ENERGY EFFICIENCY FOR BUILDING 13 AND BUILDING 14 OF ACADEMICS COMPLEX OF UNIVERSITI TEKNOLOGI PETRONAS

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CERTIFICATION OF APPROVAL

Energy Efficiency for Building 13 and Building 14 of Academics Complex of Universiti Teknologi PETRONAS

by

Mohamad Hafez Bin Abdul Malek

A project dissertation submitted to the
Civil Engineering Programme
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Approved:

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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 sources or persons.

Mohamad Hafez Bin Abdul Malek

ABSTRACT

The main purpose for this report is basically to discuss the preliminary research done and basic understanding for the chosen topic, which is **Energy Efficiency Audit for Building 13 and Building 14 of Universiti Teknologi PETRONAS**. The objective is to find the level of Building Energy Index (BEI) and the Overall Thermal Transfer Value (OTTV) for both buildings. The challenges in this project are to determine the energy consumption for 1 metre square of the building area per year and also to determine the effect of sunlight on the building envelope. Few calculations and surveys will be done for the project in order to get the BEI and OTTV. From the result obtained, the level of BEI and OTTV of both buildings can be categorized either it is efficient or not. The result of BEI for Building 13 and Building 14 of UTP are **100.9kWh/m^2/Year** and **132.7kWh/m^2/Year** respectively. While the OTTV for Building 13 and Building 14 are **94.53291 W/m^2** and **94.41165 W/m^2** respectively. In term of BEI, both building is considered efficient according to the MS1525:2007 standards but for the OTTV, the result is not within the standard.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Energy consumption is one of the major impacts in term of economical to all industries in the world now days. It also influences the environment due to its emission of carbon dioxide (CO_2), which contributes to global warning. Hence due to the economic and environmental issues, all industries around the world are constantly working out on reducing the energy consumption. In 2004 the first Low Energy Office (LEO), in Putrajaya Malaysia was occupied. This shows that the government is starting to emphasize in reducing the energy consumption in the building sector in Malaysia. Government body such as Ministry of Water, Energy and Communication (MECW) is given the role to promote the energy efficient based building through out the country. This is done by publishing all the acts, guidelines and policies. However to achieve the energy efficient building, specific energy measures (ESMs) need to be identified. The measurement can be achieved through energy audits. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), has categorized the audits into three levels depending on the depth of the audits.

The three levels categorized by ASHRAE are:

1) Level I – Walk-through assessment
2) Level II – Energy survey and analysis
3) Level III – Detailed energy audits

Once the audit is completed, the findings should be used for implementation of the ESMs. And all the measures that have been implemented need to be maintained to ensure that the building can sustain over the expected life of the system.

1.2 PROBLEM STATEMENT

Many Low Energy Buildings (LEOs) have been built by the contractors through out Malaysia for the past few years. But the green house effect is still rising although lots of countries in the world already started to implement the energy efficient policies in their buildings. As one of the university in Malaysia, Universiti Teknologi PETRONAS should also take part in improving its energy efficiency. It is not only to lower down the cost but also to minimize the impact to the environment. The energy consumption by the university can be considered as never ending use, hence it is wise to determine its building energy index to see whether it is efficient or not. The efficiency of the building also can be measured using the effect of the sunlight on the building envelope. The higher the effect of the sunlight on the envelope, the higher the cooling load will be as it will try to overcome the incoming heat. Therefore, this project will aim to audit the Building Energy Index (BEI) and Overall Thermal Transfer Value (OTTV) level so that remedial measurement can be proposed.

1.3 OBJECTIVE AND SCOPE OF WORK

The main objective for this research is to get the BEI value and OTTV for both building 13 and building 14 Universiti Teknologi PETRONAS. From the value obtained the level of efficiency of the buildings is determine. If the building is not efficient enough, remedial proposal will be discussed. The scope of work for this project can be divided into two phases which is walk-through assessment and energy survey and analysis. This methodology is proposed by American Society of Heating, Refrigerating and Air-conditioning Engineer (ASHRAE). The third phases will not be discussed in this project.

The energy consumption in term of electricity use by the building can be obtained by referring to the utilities bills. The total areas for each building also need to be measured. The area can be calculated by referring to the layout plan. Both layout plan and utilities bills will be provided by the maintenance department of Universiti Teknologi PETRONAS. Once the total energy usage and total areas for both buildings is calculated the BEI can be determine. From the result obtained the level of efficiency can be interpret.

For the OTTV, field measurement is important in order to calculate its value. The surface temperature for internal and external area is needed as well as the building humidity. In order to get the hottest point on both buildings, the sunpath diagram provided by the Malaysian Standard MS 1525:2007 will be use. Additional info such as the U-value, shading coefficient and other parameters can be obtained through the manufacturer's website or from the MS 1525:2007. Once all the parameters are known, the OTTV value can be determined. From the result obtained the level of efficiency can be interpret.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The term 'Green Building' is now a common term in most of the countries in the world. Due to economic and environment reasons, most of the developing countries is implementing the 'Green Building' system. Since the energy consumption is one of the main cost for every industries in the world reduction in energy consumption will improve the profitability of the industries. It will also give a very positive impact to the environment especially the green house effect.

Before assumption is made whether the building is efficient or not, energy audits of the building need to be conducted. From the result obtained, the level of efficiency is determined. Various type of audit is introduced by the researcher especially from European country and America.

2.2 ENERGY PERFORMANCE OF BUILDINGS (EPBD)

The Energy Performance of Buildings (EPBD) has been implemented into the national law by the European Union (EU) Members States since 4 January 2006. In accordance to the Kyoto Protocol, the EU has agreed to minimize its green house gas emission by 8% below 1990 levels during the first commitment period which is from 2008 to 2012. The methodology for calculation of energy performance should at least include the following aspects:

1) Thermal characteristics of the build
2) Air-conditioning installation
3) Ventilation
4) Built-in lighting installation
5) Position and orientation of building
6) Natural ventilation
7) Indoor climatic conditions

There are few methods for energy performance assessment which is Energy Performance Assessment of Existing Dwelling (EPA-ED) and Energy Performance Assessment for Existing Non-Residential Building (EPA-NR). Both assessments include software and tools addressing the needs of the policy and consultants with respect to energy performance certificates in line with EPBD.

2.3 ENERGY PERFORMANCE OF LEO BUILDING

The Ministry of Energy, Water and Communication Malaysia first occupied their low energy office in 2004. The construction of the building commenced on January 2001. The main objective is to demonstrate energy efficiency building as well as to obtained support from the Danish International Assistance (DANIDA). Based on the surveys by Dr. B.G. Yeoh (2006), the building has demonstrated 58% energy savings in the year of 2005.

The design adopted both passive and active features. The passive design includes building orientation, building envelope, natural ventilation and interior space layout. The active design however includes building control system of the chilled water supply and online energy management system. All the design features should be accordance with MS 1525 – Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-residential Buildings. To determine the efficiency the energy audit need to conduct. **Table 1** shows the comparison of some key parameters with the MS 1525:2001 Guidelines.

Parameter	**MS 1525:2001 Guideline**	**LEO Building**
OTTV	45	32
Temperature (ºC)	23 – 26	24
Relative humidity, minimum (%)	55	55
Lighting power in office area, maxi-mum (W/m^2)	20	11
Illuminance in office area (lux)	300 – 400	350
Motor efficiency, minimum (%)	88.4	92.5

Table 1. Comparison of Some Key Parameters with the MS 1525:2001 Guidelines

The reductions of CO2 emissions from the energy use in buildings can be achieved in the future by using more advanced technology for energy efficiency by improving the existing technology. While reducing the life-cycle costs of a building as well as reducing the CO2 emissions, the net benefit can be increased compared to its cost.

Based on the research by International Energy Agency (2006), the CO2 emissions in the year of 2004 are 8.6Gt/y. The International Energy Agency (IEA) estimated that a higher fraction of these carbon dioxide emissions is due to buildings. **Table 3** shows the difference in CO2 usage from two different perspectives. The bar at the left represents emissions of CO2 from all energy end-uses in buildings while the bar at the right hand side represents only those emissions from direct combustion of fossil fuels.

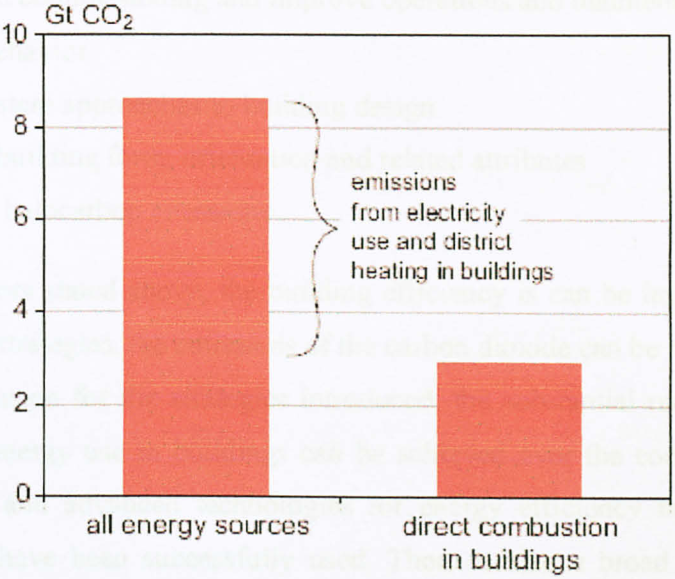

Figure 1. Carbon Dioxide Emissions from Energy, 2004

From **Table 3**, we can conclude that the emissions of carbon dioxide are more than direct combustion. Thus the effect of emissions is more severe compared to direct combustion of fossil fuels.

To reduce the GHG emissions, few design strategies were introduced. The strategies includes factors such as reducing loads, selecting systems that make the most effective use of ambient energy sources and heat sinks and using efficient equipment and effective control strategies. An integrated design approach also is required to ensure that the architectural elements and the engineering systems work effectively together.

Below are the few factors that influenced the strategies of designing the energy efficient based building.

1) Reduce heating, cooling and lighting loads
2) Utilize active solar energy and other environmental heat sources and sinks
3) Increase efficiency of appliances, heating and cooling equipment and ventilation
4) Implement commissioning and improve operations and maintenance
5) Change behavior
6) Utilize system approaches to building design
7) Consider building form, orientation and related attributes
8) Minimize halocarbon emissions

From all the factors stated above, the building efficiency is can be improve. Hence by following all the strategies, the emissions of the carbon dioxide can be reduced.

As for the conclusion for the strategies introduced, the substantial reductions in CO2 emissions from energy use in buildings can be achieved over the coming years using existing, mature and advanced technologies for energy efficiency that already exist widely and that have been successfully used. There is also a broad array of widely accessible and cost-effective technologies and know-how that can abate GHG emissions in buildings to a significant extent that has not as yet been widely adopted.

2.5 GAS DISTRICT COOLING (GDC) IN UTP

Since the study of this project involving the efficiency of the power system in UTP, the understanding of it power management is important. Compared to other universities in Malaysia, UTP use its own power supply to generate its own electricity and chilled water for air-condition purpose. However the operator that actually runs the work is a company called Makhostia Sdn. Bhd. Makhostia Sdn. Bhd. has been appointed as the operator since December 2005. The company also operates other PETRONAS GDC plants at KLCC, KLIA and Putrajaya.

The definition for district cooling is a system that distributes the heat generated in a centralized location for residential and commercial heating requirements. The heat is often obtained from a cogeneration plant. The facilities called heat-only boiler stations are also used in this plant. A district heating plant can provide higher efficiencies and better pollution control than localized boilers.

The design objective of the plants is influenced by few factors which are:

1) Reduce peak load demand of electricity in the country.
2) Improve energy efficiency using natural gas in the country.
3) Reliable chilled water supply.
4) Adaptation of proven cogeneration plant technology for a long-term operational reliability.

The capacities of the plant are about 8.4 MW for the electricity generation and 4000RT for chilled water generation when it first operates. However it may increase to 20MW for the electricity generation and 11000RT for chilled water generation due to the increases of population.

2.5.1 COGENERATION SYSTEM AND CHILLER SYSTEM

Figure 1 shows the cogeneration system in UTP. The system shows how the distribution of electricity as well as the chilled water distribution. The chiller system is represented in **Figure 2**.

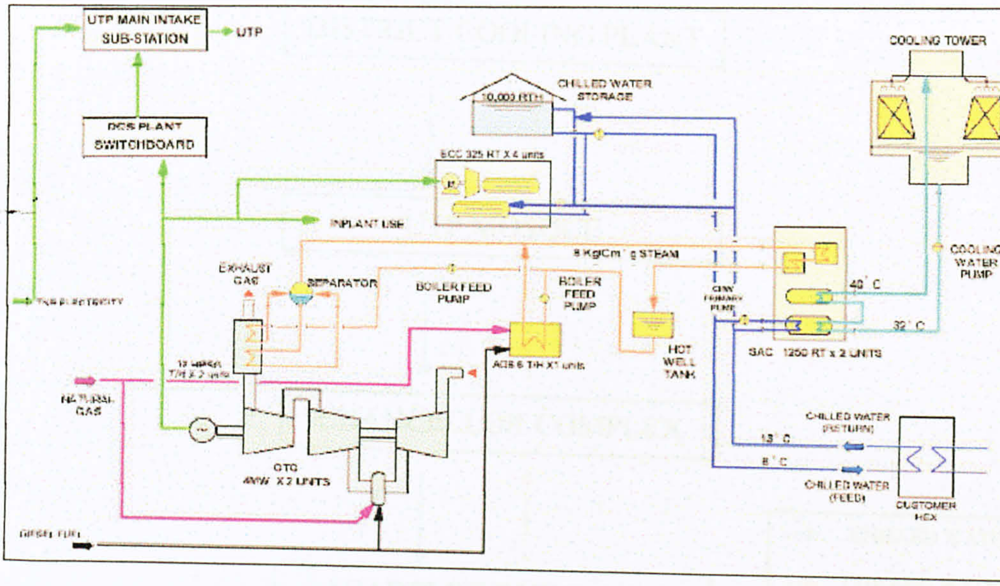

Figure 2. Cogeneration System

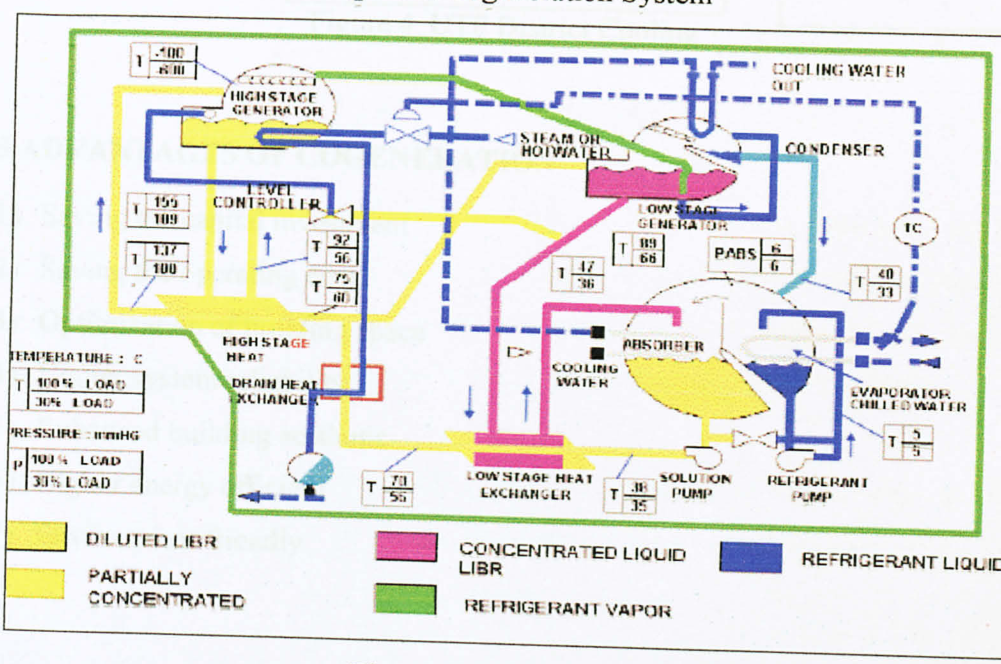

Figure 3. Chiller System

2.5.2 UTP DISTRICT COOLING SYSTEM

Figure 3 represented the UTP district cooling system. It also shows how the chilled water is distributed after coming out from the district cooling plant.

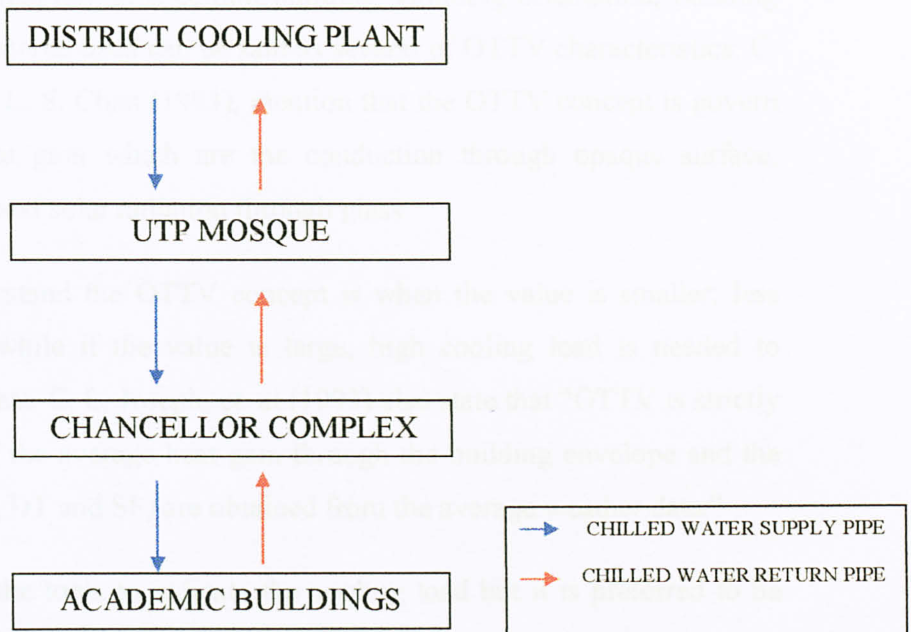

Figure 4. UTP District Cooling

2.5.3 ADVANTAGES OF COGENERATION

1) Saving the capital investment
2) Saving the operating cost
3) Optimization of building space
4) Higher system reliability
5) Enhanced building aesthetic
6) Higher energy efficient
7) Environment friendly

2.6 OVERALL THERMAL TRANSFER VALUE CONTROL OF BUILDING ENVELOPE DESIGN PART 2-OTTV PARAMETERS

Overall Thermal Transfer Value (OTTV) is considered as one of the parameters to determine the level of efficiency of a certain building. Building orientation, building envelopes and types of material used can be said as several of OTTV characteristics. C. L. Joseph, C. M. Hui and L. S. Chan (1993), mention that the OTTV concept is govern by 3 components of heat gain which are the conduction through opaque surface, conduction through glass and solar radiation through glass.

The simple way to understand the OTTV concept is when the value is smaller; less cooling load is applied while if the value is large, high cooling load is needed to overcome the incoming heat. C. L. Joseph, et. al (1993) also state that "OTTV is strictly speaking an indication of the average heat gain through the building envelope and the OTTV parameters (TDeq, DT and SF) are obtained from the average weather data."

Although OTTV can be the tools to indicate the cooling load but it is preferred to be based on heat gain. The phrase *'based on heat gain'* is used because:

1) For cooling load OTTV, different sets of TDeq, DT and SF are required for buildings with different operating hours.
2) TDeq, DT and SF derived from computer simulations and regression analysis are based on a particular computer programs and sometimes the particular HVAC systems. Different computer programs and different HVAC systems used in the computer simulations could give different values for TDeq, DT and SF.
3) OTTV is intended for comparative study on the ability of the building envelope to limit heat gain into a building, particularly during the initial design stage.

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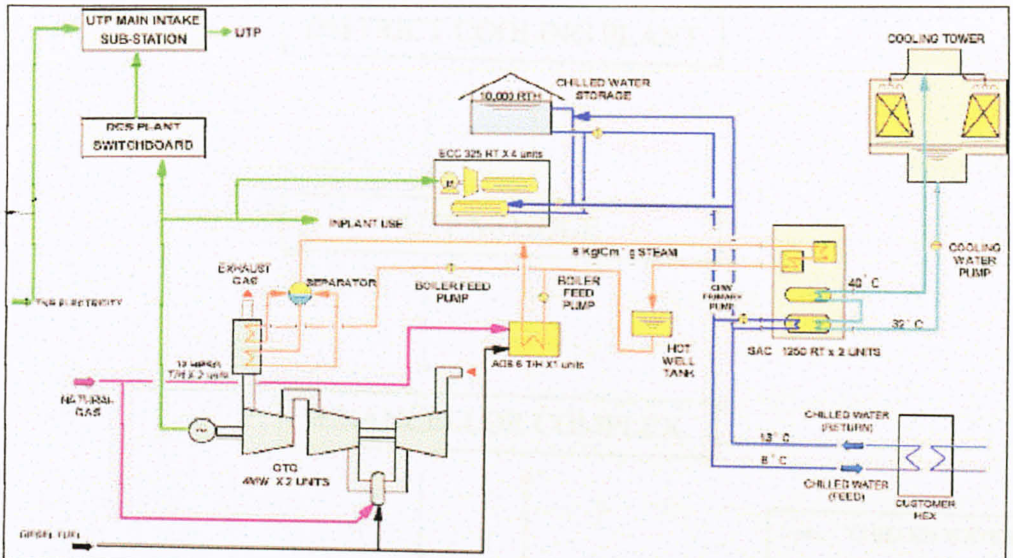

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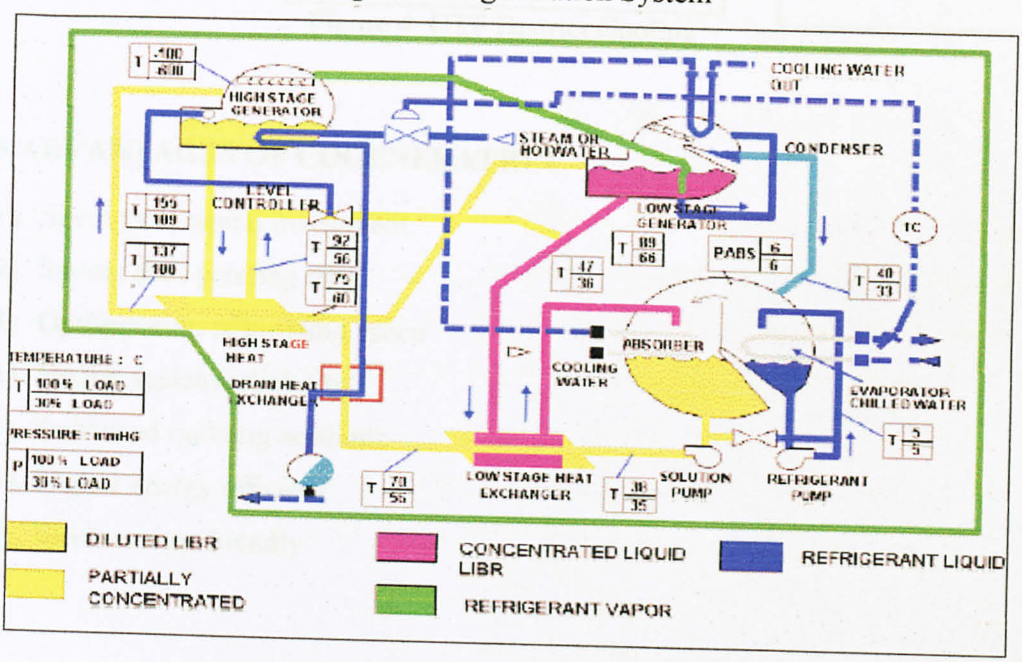

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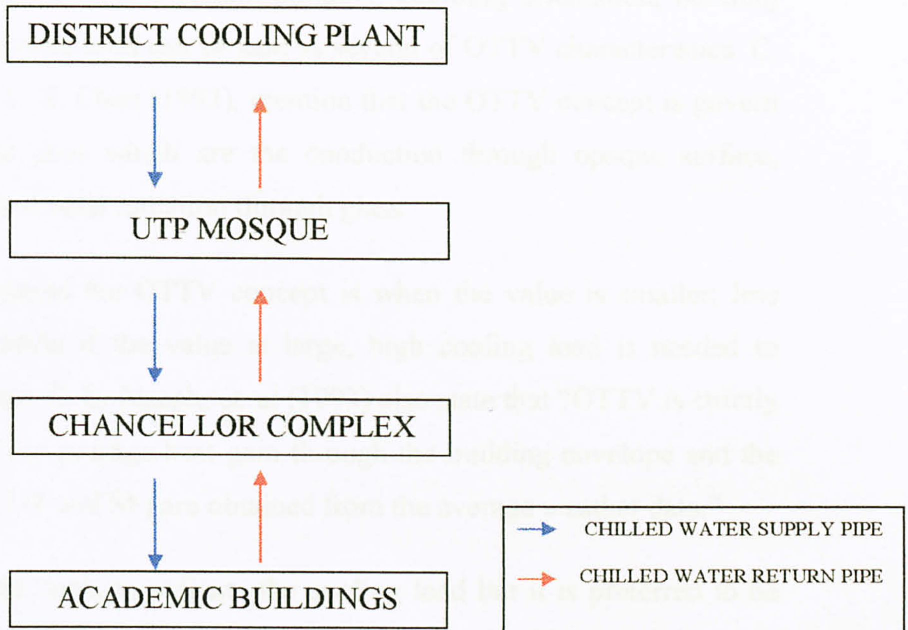

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3) OTTV is intended for comparative study on the ability of the building envelope to limit heat gain into a building, particularly during the initial design stage.

2.7 OVERALL THERMAL TRANSFER VALE (OTTV): HOW TO IMPROVE IT'S CONTROL IN HONG KONG

The building energy standards plays important role in energy efficient policies. The OTTV is used as a method to control the building envelope design by the Hong Kong Government in July 1995. The objective is to reduce the external heat gains through the building envelopes.

Hui (1997) states that "Compared with thermal insulation standards in cold climates, OTTV is more suitable for application to buildings in hot climates because it accounts for the solar heat gain at the building envelope". Singapore was the first country to develop an OTTV standards and it is solely based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards 90-75 and 90-80A.

The Hong Kong government adopted the experienced gained by the Association of Southeast Asian Nations (ASEAN) in development of building energy standards since they have similar climatic conditions and social structures. And because of these characteristics, the similarities between all ASEAN members can be seen in their standards.

However for Hong Kong OTTV, there is a limitation since it is only focus on the building envelope and does not considered the building design and the it's orientation. Another disadvantage of OTTV is that the present code of practice only provides a manual approach to the OTTV calculations.

In the articles, the author mention Chow, et. al (1995) commented that the OTTV equation developed in Hong Kong are rather unclear and many influential parameters have not been studied properly. But there is still ways to enhance the standards in Hong Kong. Below are few ways to enhance the standards.

1) Alternative paths to code compliance
2) Towards a performance-based approach
3) Integration of energy codes
4) Mandatory and voluntary requirements
5) Use of compliance software
6) Research and development
7) Education and training
8) Standards update and information network

CHAPTER 3

METHODOLOGY

3.1 PROJECT IDENTIFICATION

The main target for the project is to determine the level of efficiency of building 13 and building 14. The value of Building Energy Index (BEI) and Overall Thermal Transfer Value (OTTV) can be achieved through energy audits. American Society of Heating, Refrigerating and Air-Conditioning Engineer (ASHRAE) have divided the audits into 3 levels. The levels are:

4) Level I – Walk-through assessment
5) Level II – Energy survey and analysis
6) Level III – Detailed energy audits

However for this project, the audit will only focus only level I and level II assessment. Below are the steps to determine the BEI.

1. Level I – Walk-through assessment
   a. Involves the assessment of the building energy consumption and it efficiency through the analysis of utilities bills.
   b. It helps to identify and provides saving-cost analysis.
   c. Provide initial assessment of savings potential for building
2. Level II – Energy survey and analysis
   a. More detailed building survey and energy analysis
   b. Utilities bills for the whole year is collected
   c. The total areas of building 13 and building 14 is determine
   d. Understanding where and when the energy is being consumed and learn how it can be saved.

Based on both assessments, preliminary energy audit can be done and the BEI can be calculated. Hence the level of efficiency of the building can be determined.

3.2 DETERMINATION OF BUILDING ENERGY INDEX (BEI)

To get the BEI for building 13 and building 14 of Universiti Teknologi PETRONAS, two items need to be put under consideration. The items are:

1. Total area for both buildings
2. The energy consumed by the building per year

For the first item which is the total area for both buildings, the area can be calculated from the layout plan obtained from the maintenance department. While for the second item, the total energy consumption for both building can be obtained from Honeywell Pte. Ltd. audit report. After the value for both items is obtained, the BEI for both buildings can be calculated using the formula given in the MS1525:2007.

3.3 DETERMINATION OF OVERALL THERMAL TRANSFER VALUE

Based on the MS 1525:2007, the Overall Thermal Transfer Value (OTTV) is design to achieve the design of building envelope in order to cut down external heat gain and also to reduce the cooling load of the air-conditioning system. However the design should meet the requirement in the MS 1525:2007.

In order to calculate OTTV, field measurement is crucial because the data for the internal and external temperature of both buildings as well as the relative humidity is needed in order to proceed to the next calculation. Below are the steps taken for the field measurement.

1. Identify the sun path in order lock on the hottest area on the building surface (Appendix 2 & Appendix 3)
2. The day to conduct the field measurement must be the hottest day (if the weather is windy, cloudy or raining, the field measurement must be postponed).
3. On the chosen date, the air condition for both building is shut down so that the building is in the *"passive state"*.

4. The temperature is determined using the thermometer while the relative humidity is determined using the anemometer. Both items can be obtained from the Mechanical Department of Universiti Teknologi PETRONAS.
5. Four locations is chose to be the area to collect the data and six sets of reading for every location. The time interval for data collection between the sets is 30 minutes. Prepared few sets of table in for the data obtained (Appendix 6)

Once the field measurement data is obtained, the data will be tabulate. For the OTTV calculation, only the difference between the indoor and outdoor surface temperature will be use. For the U-value of the glass, the data can be obtained from the manufacturer's website. However, for the other material such as steel beams and opaque wall, calculation is needed in order to get the U-value. Other data such as shading coefficient can be obtained from the MS1525:2007 itself.

When all the important data is obtained, by using the formula provided in the MS1525:2007, the Overall Thermal Transfer Value can be calculated.

CHAPTER 4

RESULT AND DISCUSSION

4.1 BUILDING ENERGY INDEX (BEI)

To calculate the level of efficiency of a building, it is important to know the area of the building. By determining the area and the electricity used in a year (minimum), the Building Energy Index (BEI) can be calculated. The formula for building energy index is given below:

$$Building\ Energy\ index = \frac{total\ electricity\ in\ a\ year}{total\ area\ of\ a\ building}$$

The unit is in kWh/m^2/year. From the value, the level energy index can be determined and further improvement of level of efficiency can be considered.

4.1.1 AREAS OF BUILDING 13 AND BUILDING 14

In this part, only the calculation of areas for building 13 and 14 can be determine. By referring to the layout plan given by maintenance department with the scale of 1:150, the calculations for total areas for both building are:

<u>Third floor and Second Floor</u>

[28.5 x 48 + (7.5 x 6.75) x 2] – (24.75 x 4.2) = 1365.3 m^2

The third floor and the second floor are assumed to have the same area although the position of the void in each level is different. But the area for the void is assumed to be the same. Hence the total area for the third floor and the second floor are 1365.3 m^2 each.

First Floor and Ground Floor

28.5 x 48 + (7.5 x 6.75) x 2 = 1469.25 m^2

Since there is no void at the first floor and the ground floor the value is a bit larger than the second floor and the third floor. Hence the total area for the first floor and the ground floor are 1469.25 m^2 each.

Total Areas for Building 13 and 14

1365.3 + 1469.25 = **2834.55 m^2**

Although the MS 1525:2007 mention that the total surface area should not be less than 4000 m^2 but for BEI, it only takes the floor area. Thus summation for floor and wall area for both building will be > 4000 m^2.

4.1.2 ENERGY CONSUMPTION FOR BUILDING 13 AND BUILDING 14

Based on the energy audit report prepared by Honeywell Pte. Ltd. (2008), the energy consumption for building 13 AHU's and MV Fans is **171 558 kWh/Year** while for building 14 AHU's is **225 643 kWh/Year**. However, these values are just for the air conditioning purpose and not for the electricity used by the computers, lighting, machinery and etc. It is approximately only about 60% of energy consumed by the air conditioner in a building. Thus another 40% is consumed by others such as computers, lighting and etc. to get the total energy consumed by both buildings, simple calculation is needed. The calculation is shown below.

Building 13

$$\frac{171\ 558\ Wh/Year}{60\%} \times 100\% = 285\ 930\ kWh/Year$$

Building 14

$$\frac{225\ 643\ Wh/Year}{60\%} \times 100\% = 376\ 071\ kWh/Year$$

4.1.3 BUILDING ENERGY INDEX CALCULATION

The BEI can be determined by using the calculated energy consumed and the area for both buildings. Thus the BEI for building 13 and building 14 are:

Building 13

$$285\ 930\ \text{kWh/Year} \div 2\ 834.55\ \text{m}^2 = 100.9\ \text{kWh/m}^2\text{/Year}$$

Building 14

$$376\ 071\ \text{kWh/Year} \div 2\ 834.55\ \text{m}^2 = 132.7\ \text{kWh/m}^2\text{/Year}$$

From the calculation made, the BEI for building 13 and building 14 are **100.9kWh/m²/Year** and **132.7kWh/m²/Year** respectively. By comparing both result with the MS1525:2007 standards, the value falls within MS1525:2007 standards.

4.2 OVERALL THERMAL TRANSFER VALUE (OTTV)

In order to get the OTTV for both building, on site field measurement is needed. Data on the façade's material is also important prior to calculate the OTTV. By combining both field measurement data and material performance data, OTTV for both building can be calculated.

The OTTV of a building envelope is given by the formula below:

$$OTTV = \frac{A1 \times OTTV1 + A2 \times OTTV2 .... + An \times OTTVn}{A1 + A2 .... + An} \text{ ......equation (1)}$$

Where,

Ai = is the gross exterior wall area for orientation i; and

OTTVi = is the OTTV value for orientation i from equation (2).

For a fenestration at a given orientation, the formula is given as below:

OTTVi = [(1-WWR) x Uw x TDeq] + (WWR x Uf x DT) + (WWR x SC x CF x 194)......equation (2)

Where,

WWR = is the window-to-gross exterior wall area ratio for the orientation under consideration;

DT = surface temperature difference (°C);

TDeq = equivalent surface temperature (°C);

U_w = is the thermal transmittance of opaque wall (W/m^2 K);

U_f = is the thermal transmittance of fenestration system (W/m^2 K);

CF = is the solar correction factor; as in Table 4 in MS 1525:2007 (Appendix 1)

SC = is the shading coefficient of the fenestration system from equation (3)

The shading coefficient of a shading system is the product of the shading coefficients of its sub-systems, for example

$SC = SC_1 \times SC_2$......equation (3)

Where,

SC = is the effective shading coefficient of the fenestration system;

SC_1 = is the shading coefficient of sub-system 1 (e.g. glass); and

SC_2 = is the shading coefficient of sub-system 2 (e.g. external shading devices)

To get the value of shading coefficient, the glass value is assessed at an incident angle of 45° to the normal. The shading coefficient of external shading devices also can be obtained from Table 5, Table 6 and Table 7 in MS 1525:2007(Appendix 2 & 3).

4.2.1 FIELD MEASUREMENT RESULT

The field measurement compromises of two parameters which are the indoor and outdoor surface and also the relative humidity for indoor and outdoor. As been discussed in the methodology, the field measurement were conducted during the holiday and all the air condition for building 13 and building 14 were shut down. This is to ensure that the building is in the passive state. Below are the result obtained during the field measurement.

Indoor Surface Temperature

Time / Point	A	B	C	D
11.30AM	33.5	33.8	34.5	32.6
12.00PM	33.6	31.9	31.1	33.1
12.30PM	36.9	36.1	35.6	35.5
1.00PM	37.8	36.1	36.1	35.2
1.30PM	37.4	35.1	35.7	35.3
2.00PM	36.0	35.6	34.3	35.2

Table 3. Indoor Surface Temperature

Outdoor Surface Temperature

Time / Point	A	B	C	D
11.30AM	33.8	36.4	37.6	31.7
12.00PM	34.3	30.9	30.5	33.5
12.30PM	40.1	37.3	38.2	35.2
1.00PM	43.5	38.6	40.1	35.2
1.30PM	37.4	35.1	35.7	35.3
2.00PM	36.0	35.6	34.3	35.2

Table 4. Outdoor Surface Temperature

Indoor Relative Humidity

Time / Point	A	B	C	D
11.30AM	70.5	70.2	69.7	77.2
12.00PM	72.6	73.6	74.5	73.0
12.30PM	66.5	70.4	69.8	62.7
1.00PM	59.2	59.1	65.6	59.3
1.30PM	67.0	62.8	68.1	67.7
2.00PM	69.2	62.7	66.9	65.9

Table 5. Indoor Relative Humidity

Outdoor Relative Humidity

Time / Point	A	B	C	D
11.30AM	66.3	66.3	67.8	73.1
12.00PM	69.5	75.3	75.2	71.8
12.30PM	63.5	62.6	63.3	64.0
1.00PM	55.6	59.2	59.9	58.6
1.30PM	67.0	63.4	65.4	65.4
2.00PM	69.2	63.7	69.5	65.1

Table 6. Outdoor Relative Humidity

4.2.2 OTHER PARAMETER RESULT

For this part, only the final result of the parameters is shown. All the calculation on how to determine the value of each and every parameter will be put in the Appendices.

U-value

Since building 13 and building 14 envelopes consist of 3 major types of material which are the steel beams, opaque wall and glass; there should be 3 U-values. After all the U-values is obtained the overall Uw can be determine. Below are the result of the U-value for all the 3 materials and overall Uw.

Steel Beam = 5.91 W/m^2K

Opaque Wall = 6.05 W/m^2K

Glass (Uf) = 0.02 W/m^2K

Overall Uw = 5.975 W/m^2K

Shading Coefficient

The shading coefficient is obtained from the table in the MS1525:2007. Below is the value of SC.

SC = 0.61

Window to Wall Ratio

The window to wall ratio value can be obtained by adding all the surface area for the 3 materials on one side of the building. Below is the WWR result.

WWR = 0.7

Temperature Difference

The result for temperature difference basically comes from the result obtained from the field measurement. The differences between indoor and outdoor surface temperature is the one will be used to determine value.

Point A = 0.8 °C

Point B = 20.7 °C

Point C = 4 °C

Point D = 0.3 °C

Temperature Equivalent Difference

This value is obtained from the mean of temperature difference.

TDeq = 6.45 °C

Solar Correction Factor

The solar correction factor (CF) is based on the orientation of the building. Since the point where the data is collected falls on only two directions, the solar correction factor for each building is considered the same. The value can be obtained after the building orientation is determined by referring to the MS1525:2007. Below are the values of the CF.

B13 South-East Direction = 1.13

B13 North- West Direction = 0.9

B14 South-East Direction = 1.13

B14 North-West Direction = 0.9

4.2.3 OVERALL THERMAL TRANSFER VALUE (OTTV) CALCULATION

After all the parameters value were obtained. The OTTV value can be calculated. In order to get the overall OTTV for building 13 and building 14, each point's OTTV need to be determined first. Below are the calculated OTTV result based on the point where the data were collected.

Point A = 102.3184 W/m^2

Point B = 86.74738 W/m^2

Point C = 102.3636 W/m^2

Point D = 86.45974 W/m^2

From the data above, the overall OTTV for building 13 and building 14 can be determined. The overall OTTV for both building are:

B13 OTTV = **94.53291 W/m^2**

B14 OTTV = **94.41165 W/m^2**

From the calculation made, the OTTV for building 13 and building 14 are **94.53291 W/m^2** and **94.41165 W/m^2** respectively. By comparing both result with the MS1525:2007 standards, the value falls above MS1525:2007 standards. This shows that in term of envelope efficiency, building 13 and building 14 envelopes is not very efficient. The details will be discussed further inside the discussion part.

4.3 DISCUSSION

4.3.1 BUILDING ENERGY INDEX

The result obtained from the calculation shows that the BEI value for building 13 and building 14 is **100.9 kWh/m^2/Year** and **132.7 kWh/m^2/Year** respectively. Based on the BEI standards given by the MS 1525:2007 which is 135 kWh/m^2/Year, both building BEI's is lesser than that. From the result, both building 13 and building 14 of Universiti Teknologi PETRONAS can be considered as an efficient building in term of its electricity usage.

However the BEI obtained is actually still in a general term. This is because the value of electricity consumed by both buildings provide by Honeywell Pte. Ltd audit report [2], is actually come only from the AHU usage. According to the energy apportion, the total energy consumed by a building actually were affected by 3 major usages. The usages are:

1. Lightings
2. Air Conditions (ACMV)
3. Electrical Equipments

Between all 3 usages, the air-conditioning and mechanical ventilation (ACMV) consumed the most energy compared to the other. For this final year project we assume it to be 60% while the other 40% comes from the other 2 usages.

Factor Affecting the BEI Performance

From the observation there are few factors that affecting the BEI performance of a building. Some of the factor is listed below:

1. Not enough data provided for the research.
2. Too many uncertainties on the energy consumption

For the first factor, during the project duration the maintenance department of UTP failed to provide enough data on the building layout as well as on the amount of energy used by the building. Although the maintenance department provided the building layout plan, but the layout plan only shows the top portion of the building. Thus in order to get the total area, assumption is made based on the building parameters showed in the top layout plan. Because of this, it is believed that the result will slightly different from the actual total area.

They also failed to provide the latest energy consumed by both buildings. The energy consumption was obtained from the Honeywell Pte. Ltd. audit report [2]. However it only focuses on the AHU energy usage.

While for the second factor, there are too many uncertainties on the energy consumption which it is hard to determine which part of the building that consume the highest energy. This problem can be solved by doing the desktop data collection. The purpose of desktop data collection is to minimize the field energy related data collection by using all the available facility data. The desktop data gathering should consider as a first step data collection, which will be complemented and verified during the field data collection stage.

4.3.2 OVERALL THERMAL TRANSFER VALUE

The result obtained from the calculation shows that the OTTV value for building 13 and building 14 is **94.53291 W/m²** and **94.41165 W/m²** respectively. Based on the OTTV standards given by the MS 1525:2007, both building's OTTV is not within the standard. From the result, both building 13 and building 14 of Universiti Teknologi PETRONAS can be considered as not efficient enough in term of its envelopes performance.

From the observation, the main caused that influence the OTTV result is due to its orientation. Because the architect who built Universiti Teknologi PETRONAS focus on the "star shape" of the academics complex thus ignoring the orientation for each buildings. And for this reason the sun-path crosses building 13 and building 14 at their largest surface area (please refer Appendix 2 & Appendix 3).

The relationship between the OTTV with the energy consumption in term of cooling load is actually very small. As been stated by J. C. Lam et. al (1993) in their report "*OTTV only deals with the building envelopes. Cooling load due to heat gain through envelope is usually 10 – 20 % of the total cooling load. Direct energy saving through OTTV control might not be too significant. This would, however, generate interest in energy efficiency and would help create a more energy conscious environment among the building profession*".

Thus, from the statement, we know that although building 13 and building 14 is not very efficient in term of its envelopes performance but it will only affect the energy consumption about 10 – 20 %.

Field Measurement

For the field measurement, the result obtained is actually not sufficient enough. One of the factors is lack of equipment. If the project were provided with enough automatic data logger, the data obtained will be more thus resulting in more accurate result. But since there is no automatic data logger provided, the data were collected manually. Due to this problem, the data obtained is lesser and it took 30 minutes to finish one set of data collection. This result can be improved if there is automatic data logger.

Below are the performance graphs for indoor and outdoor surface temperature.

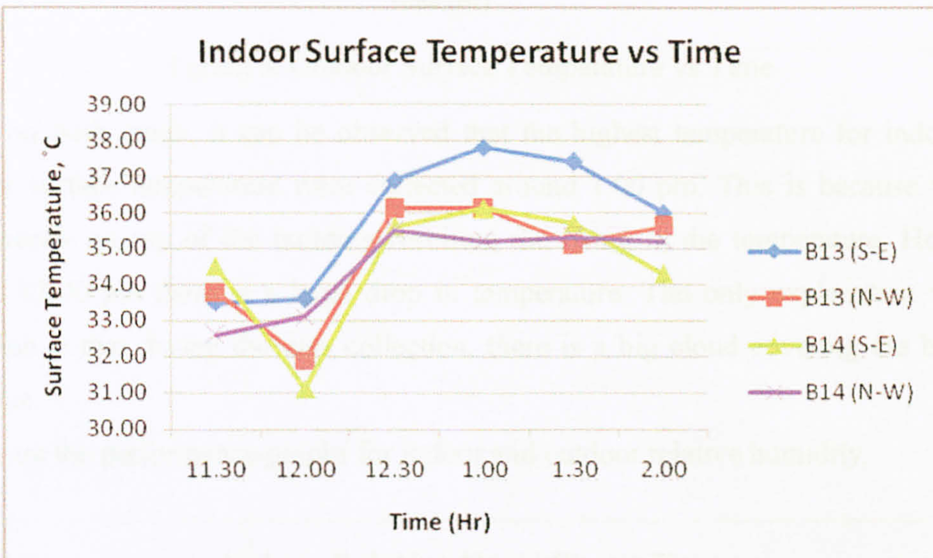

Figure 5. Indoor Surface Temperature vs Time

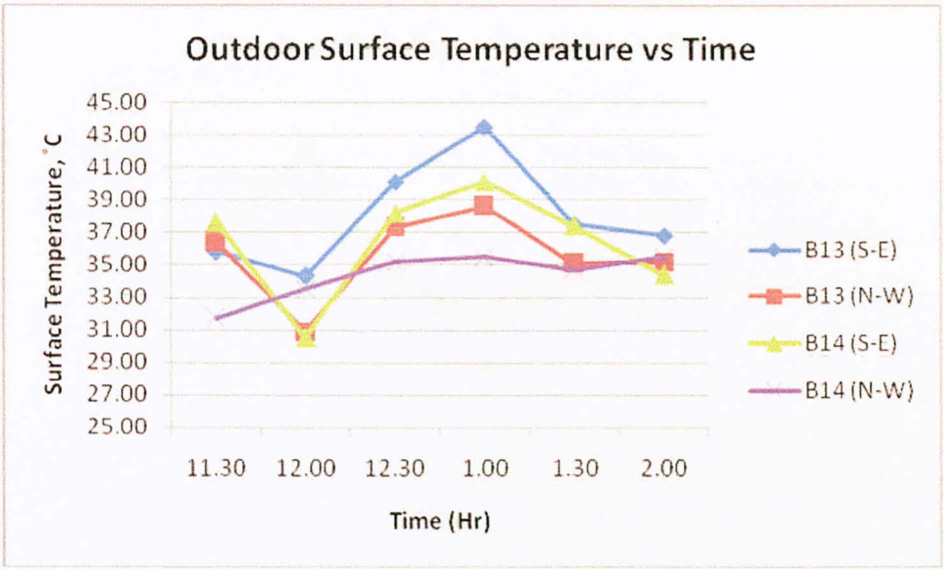

Figure 6. Outdoor Surface Temperature vs Time

Based on both graph, it can be observed that the highest temperature for indoor and outdoor surface temperature were collected around 1.00 pm. This is because the sun was directly on top of the building resulting the rising in the temperature. However, around 12.00 pm there is a large drop in temperature. The only explanation for this reduction is that during the data collection, there is a big cloud covering the building envelope.

Below are the performance graphs for indoor and outdoor relative humidity.

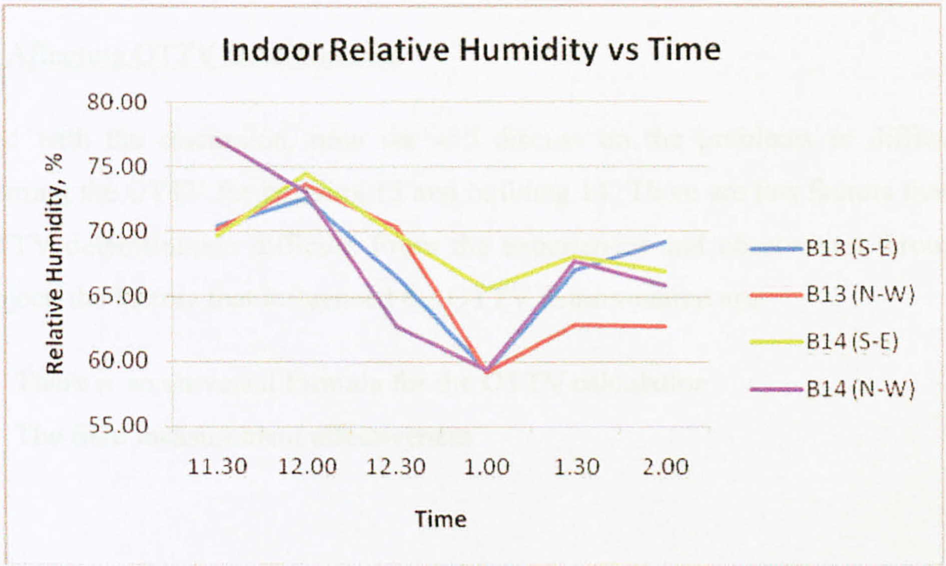

Figure 7. Indoor Relative Humidity vs Time

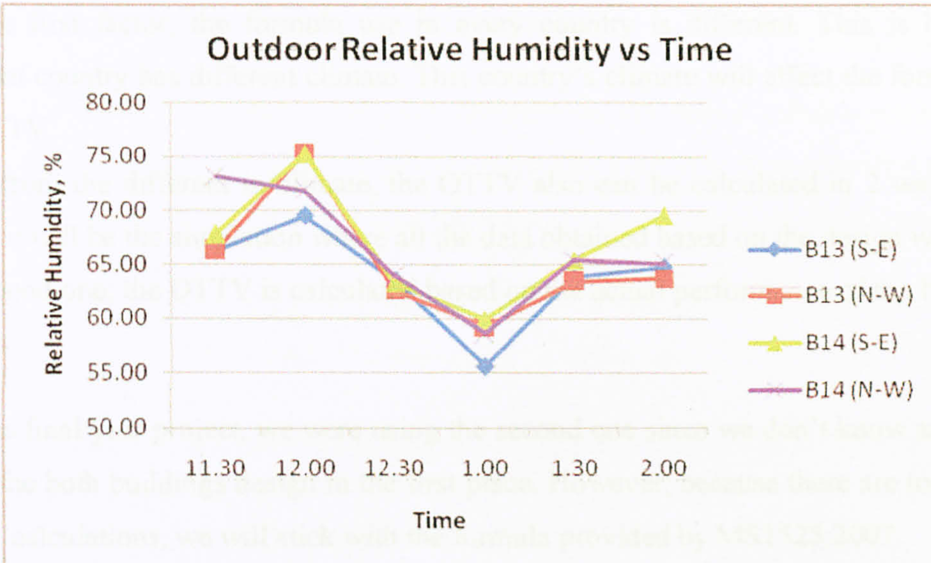

Figure 8. Outdoor Relative Humidity vs Time

Based on the relative humidity performance graphs for both buildings, the highest value falls around 12.00 pm. However at 1.00 pm the relative humidity for indoor and outdoor building 13 and building 14 falls drastically. Since the relative humidity is actually inversely proportional with the temperature, by comparing the relative humidity graph with the surface temperature graph we can see that the relationship is true. Taking 1.00 for instance, for surface temperature it has the highest value but for relative humidity, it has the lowest.

Factor Affecting OTTV Determination

Proceed with the discussion, now we will discuss on the problems or difficulty in determining the OTTV for building 13 and building 14. There are few factors that make the OTTV determination difficult. From the experiences and observation through out the project, the factors that influenced the OTTV determination are:

1. There is no universal formula for the OTTV calculation
2. The field measurement effectiveness

For the first factor, the formula use in every country is different. This is because different country has different climate. This country's climate will affect the formula of the OTTV.

Apart from the different in climate, the OTTV also can be calculated in 2 ways. The first one will be the simulation where all the data obtained based on the design while for the second one; the OTTV is calculated based on the actual performance of the building on-site.

For this final year project, we were using the second one since we don't know anything about the both buildings design in the first place. However, because there are too many OTTV calculations, we will stick with the formula provided by MS1525:2007.

The second factor will be the field measurement effectiveness. The field measurement only will be effective if the equipment such as automatic data logger is provided sufficiently. If the data were collected manually, the result obtained will vary a bit from the actual result.

<u>HSE Awareness</u>

During the field measurement also, the HSE procedure need to be follow so that the work is done safely. Hence unwanted accident can be avoided during the field measurement. Hence, prior to do the field measurement, the security department of Universiti Teknologi PETRONAS was informed via letter so that they can monitor in term of safety on site during the measurement day.

4.3.3 SUGGESTED ENERGY SAVING METHOD

1. The desktop computer can be considered as the major office equipment. It utilizes almost 350 watts of power under full load. It is recommended that the computer should be set to "Hibernate mode" during break to conserve energy.
2. The maintenance department should set the temperature of the air condition at 23°C – 24°C range. Each 1°C can save a lot of energy.
3. For the staff, use natural lighting or day lighting. If possible, turn off the lights near the windows.
4. For photocopier it is good to turn it off on the weekend and night. Use the duplex option to cut paper supply and save paper. This is because photocopier used great amount of energy during photocopying process, thus reducing the number of copies will also reduce the energy consumed.
5. If the management intended to buy a new equipment. Choose the one that has the highest co-efficient of performance or energy star rating. Select the equipment with variable processing capacity rather than a single capacity unit. Also select the equipment which has on/off switches mounted in a readily accessible/visible position.

CHAPTER 5

CONCLUSION

The main objective for this final year project is achieved. The audit has been done for both building through out the 2 semester. From the audit result, we know that:

1. The Building Energy Index (BEI) for building 13 and building 14 is within the standard given by the MS1525:2007
2. The Overall Thermal Transfer Value (OTTV) for building 13 and building 14 is not within the standard given by the MS1525:2007

From the result, we also know that:

1. Although the BEI for both buildings is within the standard, it is wise to improve its efficiency so that the energy consumed by the buildings can save more and from that particular action the CO^2 emission to the environment can be reduced.

2. For the OTTV performance for both buildings, it is aware that the value is not within the standard. From the observation for the past 2 semester, it is observed that the possible factor for this to happen is because the orientation of the building itself.

For a conclusion, from the audit result obtained, the performance of BEI and OTTV for building 13 and building 14 still can be improved. It is also hope that this energy efficient audit will help in creating awareness among the Universiti Teknologi PETRONAS management staff as well as the students. Their involvement in supporting the "green environmental policy" will give a very big impact to the energy performance of Universiti Teknologi PETRONAS and also will help to reduce the CO^2 emission to the environment.

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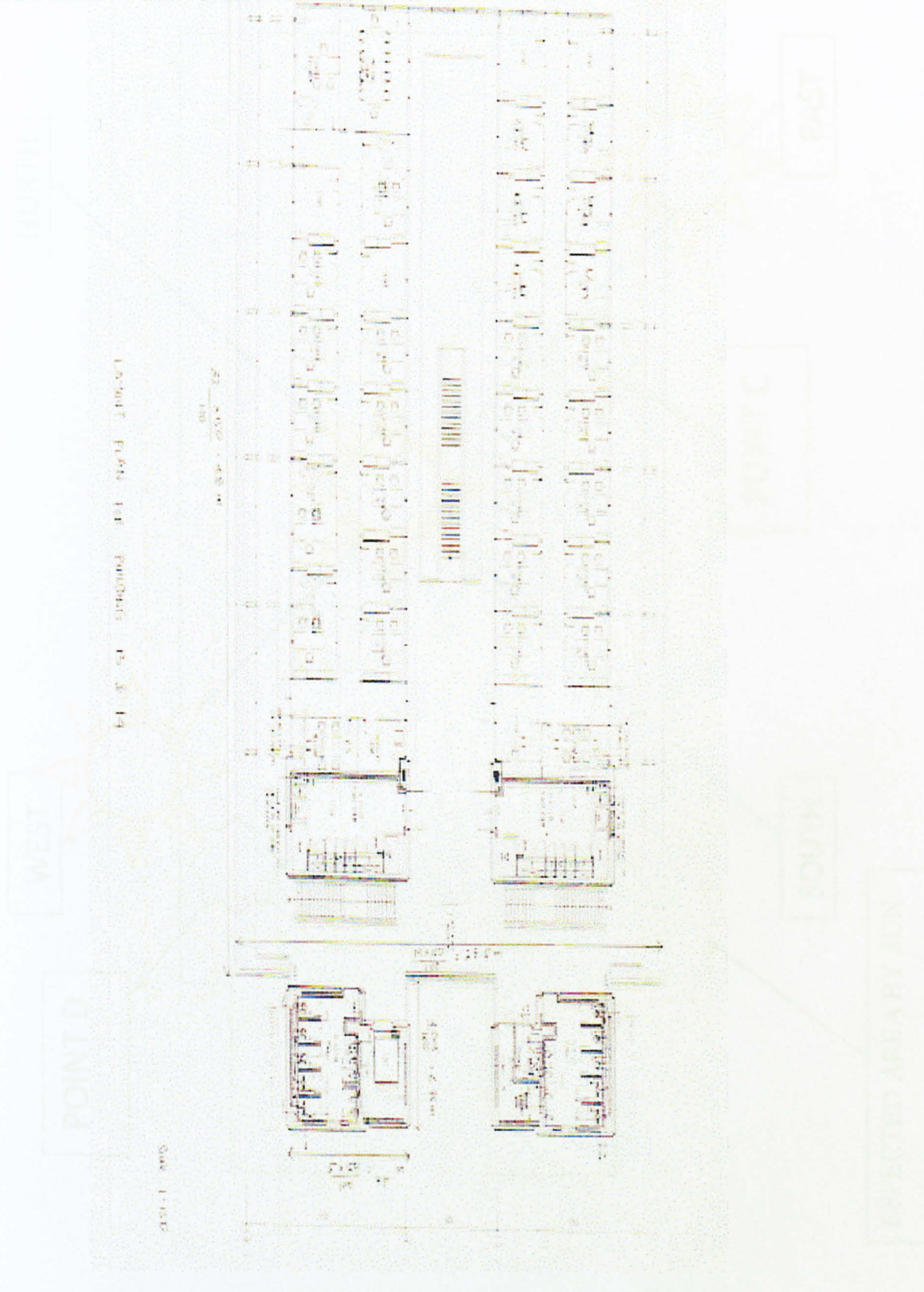
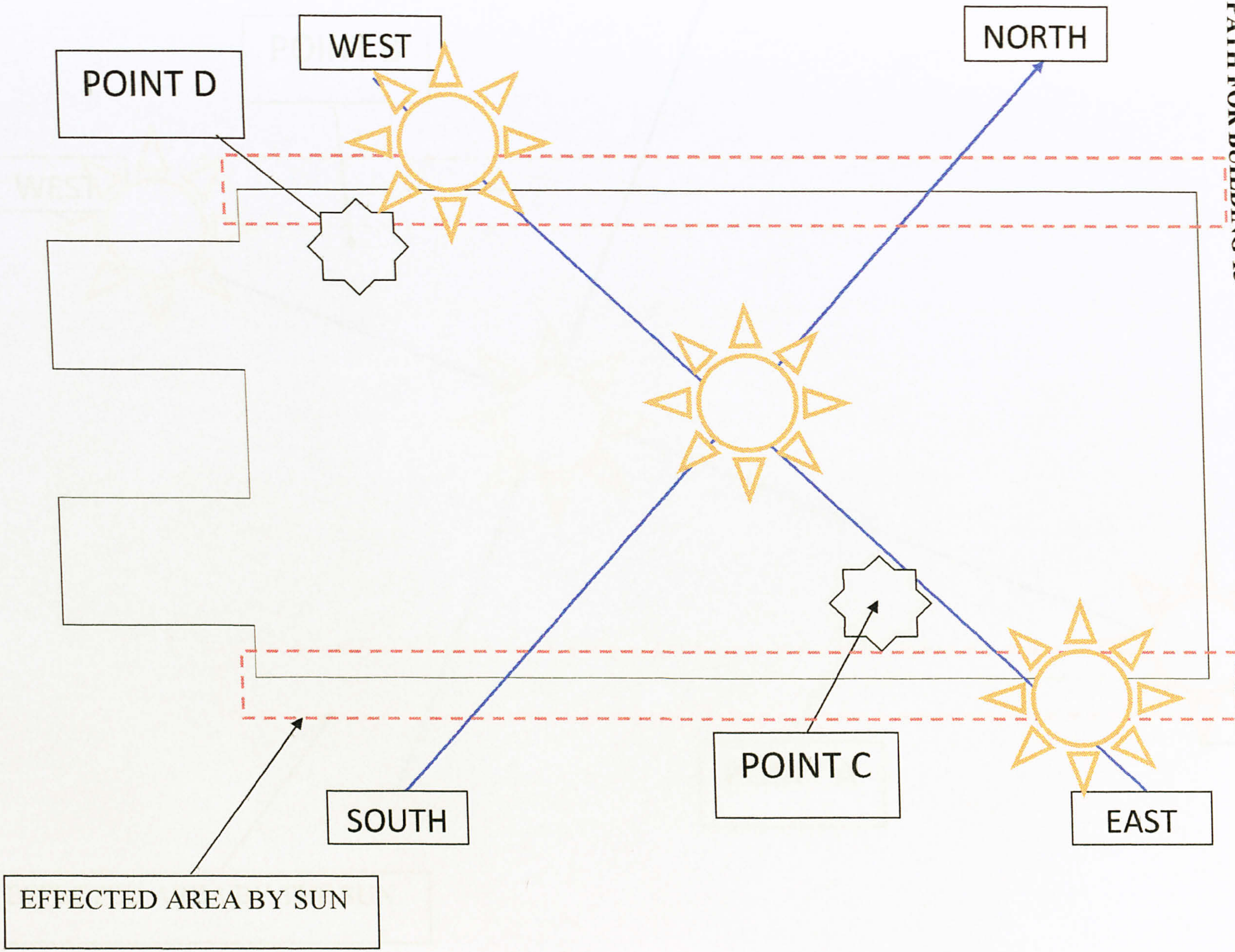
APPENDICES

LAYOUT PLAN FOR BUILDING 13 & 14



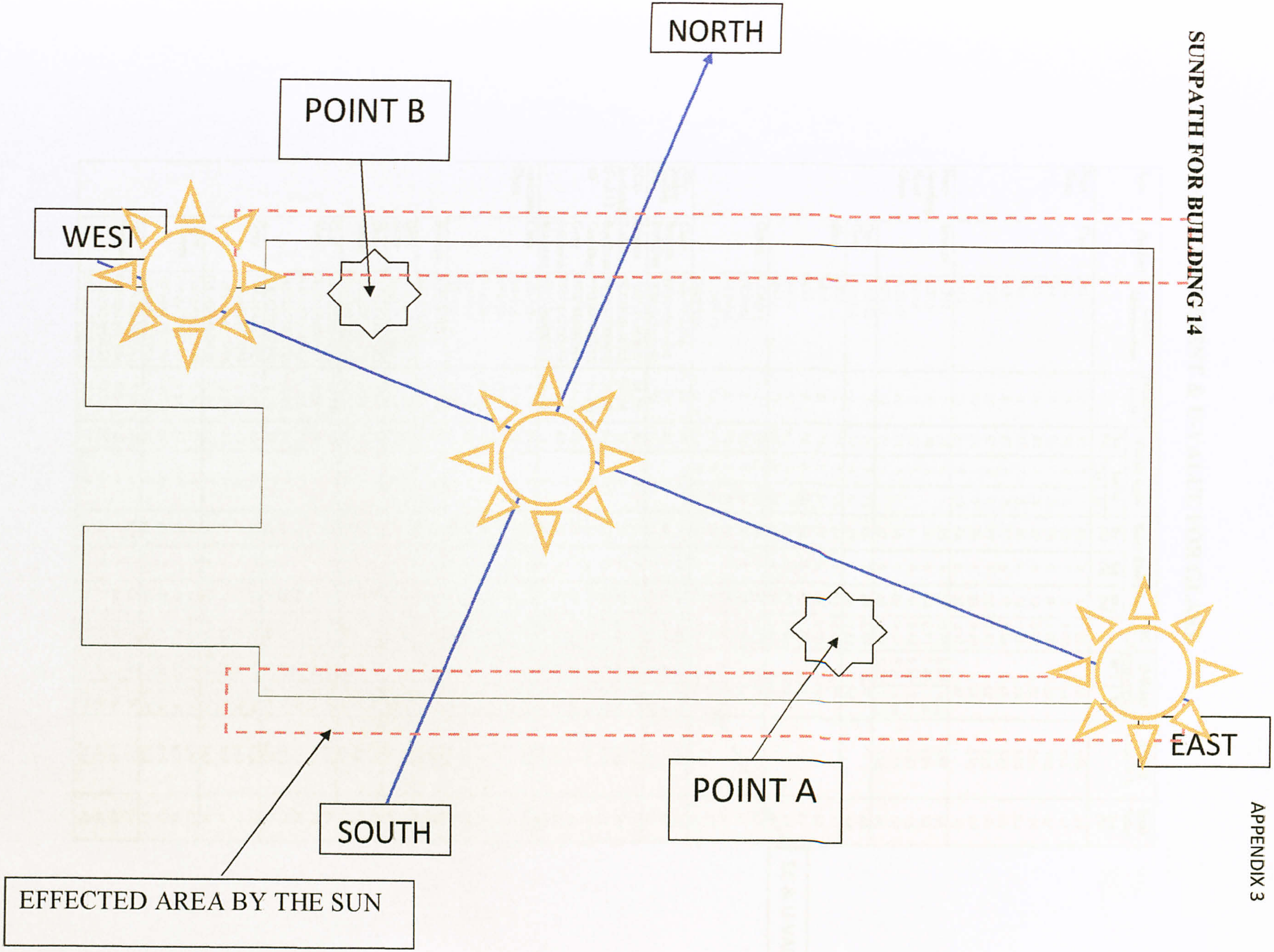
SUNPATH FOR BUILDING 13



APPENDIX 2

SUNPATH FOR BUILDING 14

APPENDIX 3



SHADING COEFFICIENT & U-VALUE FOR GLASS

Type	Product	Code Abbreviation	Thickness (mm)	Visible Light Trn (%)	Visible Light Ref(%) Out	Visible Light Ref(%) In	Solar Radiation Trn (%)	Solar Radiation Ref (%)	Solar Radiation Abs (%)	SC *2,3	U-Value Kcal/m²h°C W*1	U-Value Kcal/m²h°C S*2	RHG*4 Kcal/m²h	Total Solar Trn (%)
Float Glass	Clear	FL2	2	91	8	-	88	8	4	1.02	5.67		592	89
		FL3	3	90	8	2	85	7	8	1.00	5.84		581	87
		FL4	4	90	7	3	85	6	9	1.00	5.80		576	87
		FL5	5	89	7	4	82	6	12	0.98	5.77		565	85
		FL6	6	88	7	5	80	6	14	0.96	5.74		559	84
		FL8	8	87	6	7	77	6	17	0.94	5.68		543	82
		FL10	10	87	5	8	75	5	20	0.92	5.62		526	80
		FL12	12	86	5	9	73	5	22	0.90	5.56		515	79
		FL15	15	81	5	14	64	5	31	0.83	5.47		-	72
Heat Absorbing Float Glass	Bronze	BZFL5	5	53	6	-	55	6	39	0.75	5.53	5.26	448	65
		BZFL6	6	48	6	-	50	6	44	0.71	5.49	5.26	426	62
		BZFL8	8	38	5	-	41	6	53	0.64	5.39	5.26	388	56
		BZFL10	10	31	5	-	33	5	62	0.58	5.31	5.24	355	50
		BZFL12	12	25	5	-	27	5	68	0.53	5.22	5.22	328	46
	Dark Grey	DGRFL5	5	20	5	75	46	5	49	0.67	5.77			58
		DGRFL6	6	15	4	81	39	5	56	0.62	5.74			54
	Blue	HFL5	5	75	7	18	63	6	31	0.81	5.77		-	71
		HFL6	6	74	6	20	59	6	35	0.78	5.74		-	68
		HFL8	8	68	6	26	52	5	43	0.72	5.68		-	63
		HFL10	10	67	6	27	46	5	49	0.68	5.62		-	59
		HFL12	12	63	4	33	41	4	55	0.64	5.56		-	55
	Green	GGNFL5	5	78	7	15	54	5	41	0.75	5.77		-	65
		GGNFL6	6	75	7	18	50	5	45	0.71	5.74		-	61
		GGNFL8	8	70	6	24	45	5	50	0.66	5.68		-	57
		GGNFL10	10	65	5	30	39	5	57	0.61	5.62		-	53
		GGNFL12	12	64	5	31	34	5	61	0.57	5.56		-	50
DGU-Double Glazing Unit	Clear	FL6+A12+FL6	24	79	14		64	12	24	0.83	2.46	2.76	471	72
	Bronze	BZFL6+A12+FL6	24	42	8		40	8	52	0.58	2.46	2.84	337	50
	Dark Grey	DGRFL6+A12+FL6	24	12	6		25	7	68	0.42	2.46	2.88	250	37
DGU-(Laminated) LP+A12 +6	Bronze	LP(BZFL5\.76\FL3)	26.76	46	8		40	7	53	0.58	2.44	2.81	336	50
	Dark Grey	LP(DGRZFL5\.76\FL3)	26.76	16	5		27	6	67	0.45	2.44	2.84	266	39
	Blue Green	LP(FL3\377300\FL3)	24.38	65	11		54	10	36	0.72	2.46	2.79	412	63
	Cool Blue	LP(FL3\637600\FL3)	24.38	67	11		58	10	32	0.77	2.46	2.78	439	67
	Grey	LP(FL3\654400\FL3)	24.38	39	7		36	7	57	0.54	2.46	2.84	315	47
	Light Bronze	LP(FL3\645200\FL3)	24.38	46	8		42	8	50	0.60	2.46	2.83	347	52
	Mid Brown	LP(FL3\362800\FL3)	24.38	24	5		26	6	68	0.43	2.46	2.87	255	38
Laminated Glass	Clear	FL3+FL3	6.38	89	8		79	7	14	0.95	5.47	4.98	554	83
		FL4+FL4	8.38	88	8		75	7	18	0.92	5.38	4.96	537	80
		FL5+FL5	10.38	87	8		72	7	21	0.89	5.29	4.93	521	78
		FL6+FL6	12.38	86	8		69	7	24	0.87	5.21	4.91	510	75
		FL6+FL6	14.8	85	8		66	6	28	0.84	5.13	4.88	493	73
		FL8+FL8	16.38	84	8		63	6	31	0.82	5.05	4.86	482	71
	Bronze	BZFL5+BZFL5	10.38	52	6		49	5	46	0.71	5.29	5.13	425	61
		BZFL6+BZFL6	12.38	46	5		44	5	51	0.67	5.21	5.11	403	58
	Dark Grey	DGRFL5+DGRFL5	10.38	18	5		33	5	62	0.58	5.29	5.24	355	50
		DGRFL6+DGRFL6	12.38	13	4		28	5	67	0.54	5.21	5.21	333	47
	Blue Green	FL3\377300\FL3	6.38	73	7		67	6	27	0.85	5.47	5.11	501	74
		FL4\377300\FL4	8.38	72	7		64	6	30	0.83	5.38	5.07	489	72
		FL5\377300\FL5	10.38	71	7		62	6	32	0.81	5.29	5.03	478	70
	Cool Blue	FL6\377300\FL6	12.38	70	7		59	6	35	0.79	5.21	4.99	467	68
		FL3\637600\FL3	6.38	75	7		72	7	21	0.89	5.47	5.06	522	78
		FL4\637600\FL4	8.38	74	7		69	7	24	0.87	5.38	5.02	511	75
		FL5\637600\FL5	10.38	74	7		66	6	28	0.84	5.29	4.99	494	73
		FL6\637600\FL6	12.38	73	7		63	6	31	0.82	5.21	4.96	483	71
	Grey	FL3\654400\FL3	6.38	43	5		45	5	50	0.67	5.47	5.30	404	59
		FL4\654400\FL4	8.38	43	5		43	5	52	0.66	5.38	5.24	399	57
		FL5\654400\FL5	10.38	42	5		41	5	54	0.64	5.29	5.19	387	56
		FL6\654400\FL6	12.38	42	5		39	5	56	0.63	5.21	5.14	382	54
	Light Bronze	FL3\645200\FL3	6.38	51	6		52	6	42	0.73	5.47	5.24	437	63
		FL4\645200\FL4	8.38	51	6		50	6	44	0.71	5.38	5.19	425	62
		FL5\645200\FL5	10.38	50	6		48	5	47	0.70	5.29	5.14	419	61
		FL6\645200\FL6	12.38	50	6		46	5	49	0.68	5.21	5.09	408	59
	Mid Brown	FL3\362800\FL3	6.38	27	5		32	5	63	0.57	5.47	5.39	351	50
		FL4\362800\FL4	8.38	27	5		31	5	64	0.56	5.38	5.32	345	49
		FL5\362800\FL5	10.38	27	5		30	5	65	0.55	5.29	5.26	339	48
		FL6\362800\FL6	12.38	27	5		28	5	67	0.54	5.21	5.21	333	47

SC & U-VALUE

SOLAR CORRECTION FACTORS

Orientation	N	NE	E	SE	S	SW	W	NW
CF	0.90	1.09	1.23	1.13	0.92	0.90	0.94	0.90

SURFACE FILM RESISTANCE FOR WALLS AND ROOF

Type of Surface	Thermal Resistance m^2 K/W
A Surface Film Resistance for Walls:	
1 Inside surface (Ri)	
(a) High Emissivity	0.120
(b) Low Emissivity	0.299
2 Outside surface (Ro) (High Emissivity)	0.044
B Surface Film Resistance for Roofs:	
1 Inside surface (Ri)	
(a) High Emissivity	
(i) Flat roof	0.162
(ii) Sloped roof 22½°	0.148
(iii) Sloped roof 45°	0.133
(b) Low Emissivity	
(i) Flat roof	0.801
(ii) Sloped roof 22½°	0.595
(iii) Sloped roof 45°	0.391
2 Outside surface (Ro) *(High Emissivity)* Flat or Sloped	0.055

k-VALUES OF BASIC MATERIAL

Sr No.	Material	Density kg/m³	k-value W/m² K
1	Asbestos cement sheet	1488	0.317
2	Asbestos insulating board	720	0.108
3	Asphalt, roofing	2240	1.226
4	Bitumen		1.298
5	Brick:		
	(a) dry (covered by plaster or tiles outside)	1760	0.807
	(b) common brickwall (brickwall directly exposed to weather outside)		1.154
6	Concrete	2400	1.442
		64	0.144
7	Concrete, light weight	960	0.303
		1120	0.346
		1280	0.476
8	Cork board	144	0.042
9	Fibre board	264	0.052
10	Fibre glass (see glass wool and mineral wool)		
11	Glass, sheet	2512	1.053
12	Glass wool, mat or quilt (dry)	32	0.035
13	Gypsum plaster board	880	0.17
14	Hard board:		
	(a) standard	1024	0.216
	(b) medium	640	0.123
15	Metals:		
	(a) aluminium alloy, typical	2672	211
	(b) copper, commercial	8784	385
	(c) steel	7840	47.6
16	Mineral wool, felt	32 - 104	0.035 – 0.032
17	Plaster:		
	(a) gypsum	1216	0.37
	(b) perlite	616	0.115
	(c) sand/cement	1568	0.533
	(d) vermiculite	640 - 960	0.202 – 0.303
18	Polystyrene, expanded	16	0.035
19	Polyurethane, foam	24	0.204
20	PVC flooring	1360	0.713
21	Soil, loosely packed	1200	0.375
22	Stone, tile:		
	(a) sand stone	2000	1.298
	(b) granite	2640	2.927
	(c) marble/terrazzo/ceramic/mosaic	2640	1.298
23	Tile, roof	1890	0.836
24	Timber:		
	(a) across grain soft-wood	608	0.125
	(b) hardwood	702	0.138
	(c) plywood	528	0.138
25	Vermiculite, loose granules	80 – 112	0.065
26	Wood chipboard	800	0.144
27	Woodwool slab	400	0.086
		480	0.101

OTTV CALCULATION

U value calculation

Steel beam height

1) Steel Beam

	Component	b/k	R
1	outside air film		0.044
2	Steel	$\frac{0.250}{47.600}$	0.005
4	inside air film		0.120
	Total R		**0.169**

b/k

$$U = \frac{1}{R} = \mathbf{5.91} \ \mathrm{W/m^2K}$$

2) Opaque Wall

	Component	b/k	R
1	outside air film		0.044
2	aluminium alloy	$\frac{0.250}{211.000}$	0.001
3	inside air film		0.120
	Total R		**0.165**

$$U = \frac{1}{R} = \mathbf{6.05} \ \mathrm{W/m^2K}$$

3) Glass Window

= 0.02 $\mathrm{W/m^2K}$

U-value after conversion

4) Glass Window

SC = 0.61

Total area of one side of the building = height x width

5) WWR

(a)	Steel beam	Aw1	=	2	x	48	=	96.00
(b)	Opaque wall	Aw2	=	12	x	6.75	=	81.00
(c)	glass	Af	=	12	x	35.25	=	423.00
	Gross wall area						=	**600.00**
	WWR	=	**0.7**					

Af/gross wall area

OTTV Calculation

B13 Point A	CF	1.13
	OTTV =	102.3184
B13 Point B	CF	0.9
	OTTV =	86.74738
B14 Point C	CF	1.13
	OTTV =	102.3636
B14 Point D	CF	0.9
	OTTV =	86.45974

[(1-WWR) x Uw x TDeq] + (WWR x Uf x DT) + (WWR x SC x CF x 194)

Overall OTTV

Summation of OTTV Points / no. of points

Building 13 = 94.53291 W/m2

Building 14 = 94.41165 W/m2

FIELD PERFORMANCE ASSESSMENT OF THE BUILDING ENVELOPE

Objective : To collect the actual performance of the building envelope in order to calculate the Overall Thermal Transfer Value

Vanue : Building 13 and Building 14 of Universiti Teknologi PETRONAS

Date : 8 / 3 / 2009

References : Appendix 2 & 3 for the specific sunpath location

Results :

Time : 11.30 am

Points	Air Temperature		Surface Temperature		Relative Humidity	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
A						
B						
C						
D						

Time : 12.00 pm

Points	Air Temperature		Surface Temperature		Relative Humidity	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
A						
B						
C						
D						

Time : 12.30 pm

Points	Air Temperature		Surface Temperature		Relative Humidity	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
A						
B						
C						
D						

Time : 1.00 pm

Points	Air Temperature		Surface Temperature		Relative Humidity	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
A						
B						
C						
D						

Time : 1.30 pm

Points	Air Temperature		Surface Temperature		Relative Humidity	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
A						
B						
C						
D						

APPENDIX 6

Time : 2.00 pm

Points	Air Temperature		Surface Temperature		Relative Humidity	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
A						
B						
C						
D						