increase the awareness while fueling green based developments.

For rating and accreditation purpose, Green building index (GBI) was setup in August 2008 by PAM (Malaysian Institute of architects) council. GBI is a rating system primarily designed to be utilized in tropical climates and can be used to measure how sustainable a building is. A more recent rating system in the works is the Green Pass, soon to be introduced by Construction Industry Development Board Malaysia (CIDB). This system is in the draft stages and currently under evaluation.

In line with that, the National Green Technology Policy was drafted out to create a legislative and regulatory framework to support and develop the green aspects of the country. The policy look to achieve an efficient and independent nation in terms of energy utilization reduced adverse effects on the environment while maintaining or improving economic gain and developments. Under this policy, short term, midterm and long term plans were made to be incorporated into Malaysia plan. In 2010, the 10$^{th}$ Malaysia plan concentrates on increasing nation awareness and encouraging green technology based products, buildings and other developments as well as foreign and local investments. This short term plan is to attract such efforts by providing incentives and also to educate the nation.

Some recent incentive programs as mentioned by the Ministry of Energy, Green technology and Water are tax exemption for GBI certified buildings and availability of loans for manufacturers and consumers through Green Technology Financing Scheme. Apart from that, buyers of GBI certified buildings will be exempted from stamp duty on transfer of ownership.

It can be seen that will all this effort and push to go green being undertaken, further studies are necessary to support the implementation of sustainable technology itself. With current high dependence on fossilized fuel, the question will be whether the green technologies will be able to provide similar comfort, efficiency and performance. The findings will be able to provide valuable information on further improvements can also be undertaken and ultimately achieving the cost viability.

## 1.3 Objectives

The main objective of this study is to provide a comparison of thermal comfort between a green building and conventional building. Many design input has been gone into the construction of local green buildings to ensure similar comfort levels are achieved as in conventional buildings. However, there are many factors in deciding thermal comfort of human beings. Physical environmental parameters such as temperature and humidity are a huge influence, but the human psychology is much more complicated. It is difficult or quite impossible to actually design an algorithm to have overall influence. However studies such as this will provide valuable influence to get there.

Another objective of this study is to gain progress in understanding human thermal comfort requirements in tropical climate. Many similar studies have been conducted in other places around the world, but thermal comfort comparison between green building and conventional building in tropical climates are far and between.

## 1.4 Significance of study

With the increasingly successful implementation, construction and development of green buildings in Malaysia, studies such as this will provide supportive data and information to further improve on design of future buildings. Positive results will be encouraging to other future developments while negative results will highlight the necessary improvements required. Apart from the green buildings itself, organizations will be able to deploy justifiable cost and energy saving measures to existing building as well.

In terms of environmental sustainability, large scale developments will eventually have a positive reduction in pollution level and energy abuse.

# Chapter 2 Literature Review

## 2.1 Thermal comfort

The most well-known and relevant body regarding this topic, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (ANSI/ASHRAE, 2004) defines thermal comfort as "the condition of mind in which satisfaction is expressed with thermal environment". It further reiterates that the thermal comfort is an output of a human mind influenced by physical, physiological, psychological and other process. This definition suggests thermal comfort is subjective and not quantifiable. Human perceptions are influenced by many surrounding factors and it is difficult if not impossible to achieve entirely similar state of mind across more than one human being at any given time. Therefor most existing studies or practice around is to satisfy the highest number of occupants in terms of thermal comfort.

ASHRAE standard 55 (ANSI/ASHRAE, 2004) also states that thermal comfort and discomfort for most people seems to be affected by direct temperature, skin moisture level (Sweatiness), deep body temperature and the efforts put in by the body to regulate body temperatures.

### 2.1.1 Thermal comfort models

As thermal comfort is an important aspect of any building or in this case any locations where human activities occur. Large cooperation around the world invests in preliminary studies to relate to designs and structures of buildings to the eventual thermal comfort it creates. Researchers around the world have putting in considerable efforts for the same purpose. It is however been a challenge to achieve a single standard or model to be specific to determine optimum conditions.

#### 2.1.1.1 Heat balance Approach

Models based on this approach were basically derived by applying thermodynamic heat balance calculation to the measurable variables around human body. This approach basically concentrates on deriving conclusions from a controlled environment. Experiments taking place by this approach are basically done in a climate chamber or controlled thermal environment to limit the number of variable and controlled number of factors

Christian F.B et al (Bulcao, Frank, Raja, Tran, & Goldstein, 2000) iterated that skin-surface (Tsk) and core (Tc) temperatures are important inputs into human thermoregulatory system and therefore did a study to find a relation of this values to thermal comfort. They found that Tsk has a higher influence on thermal comfort compared to Tc. Tsk directly affected by immediate environment temperature and therefore initiate immediate behavioral thermoregulation. Tc is more influential in initiation of physiological response. They also mentioned that with each degrees increase in Tsk, Tc also increase by one degree which means that thermoregulation system of human body might take time to initiate and affect the thermal comfort.

Heat balance application to human body thermal comfort study is described in detail by Charlie Huizenga et al (Huizenga, Hui, & Arens, 2001) by studying various response of physiological mechanism such as sweating, metabolic heat production and more to the ever-changing transient and non-uniform thermal environment. They claim to enhance on models created by

Stolwijk with unlimited body segments and adding clothing factor into the relation. Their study came up with a node diagram(Huizenga et al., 2001) (Figure 2.1) to describe the heat transfer path in four different conditions: exposed skin with convective and radiant heat loss, clothed with convective and radiant heat loss, clothed skin with conductive heat loss to contact surface and bare skin. This model can be utilized for human thermal comfort evaluation for transient conditions or environment.

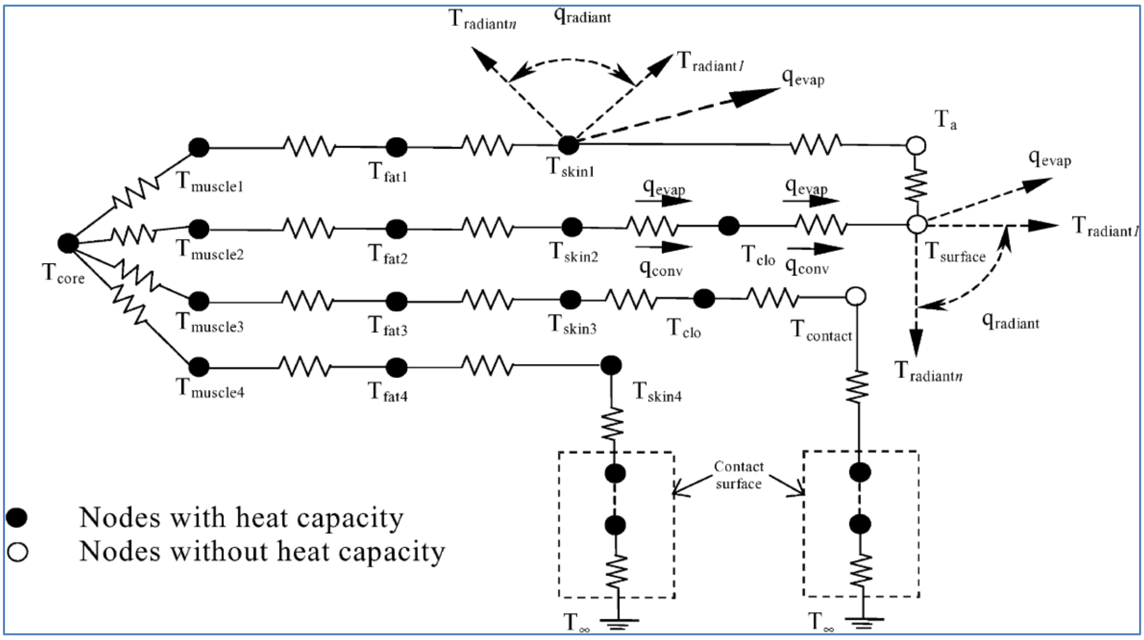


Figure 2.1 Charlie Heizunga et al Heat path node diagram (Huizenga et al., 2001)

Fanger's model (P.O, 1970), combines heat balance theory with human thermoregulation system. His experiments were done in controlled climate chamber involving 1296 people standardly dressed. They were exposed to different thermal environments and their feedbacks on comfort were recorded based on AHSRAE seven-point thermal scale. This result were then related to the actual heat flow occurring in a human body and the heat flow required for optimum comfort for the given environment at specified activity. This relation is named as Predicted mean vote (PMV) as given by the following equation:

$$PMV = [0.303\exp(-0.036M)+0.028]\ L = \alpha L$$

L describes the thermal load on the body, which is the difference between internal heat production and heat loss to environment. From this equation, the average response of large group of people can be predicted based on any given thermal environments.

Fanger then proceeded to use the data based on thermal sensation scale to classify the percentage of subjects that were dissatisfied with each different condition. The result is named as the predicted percentage of dissatisfied (PPD). The relationship of PPD and PMV were given as:

$$PPF = 100\text{-}95\exp([-(0.03353PMV^4+0.2179PMV^2)]$$

From the results, it can be seen (Figure 2.2) that even when PMV index is 0, cases of dissatisfaction still exists. It was also noted however that Fanger's experiments were done in a controlled environment with limited activity by the subjects.

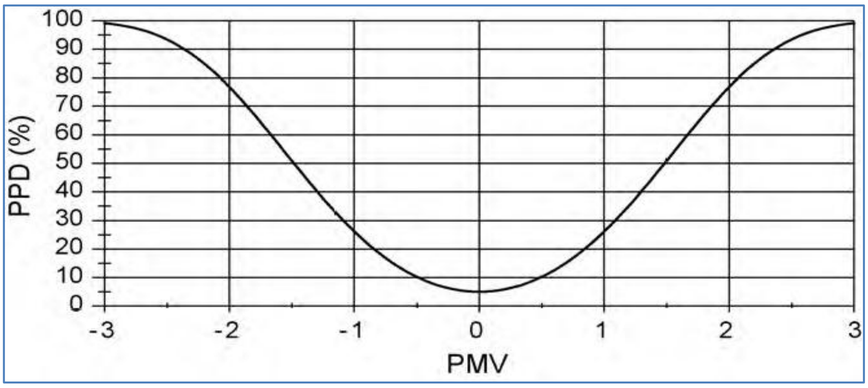


Figure 2.2 PPD vs PMV relationship (P.O, 1970)

Current existing standards on thermal comfort such as ISO 7730 and ASHRAE Standard 55 were based on the PMV-PPD approach.

#### 2.1.1.2 Adaptive approach

Compared to heat balance approach, adaptive approach takes advantage of data gathered from real world analysis.  Thermal comfort as mentioned by its definition is mainly defined by state of mind. Therefore it is important to study real world situations where many other factors influence the thermal comfort level. Field studies were undertaken to analyze real world situations where occupants' feedback on thermal comfort level based on their everyday behavior or necessary adjustments required.

J.F Nicol et al (J. F. Nicol & Humphreys, 2002) explained adaptive study is based on the survey undertaken on thermal environment on target area as well as the thermal response of the subjects involved. By summarizing this data, they estimate the conditions which are defined as thermally acceptable and these conclusions can be used to predict thermal comfort conditions in other places with the same environmental condition.  They also explains that the adaptive approach takes into consideration that human being takes certain actions to adjust themselves to the environment. Humans with ability to control or adapt themselves at their own are less likely to be in discomfort in the given environment. J.F.Nicol et al also mentions that there is contextual variable in this scenario. Firstly is the climate which is a main influence of culture, habits and attitudes of occupants. Secondly, the building they occupy in. Different buildings will have different thermal environment based on their designs, services provided and more. Thirdly, the time, whereby given time, occupants will choose to adapt accordingly or either change the environment itself to suit them.

Another field experiment by Hwang et al (Hwang, Lin, & Kuo, 2006) done in Taiwan shows that the temperature range acceptability for thermal comfort is much wider that can be obtained by ASHRAE standard. Apart from that, it was found that neutral temperature range deviated between naturally ventilated classrooms to those with air-conditioning. They also found that gender is significant in comfort level where female students showed a more narrow range of temperature acceptability compared to male students.

A few other adaptive studies such as the one  on thermal comfort evaluation of naturally ventilated public housing in Singapore (Wong et al., 2002) and on similar study in Indonesia (Feriadi & Wong, 2004), both conducted in a tropical environment suggests that compared to ASHRAE standard, thermally acceptable condition range is wider. Hugo (Hens, 2009) stressed that standards should not be set as an absolute reference. Field studies based on adaptive approach are equally important in predicting the thermal comfort zone of a certain environment.

### 2.1.2 Thermal comfort adaptation in tropical climate

Based on information from Malaysian meteorological department, temperature throughout the year in Malaysia are uniform with high humidity and regular rainfall. Temperature averages about 27° Celsius and rainfall is about 250 cm a year. Wind is described as generally light. As with most tropical countries, this relatively hot and humid climate demands necessary adjustments to maintain thermal comfort level in the local buildings.

In study on thermal perceptions and general adaptation methods by Hwang et al (Hwang, Cheng, Lin, & Ho, 2009), it was found that in hot and humid tropical climate, preferred method of adaptation is by air-conditioning system followed by electrical fan, clothing level adjustments and other methods. This result based on data gathering from offices are different compared to private homes where electrical fans are the more preferred method followed by air-conditioner, clothing level adjustments and other methods. This difference was mainly because of economical implication in terms of electricity cost. Private home owners look to save this cost by minimizing the usage of air-conditioning system. Upon further interviews they found that for quick adaption, occupants looked for reduced temperature condition and increased air-velocity.

As was the finding in many adaptive thermal comfort surveys, people tend to adjust themselves to the surroundings and find means to make them comfortable. As some adjustments takes time to take effect it might not be much of an issue in private homes but it will be very important to predict the thermal comfort in an office environment. Nicol (F. Nicol, 2004) mentioned that in hot humid condition, where convection and radiant heat transfer out of the body is substantially reduced, evaporation becomes the main medium. However due to humid condition, this mode of heat loss is slowed down, thus causing discomfort. He back this up with studies by (R.J. deDear, 1991) and (E.R. Ballantyne, 1977) by stressing that discomfort in humid environment is more prominent even with small temperature change compared to dry ones.

Based on this, it can be seen that important factors in up keeping thermal comfort level in tropical climate will come down to reduce temperature and maintaining relatively dry air condition. Most efficient methods currently used are by utilizing air-conditioning systems and electrical fans.

### 2.1.3 Thermal comfort in Green buildings

Current methods of thermal comfort control in tropical climates are a challenge to green building infrastructure. High dependency on electrical means of air flow, temperature and humidity control means great design acuity and creative planning is required to construct an efficient green building in this climate. It is important to study the impact that going green in the name of sustainability has on the level of thermal comfort. To maintain high performance and optimum output of the occupants, their comfort must not be sacrificed.

In survey of thermal comfort in low energy office buildings in Germany(Pfafferott, Herkel, Kalz, & Zeuschner, 2007), 3 different categories of summer cool, moderate and summer hot buildings were compared. Those buildings were utilizing passive cooling by natural heat sinks. In this survey it was found that only 5% of times the thermal comfort condition was exceeded. The 12 buildings that they surveyed used few different passive cooling methods; one of them being air-driven cooling reached its capacity during extended period of hot climate. They concluded that a well-designed passively cooled building will keep the thermal comfort range and suggests that local climate should be prioritized.

In another study by Kryono, researching the thermal comfort in Jakarta, concludes that thermal comfort can be achieved without unnecessary air-conditioned cooling. The indoor temperature of the target building was found to be very much influenced by the building design. Comparison of 2 buildings, one with protection from the sun and the other without, shows temperature in a building can be considerably reduced with minimum energy utilization by considering the location relative to sun shine. Natural air ventilation was proved to be sufficient in this case to provide sufficient cooling. Some of the features that assist are thick glazed windows, shading direct sun exposure to building walls, natural ventilation, and natural lighting paths.

Baird et al found encouraging results favoring sustainable buildings in terms of temperature and air quality when compared to normal buildings. This comparison were done with results of a study by Leaman and Bordass who did a wider survey involving 165 buildings in the UK comprising both sustainable and conventional building. It was also noted however that majority of the buildings rated to be on the colder side during the winter and hotter side during the summer. They suggested that it can be improved with focus given in improved design and operation of buildings.

Another study by Warren L. Paul et al made a direct comparison of occupant feedbacks on comfort between green buildings and conventional buildings. Their results were less favorable towards green building, but stressed that an important element of comfort which is the hydronic cooling system were not working at the time of study. They were additionally surprised to find that other parameters such as aesthetics and serenity were rated lower compared to conventional building and came up with the hypothesis that green awareness level of the occupants plays an important factor. A person who is more green minded were suggested will amplify their perception of thermal comfort in a green building as opposed to conventional building.

# Chapter 3 Methodology

The methods used in this study of thermal comfort were extracted from few other researches as were seen in literature review and others. It has to be highlighted that the survey and data collection for this research paper was conducted for conventional building only. The green building data was obtained from previous group who did similar survey under Dr.Yau. Thereafter the obtained data was used to compare and analyze the difference in thermal comfort performance between the two buildings

Survey was conducted on selected building to obtain respondent feedback on the sensation and satisfaction in terms of thermal, acoustic, visual and cleanliness. Additionally, physical parameters surrounding the occupants were taken during the survey. The correlation of the results will be discussed and compared to standards such as ISO 7730 (ISO7730, 2005), ASHRAE 55 (ASHRAE55:2010, 2010) and other surveys done on thermal comfort.

## 3.1 Building selection

Selected green building in this study is the Suruhanjaya Tenaga (ST Building) building in Putrajaya also known as the Diamond building due to its shape and design. The conventional building selected is a manufacturing company called Epson Toyocom Malaysia (EP building) located in Bandar Sri Damansara. Even though the conventional building is industrial based, for the purpose of this study, only the office area in both buildings are targeted for the survey and data collection. Therefore any concerns that the noise, heat and other disturbance concerns in an industrial environment that will affect the outcome of this study can be ignored. Further explanation of this point and details of both the buildings will be provided in the coming paragraphs.

ST building in a thermal comfort survey were provided by Dr.Yau. As mentioned earlier, a fresh data collection was conducted for the conventional building (EP building) to be used as a comparison study.

### 3.1.1 Green Building : Suruhanjaya Tenaga Building, Putrajaya

The Suruhanjaya Tenaga (ST building) headquarters in Putrajaya otherwise known as the diamond building is a Green mark Platinum certified building. It is one of the well know green building in Malaysia. As the highest level certification of Green mark suggests, many energy saving and sustainable design were in cooperated into this building. The building was developed by Putrajaya Perdana, designed by NR architects while the IEN consultants were appointed as the sustainability consultant

Figure 3.1 Suruhanajaya Tenaga Heardquarter Putrajaya Photo("Ministry of Energy, Green technology and water,")

Some of the energy efficient features of this building are the inverted pyramid configuration of the building to prevent direct sunlight, solar panel assembled rooftop for which can provide 10% of the electrical energy consumption and the center atrium with selective shading and glazing to admit filtered natural lighting while maintaining indoor temperature. Indoor temperature is targeted at 24°C and to achieve this, the concrete floor and roof is cooled at 20 to 22 °C. Working stations and rooms are concentrated towards the outside window or the center atrium to maximize natural lighting.

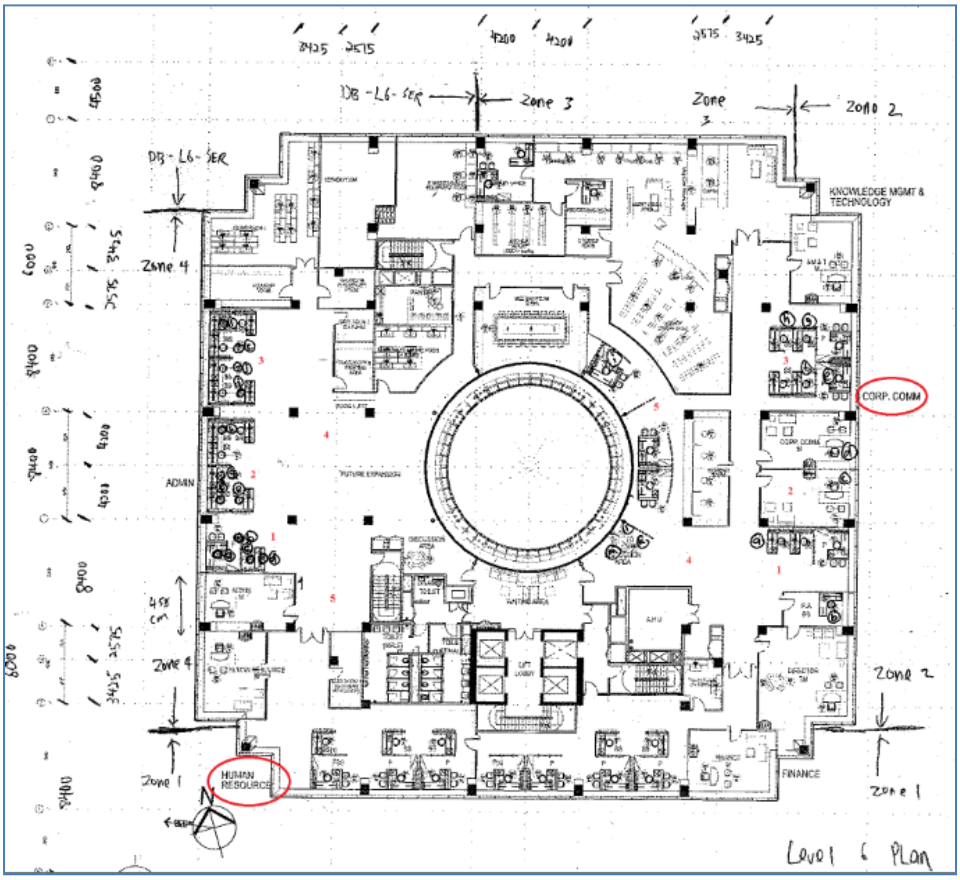


Figure 3.2 ST Building 6th Floor layut plan ("IEN Consultants website,")

For this comparison study, the data was collected from 6th floor of the ST building in the Human resource and Admin and Cooperate communication department. The collected data consists of survey results done on 2 working days from 9am to 12pm from 25 respondents with fixed work stations. These occupants were also considered familiar with the indoor environment

### 3.1.2 Conventional building: Epson Toyocom Malaysia, Sri Damansara

Epson Toyocom Malaysia, a Japanese manufacturing company located in Sri Damansara industrial park was selected as the conventional building. This factory is located in a medium industry area called Kepong industrial park in Sri Damansara area.


Figure 3.3 Epson Precision building

Figure 3.4 Epson Precision building satellite view

For this study, the Engineering office area were selected. Despite being an industrial based building, the office houses all Engineering staffs and workers and functions as work stations for analysis, data summary, report making and other management and administration function. The office area is confined by walls with proper sound insulation and protection from other disturbing factors from the manufacturing line. Despite being built with comfort of the occupants in mind, the design of the office lacks any inputs of energy sustaining design characteristics. The office is an enclosed space divided by concrete and gypsum based walls. There are 2 large packaged type, standing air conditioner to cool the room on each side of the office area. There are no natural light coming into the room due to non-existing windows, therefore lighting source are entirely from the fluorescent lights assembled on the ceiling.

The reason for selecting this office as a conventional building is due to the extreme opposite nature of the building compared to the green building. From this we hoped to gain positive information on how cost efficient and comfortable a green building could be. Additionally such information would provide valuable encouragement to this and other similar organizations everywhere to implement energy efficient construction and environmentally friendly measures without sacrificing in cost and comfort. Another reason is that as a employee of Epson Toyocom Malaysia, access is unlimited and I

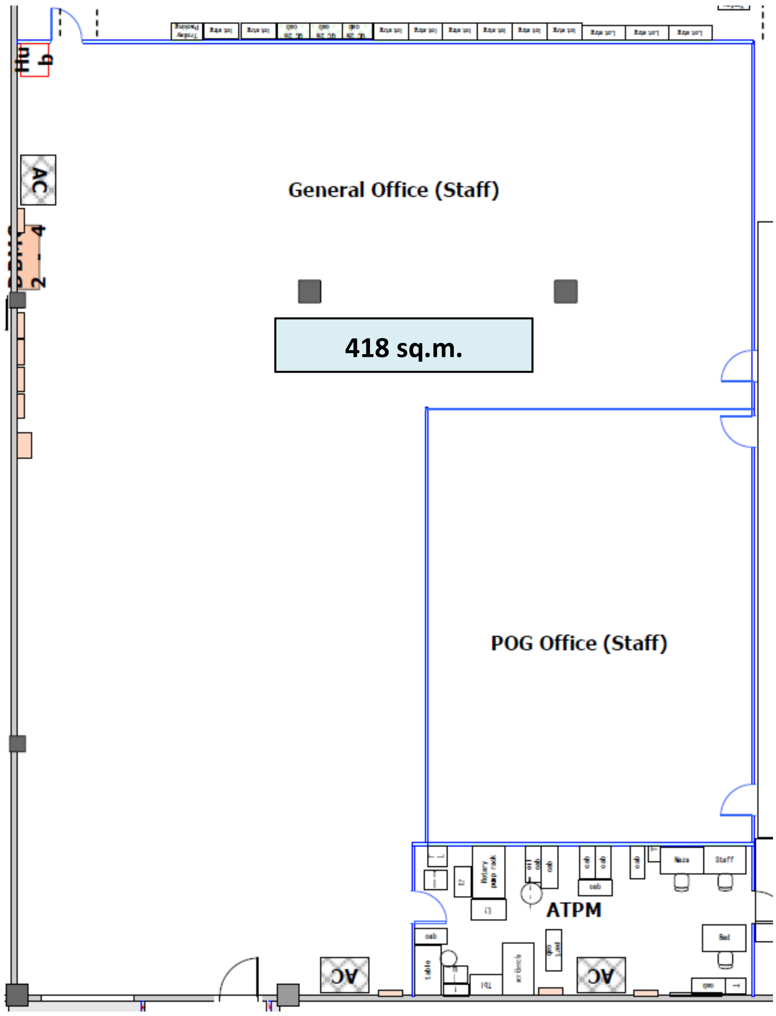

Figure 3.5 EP General office plan

do not have to sacrifice my work time for this research purpose. Furthermore, I will be able to provide invaluable information to my company on energy saving measures based on the outcome of the study.

## 3.2 Thermal Comfort survey method

First part of this study will be the survey. Individuals in the target locations were approached personally with prepared questionnaires to obtain information on thermal comfort perception. The questionnaire is prepared to be simple and direct for easy understanding of the respondent.

The first part of the survey consists of some basic details of the respondents such as sex and location. The zones which they are located in are also recorded.

To obtain feedback on the sensation and satisfaction of the occupants of their environment, a seven point scale was used. This was based on the ASHRAE thermal sensation scale(ASHRAE55:2010, 2010). Thermal sensation, acoustic satisfaction and visual satisfaction of the occupants were obtained by asking them to mark out their level of sensation on 7 points ranging from worst to best (refer Table 3.1)

Table 3.1 Survey sensation and satisfaction scale

<table>
<tr><th>Sensation scale</th><th>-3</th><th>-2</th><th>-1</th><th>0</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Thermal</td><td>Cold</td><td>Cool</td><td>Slightly cool</td><td>Neutral</td><td>Slightly warm</td><td>Warm</td><td>Hot</td></tr>
<tr><td>Acoustic</td><td rowspan="2">Very Dissatisfied</td><td rowspan="2">Moderately Dissatisfied</td><td rowspan="2">Dissatisfied</td><td rowspan="2">Neutral</td><td rowspan="2">Satisified</td><td rowspan="2">Moderately Satisfied</td><td rowspan="2">Very Satisfied</td></tr>
<tr><td>Visual</td></tr>
</table>

Additional, occupants were asked to describe their clothings. They were required to select from a list prepared based on the clothing items generally worn by Malaysian office staff and workers. Based on this selection, thermal insulation can be obtained for each respondent in reference to ISO7730 standard (ISO7730, 2005).

Also queried is the respondents' activity level at the time of survey. Similar to clothing survey, a list of activity levels such as light activity, medium, sitting or standing were listed out for the occupants' selection. From this data, the activity levels were converted into metabolic rates in reference to ASHRAE standard 55:2004 (ASHRAE55:2010, 2010).

### 3.3 Physical measurements

During the course of the survey, environmental parameters were recorder using suitable equipment. The equipment used and functions are listed in Table 3.2. Measurements recorded are such as air temperature, relative humidity, air velocity, lighting level (in lux) and sound level (in dB).

These measurements were done while the respondent filled up the questionnaire to get real time data and exact representation of the survey response.

### 3.4 Analysis

In ST building, the human resource and cooperation communication department were selected for the survey. Each of the office were divided into 5 zones each. Data gathered from survey respondents were gathered according to their respective zones while physical measurements were collected for each zones.

For EP building, similar approach is used, except that here, only one office area was involved. EP office was divided into 13 zones for gathering physical measurements and 2 respondents were selected for survey from each zones.

Table 3.2 Measurement instrument and description

| Picture | Description |
|---|---|
|  | ASI Alnor<br>Velometer Thermal Anemometer<br>AVM440<br><br>Measure: Air Temperature and Air Velocity |
|  | Kimo<br>Thermocouple Thermometer<br>with Globe temperature probe<br>TK100<br><br>Measuring range : -200 to 1300ºC |
|  | Kimo<br>Sonometre DB100<br><br>Measuring range : 30-130 dB<br>Resolution : 0,1 dB |
|  | Kimo<br>Luxmeter LX100<br><br>Measure Lighting level<br>Measuring range : from 0,1 to 150 000 lux |

All the collected data were grouped together to be made side by side comparison between green building and conventional building. For reference, ASHRAE thermal comfort standard recommendations were used to justify the estimated comfort level of each building.

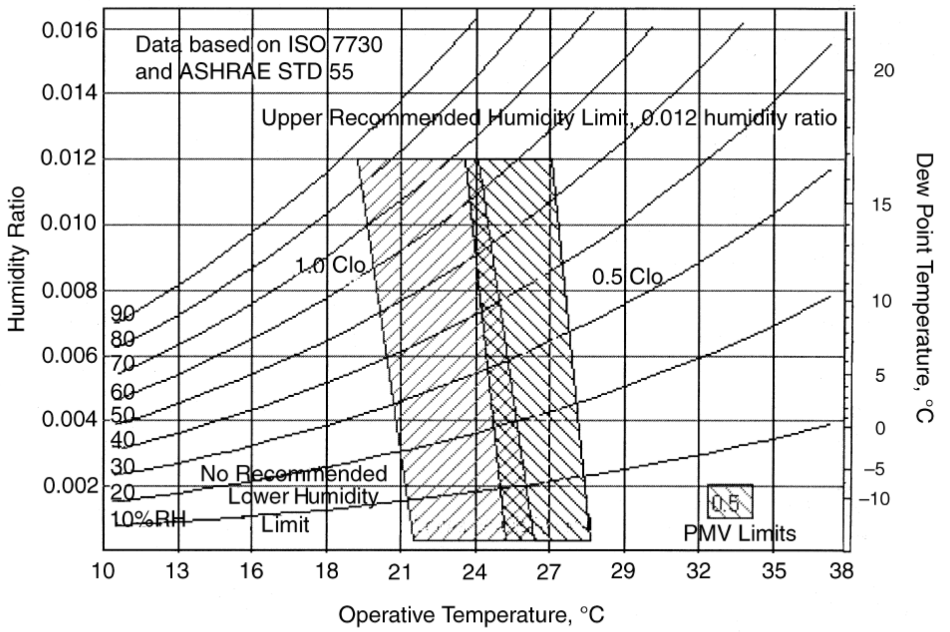


Figure 3.6 Acceptable range for operative temperature and Humidity(ASHRAE55:2010, 2010)

Figure 3.6 shows the accepted range of operative temperature and humidity level which should satisfy at least 80% of the occupants in terms of comfort. This data is based on the assumption that occupants are doing activity within 1.0 to 1.3 met and wearing clothing level of 0.5 to 1.0 clo. This information will be used to compare with actual data collected from the ST and EP building.

## Chapter 4 Results and Discussions

### 4.1 Survey Respondents

Data collection was done on the 2nd February 2013, Saturday which was a replacement working for the company. A total of 98 occupants was present on the day of survey comprising of staffs, manager and analysis workers. The office in Epson was divided into 13 zones for data collection. In each zone 2 participants were selected for survey and environmental parameters collection. From the total occupants in the office, 53% are male and the remaining 47% and females (Figure 4.1). Selected survey correspondents were balanced with 50% each from each sex, which does not deviate far from the total occupants and therefore assumed to be an overall representation of situation.

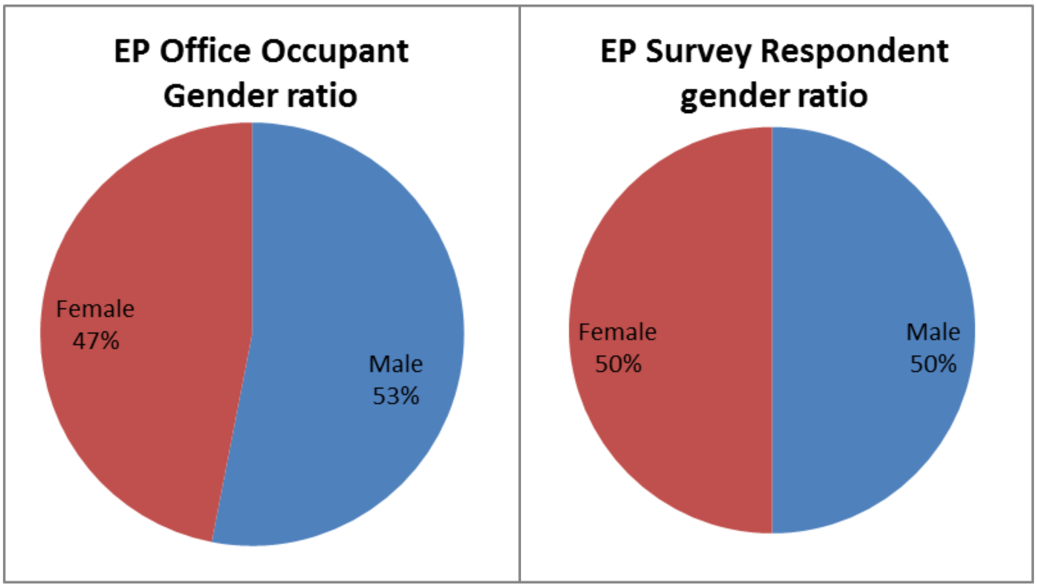


Figure 4.1 EP building overall occupant and survey respondent gender ratio

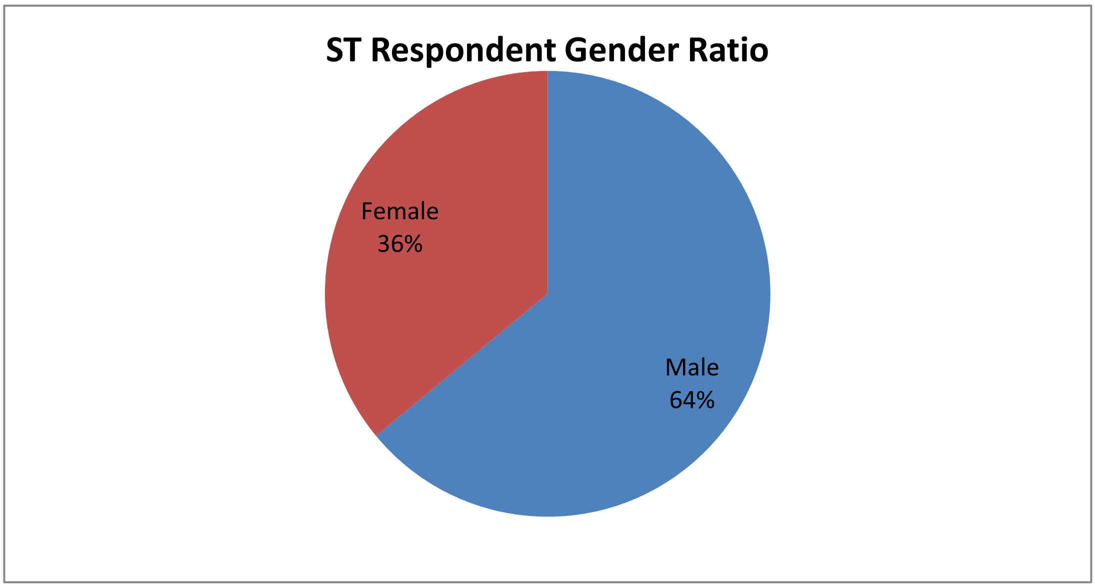


Figure 4.2 ST building respondents gender ration

In comparison with the ST building, There were more male correspondent with 64% compared to only 36% of female correspondent (Figure 4.2). According to Wang (Wang, 2006) , men and women tend to have different thermal tolerance due to differences in metabolism and clothing levels. His studies found that the men had 1$^{o}$C lower operating temperature compared to women even though the women tend to wear heavier clothes compared to men. These have to be looked into during the analysis of thermal votes in both the building.

### 4.2 General Parameters

Basic necessary environmental parameters were measured at selected zones around the survey respondents. Collected parameters are such as Globe temperature, air velocity, humidity and temperature. These parameters were necessary to calculate thermal indices such as Operative temperature and Predicted and Mean radiant temperature. Apart from that, additional measurements were also done such as lighting level and sound level measurement.

Table 4.1 Overall average of measured parameters

| | EP (Conventional) | ST (Green) |
|---|---|---|
| Globe Temperature (°C) | 26.34 | 23.75 |
| Air temperature (°C) | 26.47 | 22.80 |
| Air velocity (m/s) | 0.24 | 0.04 |
| Relative Humidity (%) | 57.07 | 61.31 |
| Clothing value (clo) | 0.67 | 0.49 |
| Activity level (met) | 1.85 | 1.26 |

### 4.2.1 Temperatures

Table 4.1 shows the comparison of average values for the measure parameters such as Globe temperature, air temperature, air velocity and relative humidity. By initial observation, it can be seen that both the Globe temperature and Air temperature for ST building is lower compared to EP building. Based on the building design, as were mentioned earlier, temperature control for office room in EP building temperature are solely dependent on the air conditioning system. In the case of ST building, additional design features helps to maintain required temperature while saving energy. From here, the possibility is either ST design features are highly efficient or the temperature setting for EP building has a higher control standard.

Parameters measured for zone and measurement points in both EP and ST buildings are shown in Table 4.2 and Table 4.3. In the same table, it can be noted that operative temperature were calculated for each zones using the globe temperature, air temperature and air velocity. On average, there are 3 degrees difference between the ST building and EP building. This is a reflection of the air temperature measurement from both building which shows a cooler environment for ST building compared to EP building

Table 4.2 EP Building parameters

| Measurement points | Globe Temperature (°C) | Air Temp (°C) | Velocity (m/s) Ave | Humidity Ave (%) | Operative Temperature (°C) |
|---|---|---|---|---|---|
| 1 | 26.4 | 26.0 | 0.32 | 59.5 | 26.5 |
| 2 | 26.4 | 26.3 | 0.14 | 57.9 | 26.4 |
| 3 | 26.3 | 26.3 | 0.34 | 57.2 | 26.3 |
| 4 | 26.2 | 26.2 | 0.24 | 58.1 | 26.2 |
| 5 | 26.4 | 26.2 | 0.39 | 57.4 | 26.4 |
| 6 | 26.4 | 26.3 | 0.37 | 57.5 | 26.4 |
| 7 | 26.3 | 26.2 | 0.47 | 57 | 26.3 |
| 8 | 26.3 | 26.2 | 0.16 | 57.8 | 26.3 |
| 9 | 26.4 | 26.4 | 0.23 | 57.1 | 26.4 |
| 10 | 26.3 | 26.7 | 0.16 | 56.5 | 26.3 |
| 11 | 26.4 | 26.8 | 0.13 | 56.1 | 26.4 |
| 12 | 26.3 | 27.1 | 0.09 | 55.5 | 26.4 |
| 13 | 26.3 | 27.4 | 0.12 | 54.3 | 26.4 |
| Ave | 26.3 | 26.5 | 0.2 | 57.1 | 26.4 |
| Max | 26.4 | 27.4 | 0.5 | 59.5 | 26.5 |
| Min | 26.2 | 26.0 | 0.1 | 54.3 | 26.2 |

Table 4.3 ST Building parameters

| Measurement points | Globe Temperature (°C) | Air Temp (°C) | Velocity (m/s) Ave | Humidity Ave (%) | Operative Temperature (°C) |
|---|---|---|---|---|---|
| HR Station 1 | 24.5 | 23.3 | 0.1 | 60.3 | 24.2 |
| HR Station 2 | 24.3 | 23.0 | 0.0 | 61.1 | 24.0 |
| HR Station 3 | 24.2 | 22.7 | 0.0 | 62.0 | 23.8 |
| HR Station 4 | 23.9 | 22.8 | 0.1 | 63.3 | 23.7 |
| HR Station 5 | 23.8 | 22.9 | 0.1 | 62.8 | 23.6 |
| CD Station 1 | 23.3 | 22.8 | 0.0 | 59.8 | 23.1 |
| CD Station 2 | 23.4 | 22.6 | 0.0 | 58.1 | 23.2 |
| CD Station 3 | 23.4 | 22.9 | 0.0 | 58.1 | 23.2 |
| CD Station 4 | 23.4 | 22.3 | 0.0 | 64.3 | 23.1 |
| CD Station 5 | 23.3 | 22.7 | 0.1 | 63.3 | 23.2 |
| Ave | 23.8 | 22.8 | 0.0 | 61.3 | 23.5 |
| Max | 24.5 | 23.3 | 0.1 | 64.3 | 24.2 |
| Min | 23.3 | 22.3 | 0.0 | 58.1 | 23.1 |

### 4.2.2 Relative Humidity

Relative humidity measurements came out with small difference between the 2 offices in EP and ST building. EP registered 57.07% compared to ST building with 61.31%. Referring to ASHRAE standard 55(ASHRAE55:2010, 2010), the combination of relative humidity of around 60% at operating temperature of average 26°C for EP building and 24°C for ST building are both within the acceptable thermal comfort range.

Relative humidity for EP building is lower at higher temperature compared to ST building, which seems to have higher relative humidity at lower temperature (Refer Figure 4.4).

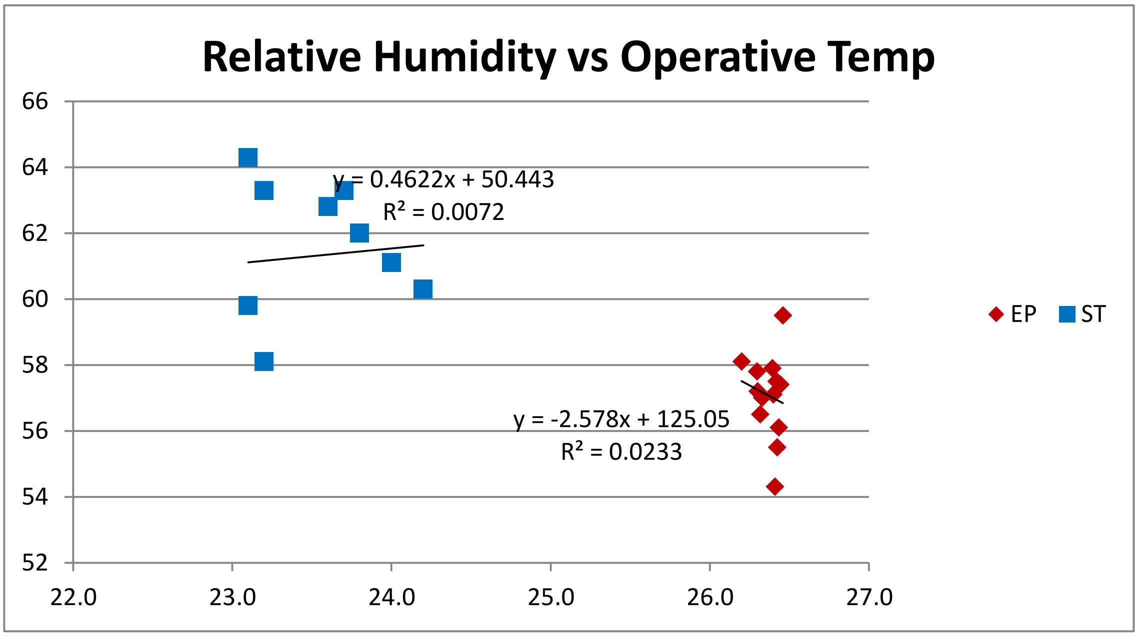


Figure 4.3 Relative humidity vs Operative temperature

For EP building, the temperature is entirely reliant on air conditioning system. Air conditions, apart from cooling the indoor air, also remove humidity. This explains the lower humidity levels in EP building. Compared to ST building, which has natural air circulation and sun light filtering, temperatures are naturally lower with lower air conditioning load, and yet higher relative humidity levels.

### 4.2.3 Air velocity

Air velocity in EP office averages about 0.24 m/s which is significantly higher compared to ST building's reading (0.04 m/s) (Figure 4.5). Air movement is almost standstill in the ST building. This will probably have high influence in the survey respondent judgment of thermal comfort between the 2 buildings. From observations, air condition system used in EP building is the large split type standing units. Since these units are located at 2 different points in the office, the air velocity caused by the blower tends to differ by zone.

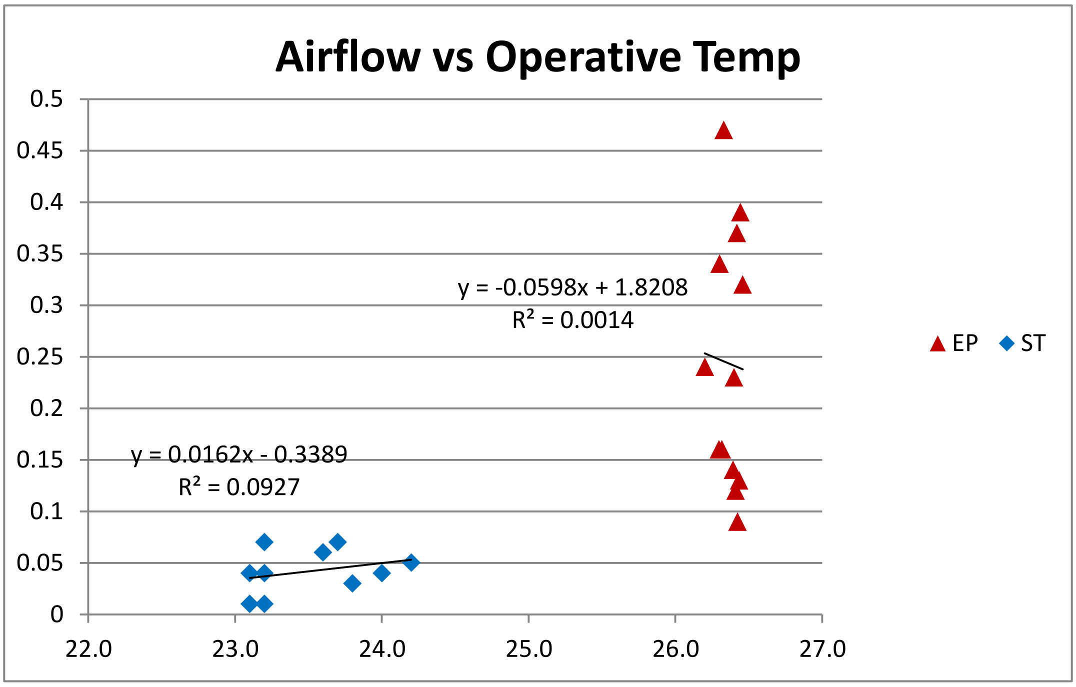


Figure 4.4 Airflow vs OperativeTemp

Despite this, air flow in EP building is higher compared to ST building. It has to be noted that the airflow levels varies by zones with wide range of value measured. Compared to ST building, the measured values of airflow are within a small range. For the office room in EP building, certain zones have been affected by the indoor air condition split units blowing cool air. This can be seen in Figure 4.6 where zones 1 to 7 have noticeably higher velocity of air flow compared to zone 8 to 13.

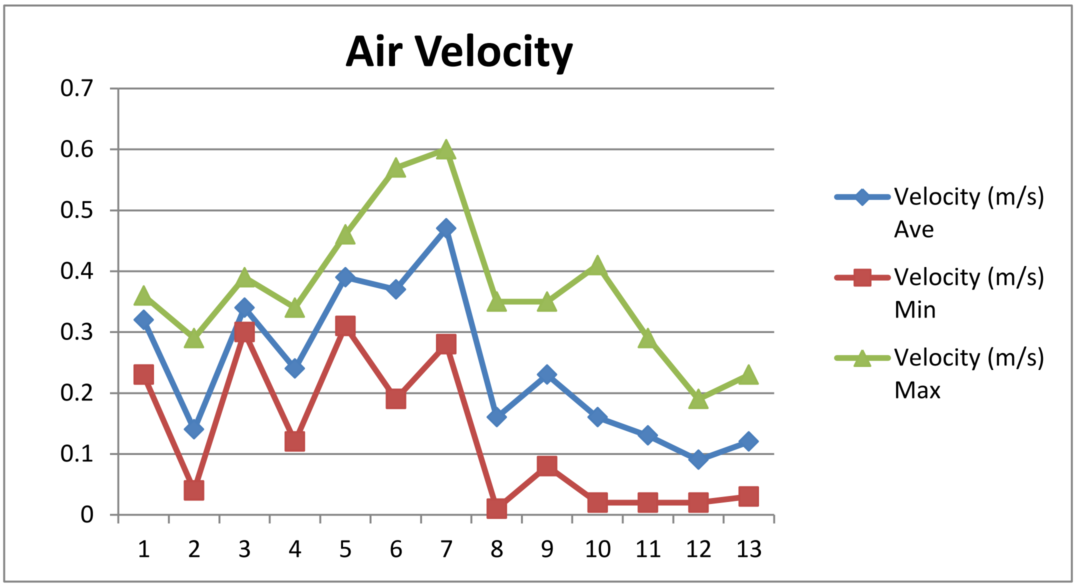


Figure 4.5 Air velocity at different zones in EP building

### 4.2.4 Clothing level

As for clothing level, most respondents in ST building were wearing short or long sleeve thin cotton shirts, t-shirts and long trousers for males, while the females were wearing either long trouser or long dress. In EP building, it was similar clothing patterns with the addition of jacket or 2$^{nd}$ layer of short sleeve shirt which was part of their uniform. This shows in the clothing value of occupants from both building whereby ST building clothing value on average is 0.49 clo while EP building occupants wore an average of 0.67 clo.

### 4.2.5 Activity Level

Activity levels in EP building is slightly higher at 1.85 met compared to ST building with 1.26 met. Occupants of ST building were mainly doing some light activities such as seating, reading and typing. EP occupants on the other hand had slightly higher activity level whereby some of them were required to do some medium to high activity while standing.

### 4.2.6 Thermal comfort

Initial analysis of the data gathered from the survey requires calculation of important parameters for thermal comfort at such Operative temperature and mean effective radiant temperature.

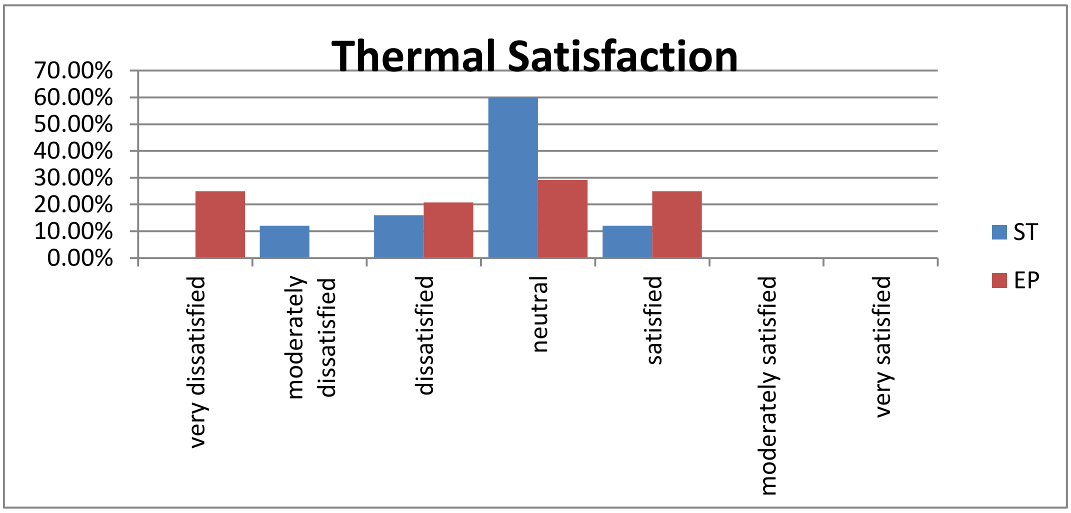


Figure 4.6 Thermal Satisfaction Respond percentage comparison between ST and EP Occupants

Figure 4.6 shows that the high percentages of occupants in ST building are feeling neutral. The other 12% of them felt satisfied, and the remaining 16% and 12 % felt dissatisfied and moderately dissatisfied respectively. In comparison, EP building occupants were spread out between being dissatisfied (20.83%), neutral (29.17%) and satisfied (25%). It has to be noted that the remaining 25% of occupants have voted very dissatisfied with the environment.

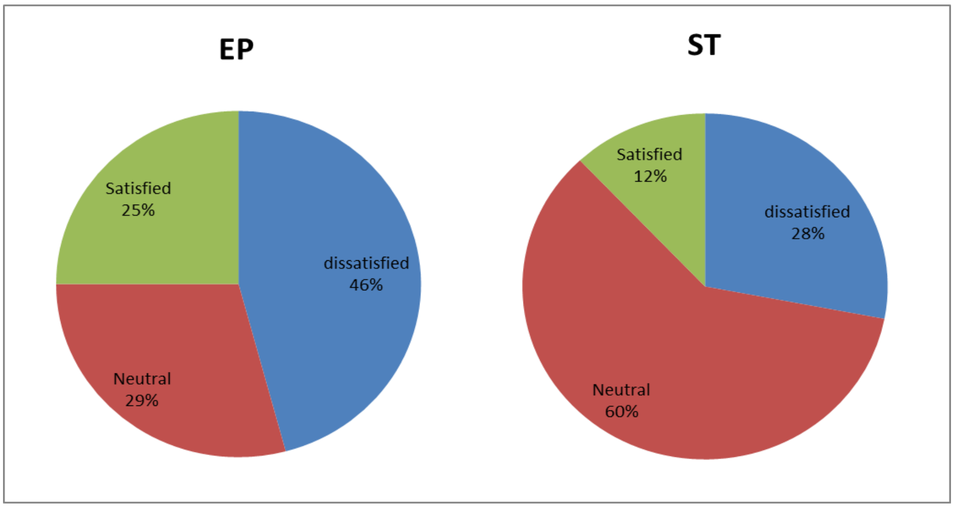


Figure 4.7 Comparison of Thermal Satisfaction vote

Overall thermal satisfaction comparison from **Figure 4.7** shows that EP building has a majority of occupants whom are dissatisfied with the thermal environment. In comparison, ST building occupants tend to vote neutral with 60% majority.

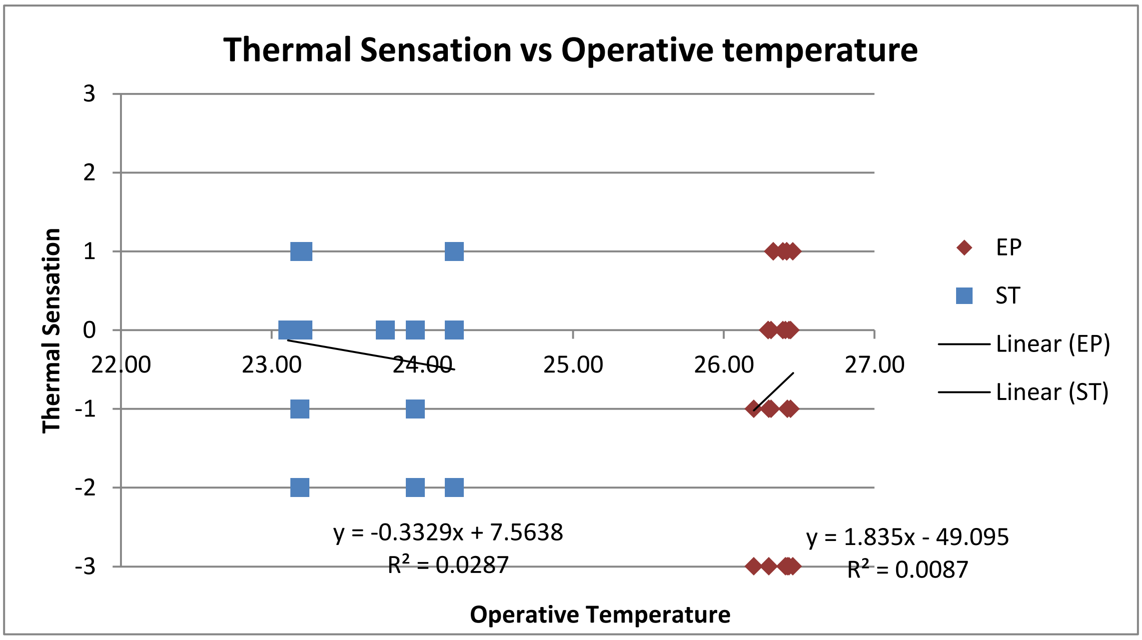


Figure 4.8 Thermal sensation vs Operative Temperature

From Figure 4.8, we can see that there are difference in operative temperature of EP and ST building. ST building operative temperature has a wider temperature range from about 23.1 to 24.1 degrees compared to EP building which ranged within 26.2 to 26.4 degrees Celsius. On average ST building is cooler averaging at 23.57 degrees Celsius compared to EP building which averages at 26.37 degrees Celsius. Despite this, larger group of ST building occupants have voted for neutral and satisfactory compared to EP building

### 4.2.7 Visual Satisfaction

Based on the survey, highest percentage of ST building occupants (40%) voted satisfied visually (Figure 4.9). EP building occupants were more divided between their votes with the two highest percentages of votes going for neutral (41.67%) and moderately satisfied (29.17%). There were also 4.17% of occupants who were very dissatisfied with the lighting conditions in EP building.

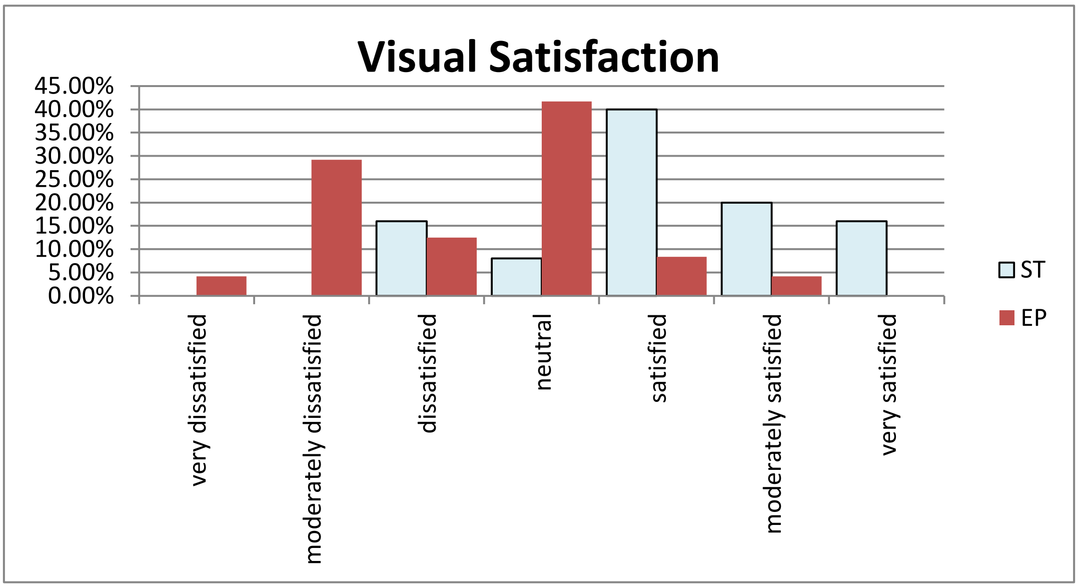


Figure 4.9 Visual satisfaction vote comparison

Overall ST building a large majority (Refer Figure 4.10) or 88% of the

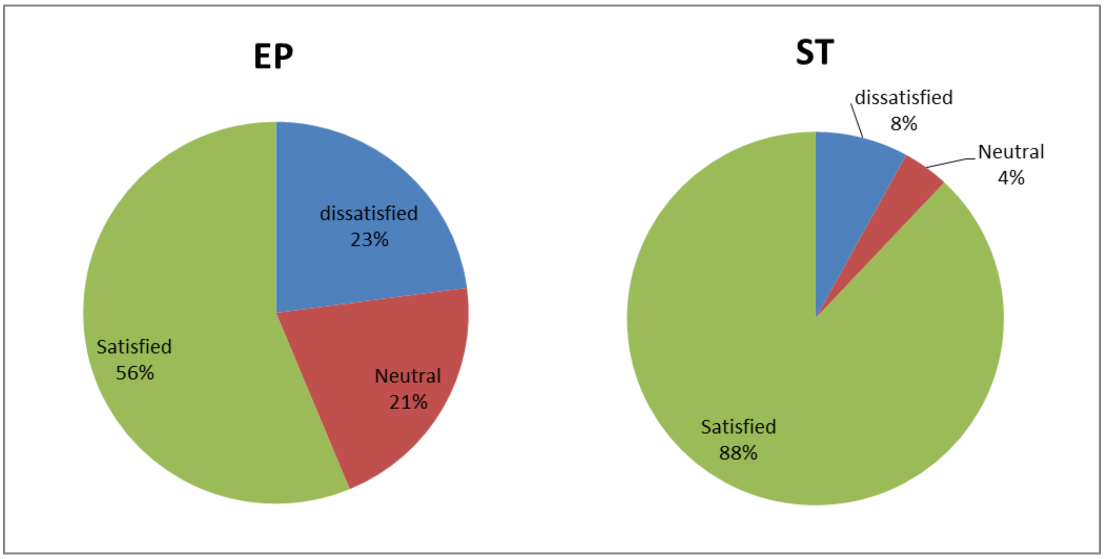


Figure 4.10 Visual Satisfaction breakdown

occupants was satisfied with ST building visually. In contrast only 56% of EP building occupants were satisfied whereas 23% of them were dissatisfied with the lighting conditions in the office.

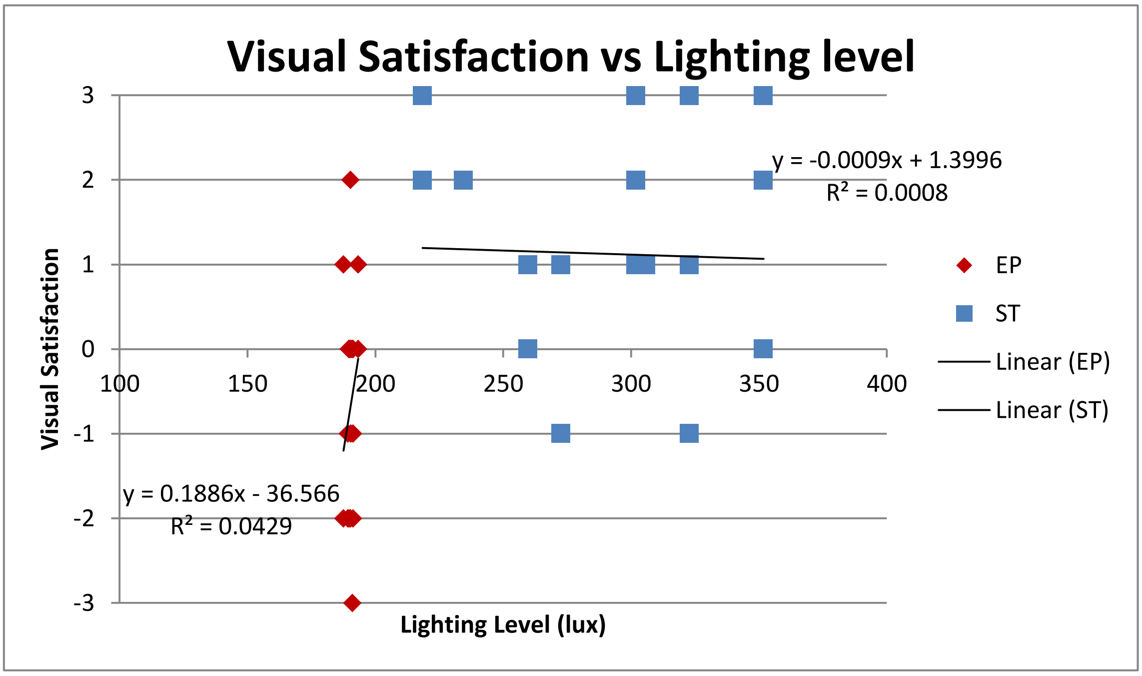


Figure 4.11 Visual Satisfaction vs Lighting levels

Lighting level measurements in Lux unit when compared between the two buildings (Figure 4.11), shows brighter levels for office in ST building, averaging at 295.57 lux and ranging from 218.40 to 351.80 lux. Whereas for

EP building, the average lighting levels are lower with 190.39 lux only. EP building also has a lower range of lighting, maxing out at 193.31 lux and minimum 187.55 lux. This seems to show in visual satisfaction survey with EP building, where occupants satisfaction feedback ranging from very dissatisfied to moderately satisfied. Compared to ST building, there were only 2 votes for dissatisfied while the majority of them voted neutral or better lighting.

### 4.2.8 Acoustic Satisfaction

Being an industrial manufacturing company, EP building was forecasted to have a lower acoustic dissatisfaction results in survey. Generally, the satisfaction vote breakdown for both ST and EP building was almost similar (Figure 4.12). There were however higher percentage of occupants in EP building voted dissatisfied for acoustic levels. It has to be noted that highest percentage of occupants for both EP and ST building voted neutral

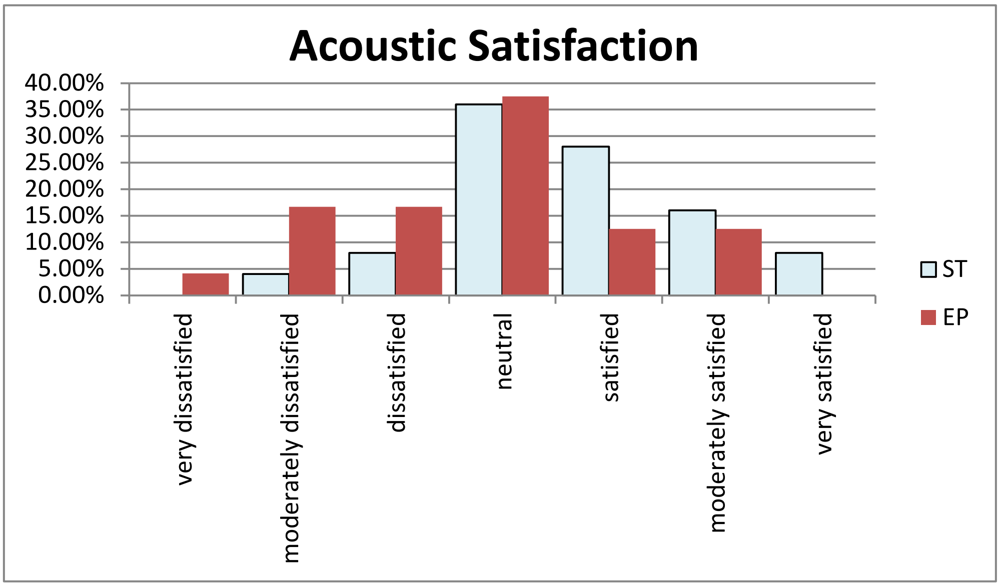


Figure 4.12 Acoustic Satisfaction vote percentage

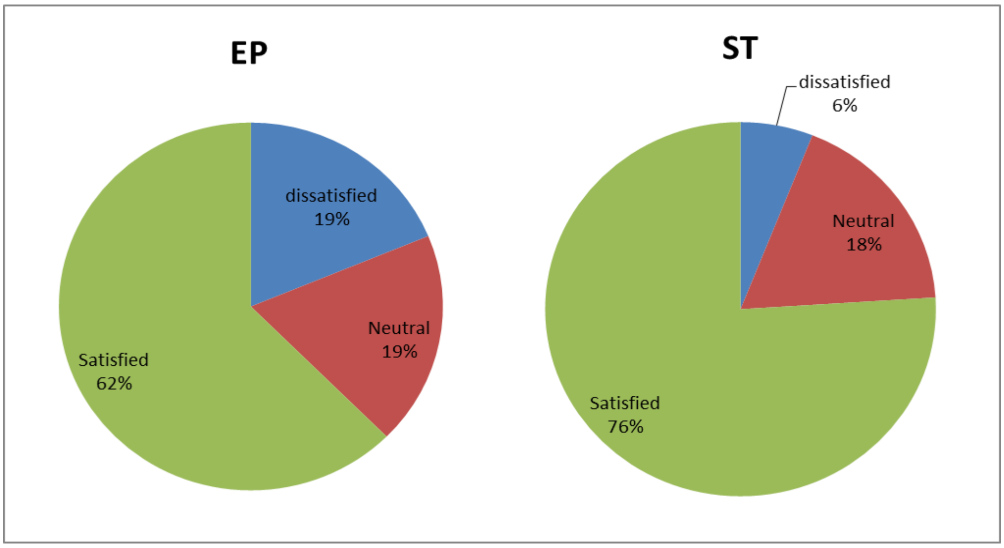


Figure 4.13 Acoustic satisfaction vote breakdown

As you can note from Figure 4.13, EP occupants registered 19% of dissatisfied voters compared to 6% from ST building.

Measurement results shows similar sound levels with EP building resulted in average 53.59 dB and ST building sound levels averaging at 53.78 dB. Maximum sound levels measured in EP were at 64.24 dB compared to ST building maximum levels at 58.35 dB showing at certain locations in EP office, sound levels being slightly higher (Figure 4.14).

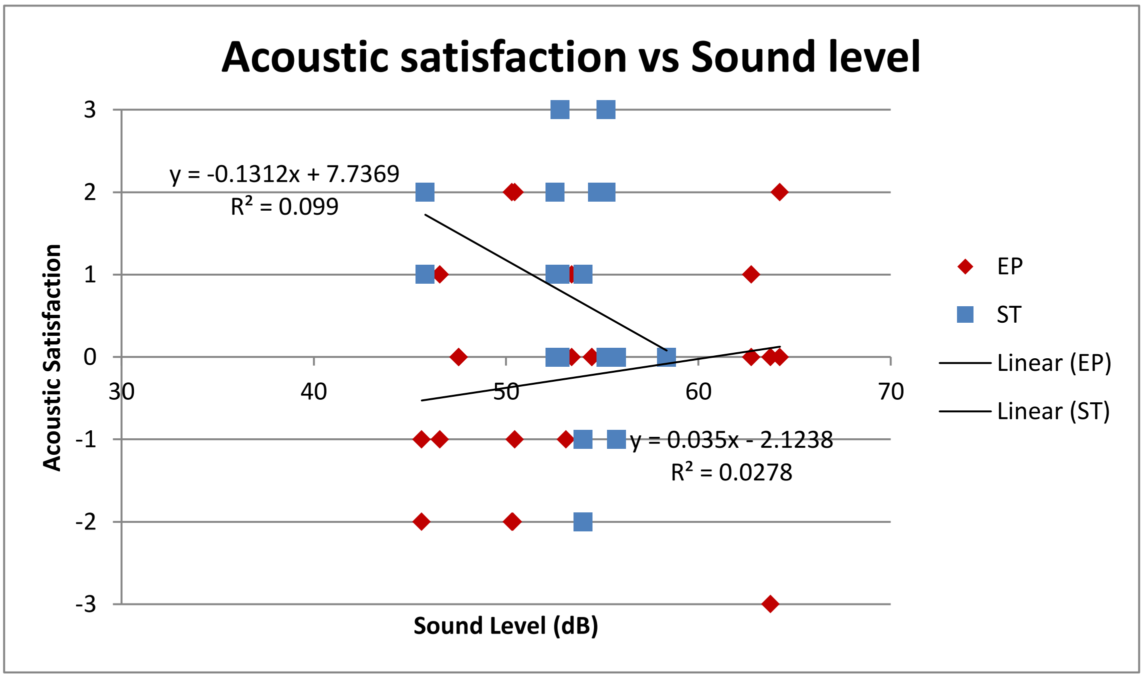


Figure 4.14 Acoustic satisfaction vs Sound level

One occupant of EP building voted for very dissatisfied. Sound levels at the occupants' zone measured at 63.75 dB. Apart from that, the remaining occupants ranged from feeling moderately dissatisfied to moderately satisfied. In comparison, none of the ST building occupants felt very dissatisfied with the sound levels, though the votes were spread out from moderately dissatisfied to very satisfied.

### 4.2.9 Discussions-Overall Review

The office in EP building is located in an enclosed space surrounded by concrete wall and gypsum based wall with 2 exits. Temperature control is done via 2 large package type standing air conditioners on 2 different locations of the office. Ventilation and air circulation in this room also seem to be through the air conditioners and the exit doors. There were no source of natural lightings and air flow.

In the case of rooms in ST building, there were many environmental friendly and energy sustaining features implemented. Temperature control is done via air condition, floor and ceiling cooling system using recycled rain water, shaded and glazed sun light admitting glass panels to provide proper natural lighting with reduced temperatures and natural air circulations all around.

Operative temperature for EP building averaged at 26.4$^{o}$C which is about 3$^{o}$C higher compared to ST building which averaged at 23.5$^{o}$C. Relative humidity for both buildings are close to 60% with ST building at 61.3% and EP building at 57.1%. ST building temperature is at borderline of ASHRAE standard 55 recommendations for thermal comfort while EP well within standard for the given operative temperature. However for EP building, at the measured operative temperature, the resulting relative humidity may prove to be borderline uncomfortable being on the higher side.

ST building's operative temperature being at the borderline of ASHRAE recommended values however does not reflect in their clothing values. ST building occupants were found to be wearing lighter clothing at 0.49 clo compared to heavier clothing at EP building with 0.64 clo. Again, the ST building clothing value results is at borderline ASHRAE standard 55 assumption which is at 0.5 clo. It has to be noted that for EP building, all staff are required to wear a short sleeved cotton based uniform on top of their normal tops such as shirt and pants. Activity level for EP building is also higher at 1.85 met compared to 1.26 met for ST building.

Looking at the thermal votes, results are varying for both the buildings. 60 % of ST building respondents voted neutral which is majority with 28% of votes going for dissatisfied and below. EP building votes were broken down between very dissatisfied to satisfied with none of the votes gaining clear majority. Overall we can judge that ST building is voted thermally more comfortable compared to EP building. These results might seems to conform to the hypothesis derived from ASHRAE recommendations as mentioned above.

Analyzing the entire outcome above, for EP building, with the higher activity and clothing level, the higher operative temperature proves to be thermally uncomfortable for its occupants. For ST building on the other hand, despite getting borderline ASHRAE recommended values as results, majority of its occupants voted between neutral and satisfied with its thermal environment.

For visual satisfaction criteria, the clear outcome is that ST building is voted higher on the satisfactory scale compared to EP building with 88% of ST building occupants being satisfied compared to only 56% of EP building being satisfied. This is probably due to the lower lighting level in EP building averaging at 190.39 lux compared to higher lighting levels in ST building with average of 295.97 lux. EP building relied only on fluorescent lighting whereas ST building has good natural lighting to compensate. It has to be noted that the survey was done during working hours in the day where the sun light is shining brightly.

Sound levels in EP building averaged at 53.59 dB while ST building averaged at 53.78 dB. Even though average values are about the same, EP building measurements of sound level shows a larger range compared to ST building with maximum readings going up to 64.24dB with one occupant voting dissatisfied with measurement around the occupants' zone reading at 63.75dB. It has to be noted that this occupant was located near to the air condition unit and suspected the discomfort is sourced from there. Overall, being in the industrial based building, the acoustic satisfaction result seems to be on the better side for EP building showing the sound insulation in the office area itself is quite efficient.

# Chapter 5 Conclusion and recommendation

## 5.1 Conclusion

In conclusion, thermally it was found that the ST building is more comfortable compared to EP building. With better air circulation, floor cooling and controlled heat admission from sun, the ST building achieved higher satisfactory votes compared to EP building. It also has to be noted that the higher humidity levels and requirement to wear thicker clothing (uniform) may have contributed to the lower satisfactory vote in EP building.

Visually the ST building survey outcome were again better than EP building and as discussed, this is largely due to brighter lighting levels in ST building which were sourced from artificial and natural light. Again, it has to be stressed that the office in EP building relied entirely on the fluorescent lights with the lack of windows. In acoustic terms however, both the green ST building and EP conventional building performed similarly with similar satisfactory votes from its occupants. There was one very dissatisfied vote in EP building which is due to close proximity to the air conditioner unit. Otherwise, the EP building achieved admirable results despite being an industrial based company with machinery operations very near to the office area.

Overall, the survey results are in favor of the green building (ST) although it cannot be said it was by wide margin.

## 5.2 Recommendations

Over the timespan of this study, there are a few weakness and further improvement that was noted. This is in terms of the improving the research methodology itself and design features of the buildings in subject.

### 5.2.1 Building Design and control

For the green building in question, the Suruhanjaya Tenaga building, it was highlighted that the operative temperature is on the lower side of ASHRAE recommended values. This is impressive given the minimum air condition energy consumption. Added with the good natural air circulation system and floor cooling, the building seems not to consume much energy to achieve such low temperature. However, further savings can be done with further optimization of temperature. There are margin for the temperature to be still increased without sacrificing the thermal comfort of its occupants. In that scenario, it has to be ensured that the relative humidity remains at same level. Similar for lighting levels, high lighting levels from natural source, the artificial and electronic lighting amount can be considered to be reduced during the day for further energy savings. There seem to be quite a large margin for further improvement in this building, therefore it has to be recognized that the building design and structure is really impressive

As for the conventional building, the office in Epson Precision Malaysia was constructed about 20years back. Therefore there will be some setback when compared to the newer ST building in terms of technological innovations. The factory design itself simple but practical. But based on the findings of this survey, improvements can be done to the office area for long term return of investments in terms of energy savings. Increased occupant comfort can also contribute to increased work performance and workplace happiness. In the study, the operative temperature was found to be within ASHRAE standard 55 recommended range but its relative humidity is on the higher side for the given operative temperature. With the requirement for additional clothing which is the company uniform, this seems to results in some uncomfortable votes.  Temperature can be reduced to increase the thermally satisfied votes but this will contribute in higher energy consumption.

It is recommended that for factories such as EP building, considerations can be made for future construction. If the returns in investments are justifiable, then renovations can be done to the current building. Certain elements from the ST building can be deployed here such as allowing more natural lights, floor cooling. Temperature levels are good, but further improvements can be done in terms of relative humidity control.

### 5.2.2 Research

This study comprises of comfort survey of occupants, thermal, acoustic and visual parameter measurements and analysis. It is not very extensive and further study can be undertaken to have more reliable data. Inclusion such as TVOC data, relation to construction material, occupants mentality and happiness relation and other comparison study is recommended in the future for a more solid conclusion in the comparison between green building and conventional building. Additionally, data collection on a longer time basis with inclusion of actual climate condition will contribute to achieving a clearer difference. Inclusion of comparison data of energy consumption for comfort control will be able to provide a difference in terms of cost versus construction for green building and conventional building. With positive results, it is hoped that these studies will give the incentives for the developers and other organizations to invest in green technology for the future of earth.

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# Appendix A

# Appendix B

# Appendix C

# Appendix D