Study on the Effects of Heat Transfer through Glass Walls on Cooling Load

by

Ahmad Nazri bin Ahmad Latphy

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JANUARY 2009

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Study on the Effects of Heat Transfer through Glass Walls on Cooling Load

by

Ahmad Nazri bin Ahmad Latphy

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____
(Dr Ir Shaharin Anwar Sulaiman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2009

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.

AHMAD NAZRI BIN AHMAD LATPHY

ABSTRACT

The academic buildings in Universiti Teknologi PETRONAS (UTP) are very unique in its design and are exceptional. One of the things that makes it outstanding is the use of glass as the wall material. Highly glazed buildings are intended to be airy, light and transparent with more access to daylight. However, direct access to sunlight means more heat is gained and this significantly increases the total cooling load of buildings. Thus more energy needs to be supplied through the air conditioning to create a comfort zone for the occupants within. Therefore, a study on the heat transfer through the glass walls and its implication to the buildings' cooling load would be necessary in order to understand the suitable approach of energy savings. The present research focuses on the effect of heat transfer through glass walls via conduction and solar radiation on buildings' cooling load. Estimation on energy requirement with respect to solar radiation is calculated. This is done by calculation using equations and data provided in the ASHRAE Handbook. Experiments were also done using solarimeter to get the actual data for solar radiation with and without the presence of shading devices. From the results obtained, the effect of different orientation of the academic building in UTP on the total cooling load is studied. The direction of the sun which rises from the East North East to West North West affected the buildings in Zone 1 in the morning and also buildings in Zone 3 throughout the evening as the sun radiation is emitted directly to the buildings without any blockage. The occupied areas that are located under the main canopy of the academic complex are not exposed to the radiation as they are shaded. Actual measurements prove that the solar radiation emitted by the sun is much lower than calculated value. This is due to several factors which the movement of the clouds being the main reason. The use of shading materials such as window blinds and curtains further reduces the solar radiation up to 53 percent but also significantly reduces the amount of illuminance.

ACKNOWLEDGEMENTS

The author wishes to take the opportunity to express his utmost gratitude to the individuals who have taken the time and effort to assist the author in completing the project. Without the cooperation of these individuals, the author would undoubtedly have faced complications throughout the course.

First and foremost the author’s utmost gratitude goes to the author’s supervisor, Dr. Ir. Shaharin Anwar bin Sulaiman. Without his guidance and patience, the author would not be succeeded to complete the project. To the Final Year Research Project Coordinator, Prof Dr. Vijay R. Raghavan and Assoc. Prof. Dr. Puteri Sri Melor Megat Yusoff for providing him with all the initial information required to begin the project.

To all the technicians in Mechanical Engineering, Electrical Engineering and Civil Engineering Departments, thank you for assisting the author in the technical work.

To all individuals who have helped the author in any way, but whose name is not mentioned here, the author thanks you all.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND NOMENCLATURES

HVAC	Heating, Ventilating and Air Conditioning
HB	Heat Balance
RTS	Radiant Time Series
CLTD	Cooling Load Temperature Difference
SHGF	Solar Heat Gain Factor
SC	Shading Coefficient
CLF	Cooling Load Factor
IRC	Information Resource Centre
$W/m^2 K$	Watts per meter square Kelvin
W/m^2	Watts per meter square
e	Emissivity
τ	Transmittance
q	Heat flux
G	Incidence irradiance
g	Total energy transmittance
mm	millimetre

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Non-residential buildings are often highly glazed, causing unwanted external heat gains during sunny days. A lot of factors contribute to the excessive heat from solar radiation. However the main concerns regarding this design is the sensitivity of the building to its surrounding condition. Good thermal separation and low transmission losses between inside and outside through a highly insulated building skin characterizes a low energy building.

The air inside a building receives heat from a number of sources. If the temperature and humidity of the air are to be maintained at a comfortable level, this heat must be removed. The amount of heat that must be removed is generally referred as the cooling load. The cooling load must be determined because it is the basis for selection of the proper size of air conditioning equipment and distribution system. It is also used to analyze energy use and conservation.

The cost of running heating, ventilating and air conditioning (HVAC) systems is often the largest part of the utility bills for a building (McQuiston et al., 2005). Compressors, fans, boilers, furnaces, and pumps are responsible for much of that cost. All modern HVAC systems utilize some electrical energy. Electricity is normally the utility for which the most expense is involved, especially where a large amount of cooling is involved. With the escalating price of fossil fuels, which are the major energy sources to generate electricity, it has now become a necessity to reduce the energy consumption hence reducing the overall cost.

1.2 Problem Statement

The air conditioning systems for occupied buildings need to be operated within optimum condition using the least amount of energy while creating comfort zones for the tenants. Glazed buildings, such as the ones in UTP, permit high heat transfer rate mainly because of the direct sun radiation into the buildings. Hence, during daytime this increases the total cooling load for the particular buildings. As it is very costly to remove the heat from the building through air-conditioning system, a research is required to understand the nature of heat transfer through the glass wall in order to minimise the cooling load of buildings.

1.3 Objectives

The objectives of this research are to study the effects of heat transfer through the glass walls, within academic buildings in UTP, on the buildings' cooling load and to identify suitable methods to minimize the solar heat gain.

1.4 Scope of the Study

This research focuses on the heat transfer through the glass walls within the academic buildings in UTP. The first part of the research includes estimation of the room energy requirement as the cooling load of the building is the main criteria that are being investigated. The variation in the orientation of the academic buildings is studied to identify the differences in solar radiation upon the buildings. Different orientations of the building would result in different amount of solar heat gains. This variation of data is studied and a thorough research on the effect of building location to the amount of heat transfer is determined. A shading system is considered in the study as an external sun shade system and the effectiveness of this material is studied. Measurements of the solar radiance are taken to observe the actual heat transfer during daytime and also to understand the effect of the shading systems to the overall heat transfer thus determining whether it is effective in reducing the unwanted external heat gain.

CHAPTER 2
LITERATURE REVIEW

2.1 Previous Studies on Energy Performance of Buildings

The energy efficiency and the thermal performance of highly glazed office buildings are often questioned. However, nowadays more and more glazed buildings are built. This is because there is a rising tendency on the part of architects to use large proportions of glass that lead to higher transparency. Besides users who do not take into account the risk of visual and thermal discomfort that can occur due to this construction type often also like the idea of bigger glass area, relating it to enhanced view and more pleasing indoor environment (Poirazis, 2005). Companies that want to create a unique image for themselves often like the idea of being situated in a glazed office building.

According to Wouters (2000), building design is the most essential step in achieving an satisfactory indoor climate. The limitations on the energy use of the technical installations represent an important part of the building performance. Thus, the energy efficiency can be considered as a vital part of the building design. However, low energy design can not be the only target since other parameters also contribute to the improved overall performance.

In sustainable building design the integration of solar technologies is a delicate matter. Good performance of passive or active solar systems can not be achieved unless the integration of the solar technologies is considered in the early design stage (Poirazis, 2005). The systems' efficiency is highly connected with the location and use of the building and is directly influenced by the building's shape and orientation. It has impacts on the life cycle cost, on the environmental profile, and it can be crucial for the quality of the indoor environment.

The building can be considered as a sub system of the environment. During its entire life the building has impacts that are related mainly to environmental and energy use issues. It also can be considered as a hyper system influencing the comfort and productivity of the occupants (Poirazis, 2005). In order to succeed in a holistic approach during the design stage of an office building, it is important to consider the parts that interact with each other, and influence the systems' performance, as shown in Figure 2.1.

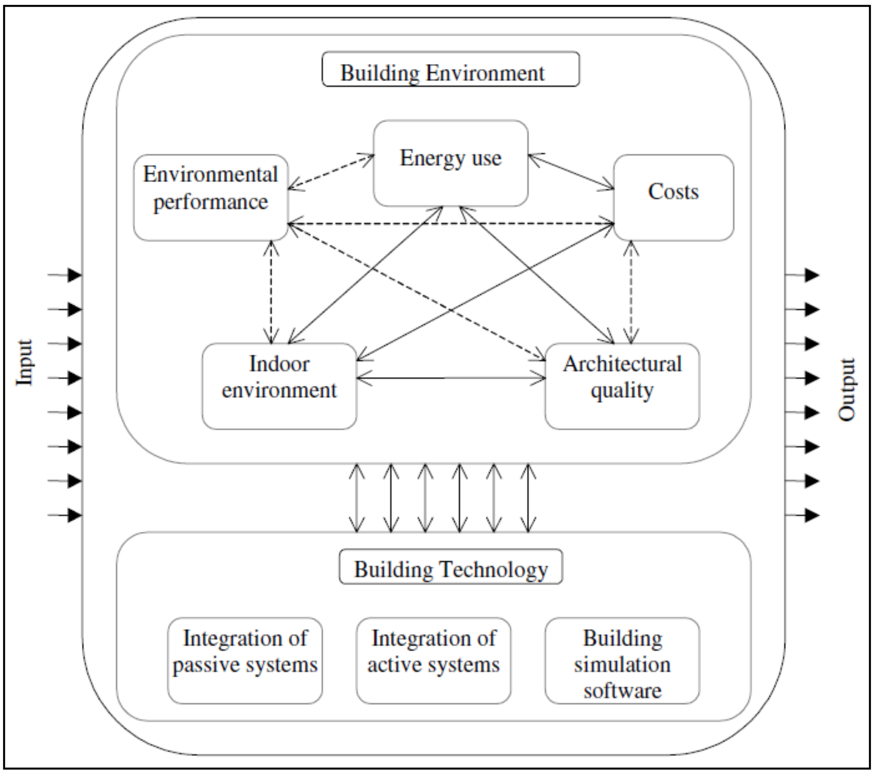

Figure 2.1 : Description of the building system (Poirazis, 2005)

In most modern buildings cooling must be provided to make the occupants comfortable, especially in warm seasons. Some buildings are cooled to provide a suitable environment for sensitive manufacturing or process control. Even in cold climates there may be need for year-around cooling in interior spaces and in special applications. Energy gain to a space is typically from warmer surroundings and sunlight or from internal sources within the space, such as occupants, lights, and machinery (McQuiston et al., 2005).

Achieving a satisfactory indoor environment with respect to energy use is one of the major challenges when an office building is planned (Poirazis, 2005). The main components that characterize the indoor environment are shown in Figure 2.2. These parameters have an impact on the occupants' productivity and furthermore on the total economic value of the building. According to ASHRAE Standard 55 (1981), *"Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment".*

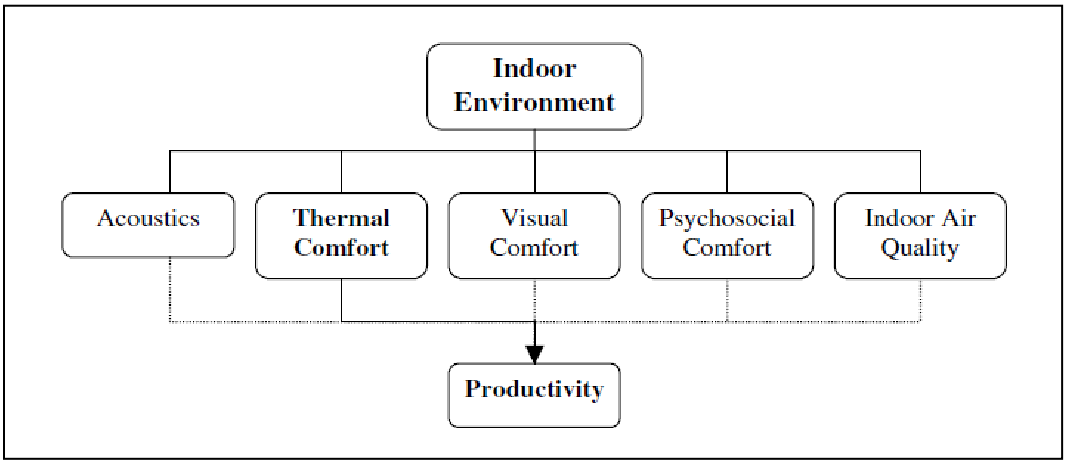

Figure 2.2 : Criteria of indoor environment (Poirazis, 2005)

Becker and Paciuk (2002) reported a study, which investigated the impact of night ventilation and pre-cooling on peak cooling demand for an office building in coastal region of Israel. However, the size studied is small which about 1000 m^2 is and only one flat of the multistory building was considered. Moreover the glazing material is not highlighted to be part of the main research and only north–south facing windows with constant window ratio are included in the model, which does not correspond with the majority of office buildings design.

There are various aspects of energy conscious design, but the most important element is on the energy performance of the building, especially for office buildings. Most of the previous studies are valid for cooling load in the hot and humid climates, majority of office building studies have been done in Hong Kong (Leung et al., 2005). However there are still demands for energy-efficient office building design in cold and mild climates. Quite a few of the studies which were associated with cold and mild climates have focused either on HVAC operational strategies in the buildings or comfort conditions for building occupants (Alhoumod, 1997).

Another research by Dascalaki and Santamouris (2002), investigated the energy conservation potential of office buildings in five climatic zones in Europe for different passive retrofitting scenarios. This particular research shows that the use of shading reduces both the cooling load and yearly energy consumption of buildings. However, occupancy schedule or internal loads were not incorporated for the buildings. The effect of insulation layer thickness and its position on both cooling–heating loads and peak cooling and heating loads at each climatic zone were not investigated. Therefore the applicability of the results is limited.

The usage of electricity for commercial consumers always depends on the efficiency of the HVAC systems. In four-season countries, for a certain month in a year, the usage is always at the maximum capacity which is called peak demand period. For example, the peak demand period in the southern United States might be between the hours of 2.00 P.M and 8.00 P.M. Monday through Friday from May 15th to October 15th. This would be typical of the time when the electrical utilities might have the most difficulty meeting the requirement of the customers (McQuiston et al., 2005). Shown in Figure 2.3 is a typical monthly variation in electric utility charges for a typical commercial customer.

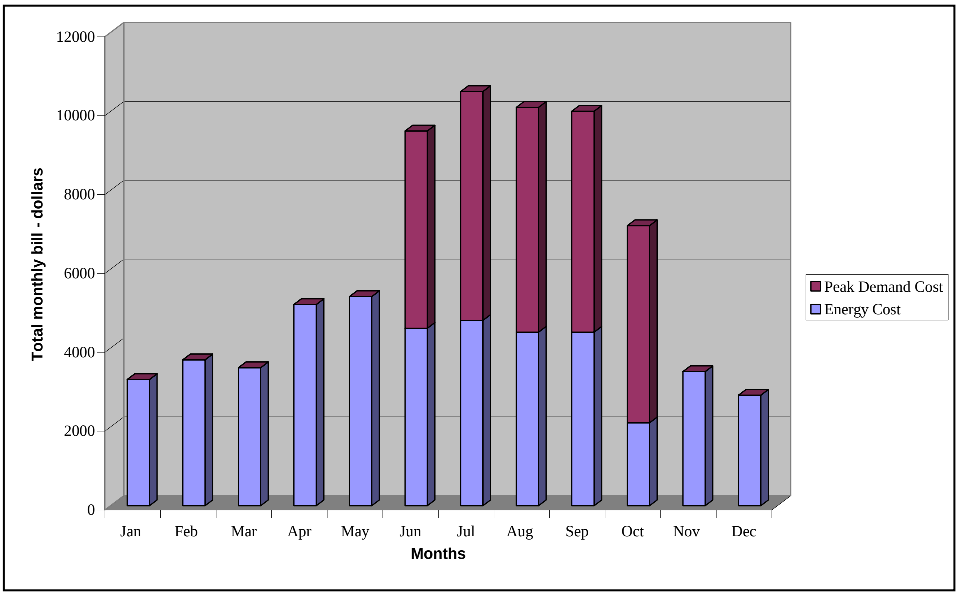

Figure 2.3 : Monthly electric utility charges for a typical commercial customer (McQuiston et al., 2005)

2.2 Glazed Buildings

Modern office buildings have high potentials for energy savings and indoor climate improvements. According to Poirazis (2005), during the nineties many office buildings with glass facades were built, in several cases with double skin glass façades. The advantages of buildings with double skin façades (compared with single skin glazed ones) are considered to be the reduced heating and cooling demand, the increased sound insulation towards the outside and the efficient solar shading.

Highly glazed office buildings risk having a higher energy use for heating and cooling and at times poorer thermal comfort, compared with a building with conventional facade. However, it was shown that energy reduction is clearly possible with improved window types combined with proper shading devices, but the energy use is likely to still be somewhat higher than for the conventional building (Wouters, 2000).

Studying indoor climate in a highly glazed building, where the external skin is much more sensitive to the outdoor climatic conditions than a conventional façade, is a complicated task, since many parameters influence its quality (Poirazis, 2005). It was shown that an improved indoor environment with low energy use can be obtained if a detailed study for each building design is carried out, involving proper combination of control set points and choice of widow and shading devices, used for certain occupancy and function of the building.

Most designers use either single or double glazed façade. This is because for double glazing, it provides a direct protection from the solar radiance. Thermal transmittance or *U*-value, defined as the heat flow transmitted through a unit area of a given structure, divided by the difference between the effective ambient temperatures on either side of the structure, under steady conditions (Limb, 1992). For a single façade, coated heat protection double glazings with low *U*-values between 1.0 and 1.7 $W\ m^{-2}\ K^{-1}$ dominate the Northern European market. Meanwhile for Southern Europe, uncoated double glazings with *U*-values between 3 and 3.5 $W\ m^{-2}\ K^{-1}$ are still used regularly. *U*-values determined the rate of heat transfer through a fenestration system.

Solar radiation has important effects on both the heat gain and the heat loss of a building. The effects depend to a great extent on both the location of the sun in the sky and the clearness of the atmosphere as well as on the nature and orientation of the building. The variation of sun's location in the sky during the day are vital to the research and also the measurement of the solar irradiation of any surface at any given time and location on the earth (Pita, 2005).

Fenestration solar heat gain has two components. First is directly transmitted solar radiation. The quantity of radiation entering the fenestration directly is governed by the solar transmittance of the glazing system. The second component is the absorbed solar radiation, radiation that is removed from the main beam and absorbed in the glazing and framing materials of the same window, some of which is subsequently conducted to the interior of the building (Pita, 2005).

Total energy transmittance is given by the *g*-value, which adds to the optical transmittance τ (dimensionless) and the secondary heat flux q_i (given in W m^{-2}) normalized by the incidence irradiance G which is given in W m^{-2} (Eicker et al., 2008). The equation given:

$$g = \tau + \frac{q_i}{G} \tag{2.1}$$

2.3 Factors Affecting : Conduction

The heat gain component that contributes to the room cooling load consists of conduction through exterior walls and glass and also solar radiation through glass. The cooling load caused by conduction heat gain through the exterior walls and glass are each found from the equation:

$$Q = U \times A \times CLTD_C \tag{2.2}$$

Cooling load for the glass, given by Q-value, (given in W) which is the product of the overall heat transfer coefficient for glass, U (given in W m^{-2}) and the area of the glass A (given in m^2) and also the corrected cooling load temperature $CLTD_c$ (given in °F). The cooling load temperature difference (CLTD) is not the actual temperature difference between the outdoor and indoor air. It is a modified value that accounts for the heat storage/time lags effect (ASHRAE, 2001).

2.4 Factors Affecting : Solar Radiation

Radiant energy from the sun passes through transparent materials such as glass and becomes a heat gain to the room. Its value varies with time, orientation, shading, and storage effect. The solar cooling load can be found from the equation:

$$Q = SHGF \times A \times SC \times CLF \tag{2.3}$$

Solar radiation cooling load for the glass is given by *Q*-value (W), which is the product of maximum solar heat gain factor, SHGF (given in W m^{-2}) and area of the glass, A (given in m^2) also the shading coefficient, SC (dimensionless) and cooling load factor for glass CLF (dimensionless). The maximum solar heat gain factor (SHGF) is the maximum solar heat gain through single clear glass at a given month, orientation, and latitude (ASHRAE, 2001).

2.5 Shading Systems

Eicker et al. (2008), reported that high quality glazing with the overall unit thermal conductance, called *U*-values, which is below 1.5 W m^{-2} K^{-1} and high total energy transmittance with a *g*-value above 60% play an important role in reducing energy consumption buildings. An excellent daylight performance buildings will depends on additional features which include excellent sun protection through shading devices on the outside of the façade and also a good ventilation schemes to remove part of the daily loads.

Report by Dascalaki and Santamouris (2002), proved that the use of shading devices greatly reduces the yearly consumption load of the building. In the report, the experiment is being done on several types of shading elements. Although each elements has its own characteristic towards the heat, the results are the same which help in reducing both the solar radiation and cooling load of the building. It is also reported that each difference in angle of shading system greatly affect the total radiation absorbed by the glass walls. It is then observed that the shading system by sunshade and other sun blind has tremendous effect on the total solar radiation caused by direct sunlight.

2.5.1 Shading Systems : Window blind

There a lot of shading elements available in the market. According to Alio (1994), the most common type of shading devices is window blind. It is used widely regardless of the location and place. A window blind is a specific type of window covering which is made with slats of fabric, wood or metal that adjust by rotating from an open position to to a closed position by allowing slats to overlap. Metal window blinds are often used outside of the house or business to protect against theft, temperature, vision, bad weather and fire. Often these blinds are machine-operated, rather than hand operated.

The horizontal version uses a thin woven "ladder" system to suspend the slats and enable slats to be closed via a rotating drum to which each upper end of the woven ladder is wrapped and attached. A lift cord allows blind to be pulled up and stack tightly to top of window when desired. The vertical version uses a generally wider slat and has the added feature of being able to pull a cord to stack the slats together either to one side or to separate in the center and stack on each end. This vertical blind allows rotation of slats by a rotating shaft in the upper head rail housing which runs throgh independent geared carriers that will convert twisting of tilt rail to a rotation of each individual slat in sync (Rea, 1984).

2.5.2 Window blind : Slat / Persian

The most common window blinds are slat blinds, which consist of many horizontal slats, usually of metal or vinyl, connected with string in a way that they can be rotated to allow light to pass between the slats, rotated up to about 170 degrees to hide the light, or pulled up so that the entire window is clear. Vertical blinds consist of slats of stiffened fabric, plastic, or metal hanging by one end from a track; like the horizontal versions, the slats can be rotated 90 degrees to allow light to pass through or to fold up on one side of a door or window (Kuhn, 2006). Vertical blinds are very good at controlling how much natural or exterior light comes into a room, due to the ability of the slats to close tightly.

2.5.3 Window blind : Venetian

Report by Alio (1994) states that a Venetian blind has horizontal slats, one above another. They are suspended by strips of cloth called tapes, or by cords, by which all slats in unison can be rotated through nearly 180 degrees. The slats can be rotated such that they overlap with one side facing inward and then in the opposite direction such that they overlap with the other side facing inward. Between those extremes, various degrees of separation may be affected between the slats by varying the rotation.

There are also lift cords passing through slots in each slat. When these cords are pulled, the bottom of the blind moves upward causing the lowest slats to press the underside of the next highest slat as the blind is raised. A modern variation of the lift cords combines them with the rotational cords in slots on the two edges of each slat (Alio, 1994). This avoids the slots otherwise required to allow a slat to rotate despite a lift cord passing through it, thus decreasing the amount of light passing through a closed blind. Figure 2.4 shows the typical Venetian blind.

Figure 2.4 : Venetian blind

2.5.4 Window blind : Vertical

Unlike horizontal blinds, vertical blinds are less likely to be damaged in strong winds, to hold dirt and be less likely to break down. Generally they require less muscle strength, and are faster to operate. Stationary vertical blinds are hung in the doorways of some homes and businesses which generally leave the door open. Movement of the blind may signal a change in air flow, or someone entering the doorway (Kuhn, 2006).

CHAPTER 3
METHODOLOGY

3.1 Overview

This research can be categorised into two main sections. The first part is on the calculations of the buildings solar radiation and the second part is on the measurements of the actual solar radiation with and without the shading systems.

3.2 Gantt Chart and Project Flow

To ensure the accuracy of the calculation, getting the right specification is essential before completing the calculation for the whole building area to get the overall result. The material that are used for the whole building needed to be checked to determine the right values are used to calculate the overall cooling load of the building. Furthermore experiment to measure the actual solar radiation and heat conduction that were caused by the sun is conducted to maximise the accuracy of the data governed. Shown in Figure 3.1 and Figure 3.2 is the Gantt chart for the project planning and progress.

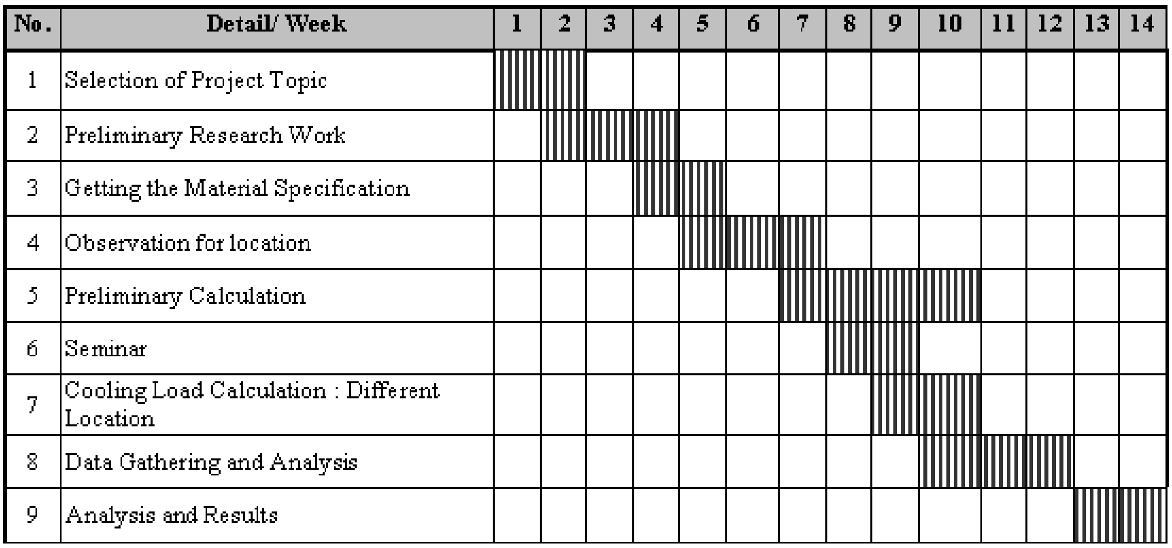

Figure 3.1 : Semester 1 Gantt chart

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Procurement of Equipment														
2	Planning Experiments														
3	Updating the Material Specification														
4	Calculation for Different Location														
5	Experiment : Different Location														
6	Data Gathering and Analysis														
7	Finalizing on the Analysis and Results														
8	Oral Presentation														

Figure 3.2 : Semester 2 Gantt chart

Shown in Figure 3.3 is the flowchart of project planned for Semesters 1 & 2. The information is obtained from internet and previous research by other institutes. The suitable location is needed in order to demonstrate the effect of the sun movement to the total cooling load with respect to solar radiation and conduction. Observation and measurement is done to ensure that all the data is accurate and the specification used is correct. Calculation for cooling load will be done and the results will be analysed further to explain on the behaviour and characteristic of the sun and also the academic buildings.

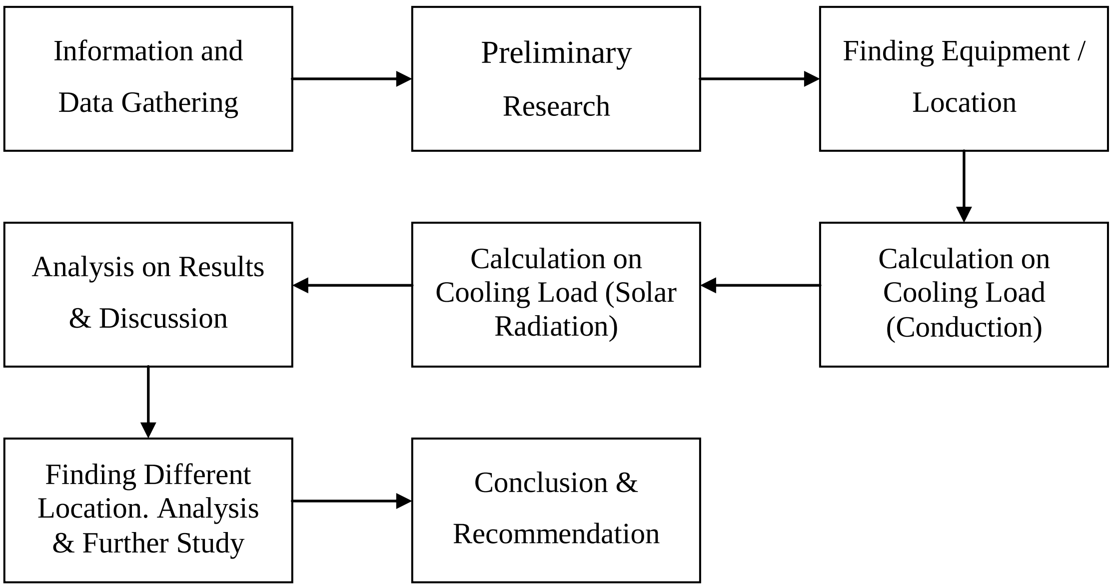

Figure 3.3: Project flow planning for both semesters

3.3 Cooling Load Calculation

The first part of the research focuses on getting the cooling load calculation. There are several ways to get the actual calculation for cooling load with respect to the solar radiation and conduction. The two most current load calculation methods represent a significant departure from those in common use.

The first of the two methods is the heat balance (HB) method. The calculation procedures and scientific principles are explained in equation format. These equations are coded in a generic computer program named Hbfort, released with *Cooling and Heating Load Calculation Principles* (Pedersen et al. 1998), and linked to a user interface program to allow input and output in either inch-pound or SI units.

The second method is called the radiant time series (RTS) method, which is a simplified method directly related to and derived from the HB calculation procedure. The present research uses calculation that involves the cooling load caused by conduction heat gains through the walls and also the solar radiation through the glass walls.

The key elements for calculating the cooling load is identified and by using Microsoft Excel spreadsheet, a template was constructed to ease the calculation of the room cooling load. Figure 3.4 shows the Excel spreadsheet that is being used.

Cooling Load Calculations								
Month								
Location								
Altitude								
							SCL = Sensible Cooling Load	
Conduction	Direction	Colour	*U*	Area (m^2)	CLTD (F)	CLTD Corrected	**SCL (W)**	
	N						0.00	
Glass	SW	Transparent					0.00	
	W						0.00	
	SE	Transparent					0.00	
								0.00
Solar	Direction	Shading	SHGF	Area	SC	CLF		
Glass	N						0.00	
	SW	No					0.00	
	W						0.00	
	SE	No					0.00	
								0.00
							Total	**0.00**

Figure 3.4 : Cooling load calculation template

3.3.1 Sun Directions and Buildings Orientation

UTP academic building consists of sixteen academic blocks for five engineering and two technology programmes. There are also two special buildings called pocket C and pocket D respectively which houses several lecture halls that can accommodate up to three hundred students at a time. The main building for this complex is the round-shaped buildings that comprises of a Chancellor Hall, an Information Resource Centre (IRC) and an Administration building that is being situated under one big circular roof. All of these buildings are interconnected with each other under a canopy which sheltered some of the sixteen academic buildings partially.

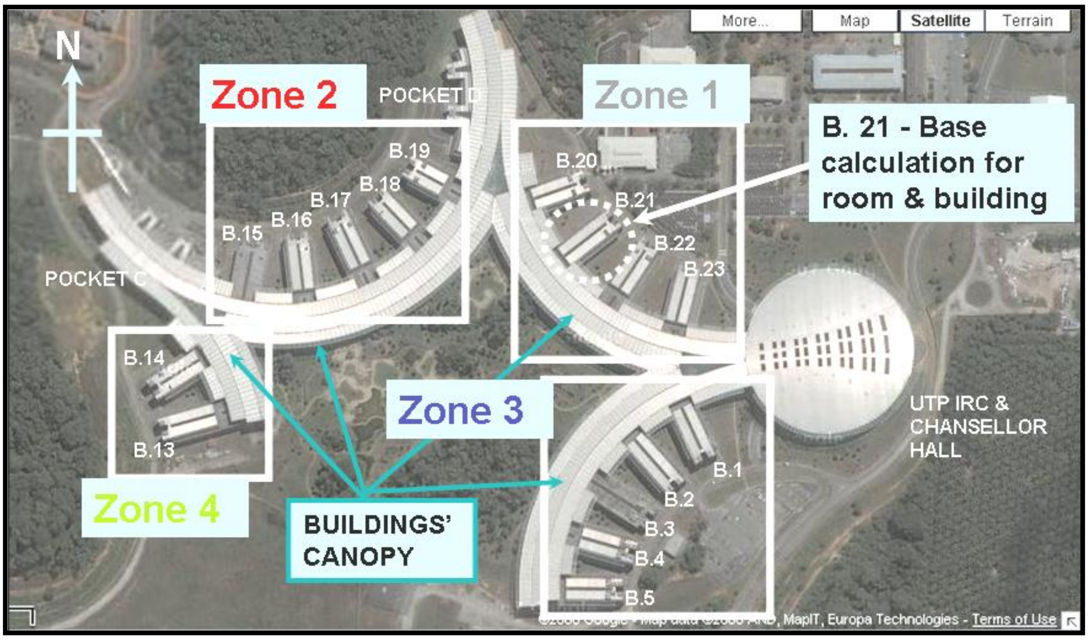

Figure 3.5 : Academic buildings and zones (Google Maps, 2008)

The four zones represent different orientation of buildings that will result in distinct sets of solar radiation characteristics. The unique design of the academic buildings which has a canopy on the inner side of the academic complex also plays a factor in determining the overall heat transfer. The portions of buildings that are exposed to direct sunlight will gain extra heat and thermal energy transfer as compared to those that are shaded. The areas that are always shaded by the roof will experience less exposure to solar radiation. The pattern of the result will be studied to determine the effect of building orientation to the cooling load.

The present location for this research is one of the sixteen academic buildings that is usually being used by the Faculty of Electrical Engineering which is Block 21. It is a four-storey building comprises of several labs, lecture rooms and also the lecturers' office placed strategically at different level to enhance the optimum usage of the buildings.

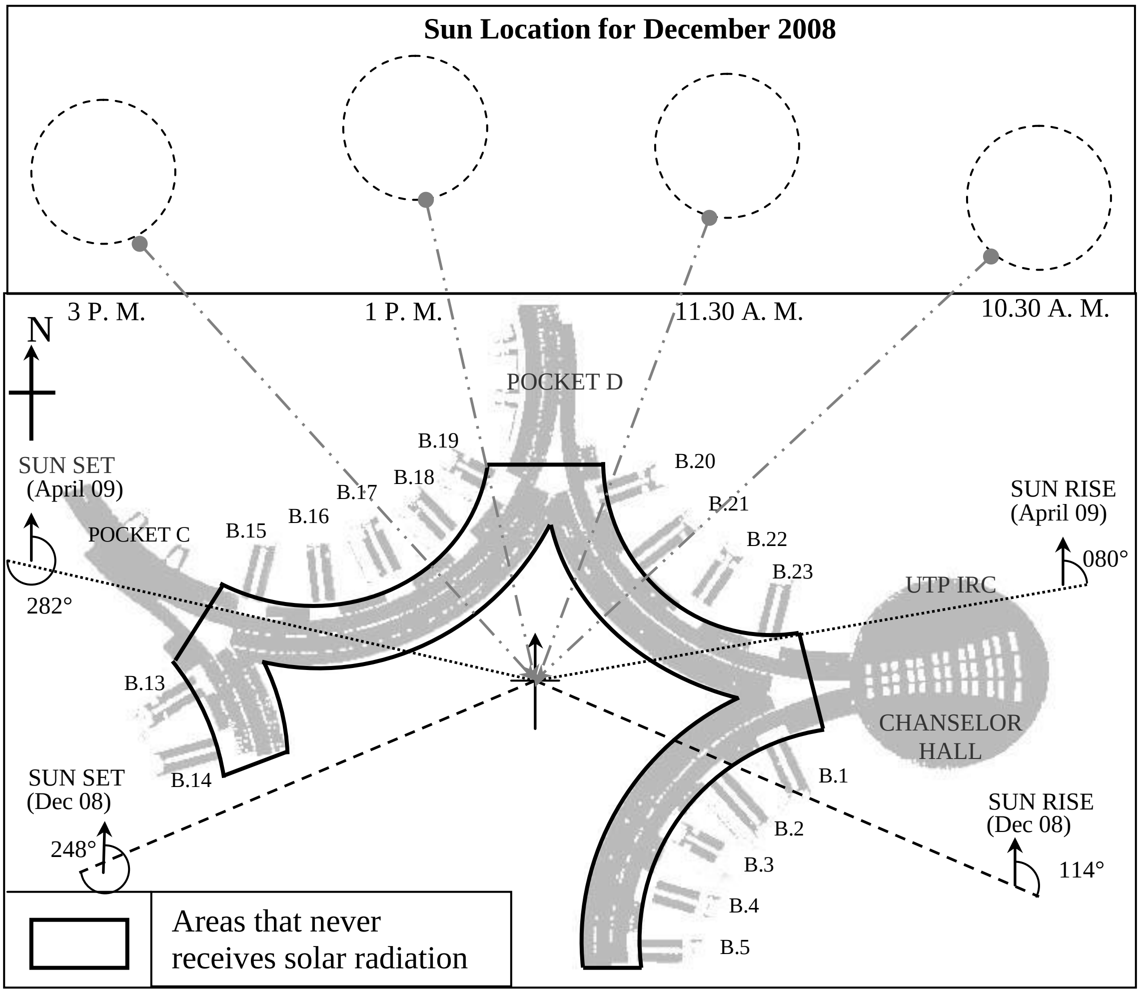

Figure 3.6 : Sun Direction and the Solar Radiation within UTP academic buildings

As the unique design of UTP academic buildings, the room that are located below the canopy will not receive solar radiation from the sun at specific time. However there are certain times when the sun position farther, the radiation still reaches the glass walls. The effect of heat conduction through the glass walls follows the same patterns.

3.3.2 Sample Area for the Calculation of Cooling Load

The purpose of this calculation is to prove how the effect from solar radiation and also conduction from the glass walls are affecting the cooling load of the room. Other affecting variables for the total cooling load of the room are not considered in this calculation as it will not give any difference in determining the effect of the glass walls. In this calculation, the *U*-values from the specification of the glass walls are needed along with the cooling load temperature difference (CLTD) values.

By observing the movement of the sun and also the location of the canopy, a suitable room in Block 21 is chosen for the preliminary calculation. Room 21-02-07 is selected because of the ideal size and accessibility. This room is one of the lecture rooms that are available in this particular building as most of the rooms are specifically for lab purposes.

This room is located at the South East corner of Level 02 and is easily accessible as it is beside the staircase. The plan layout for this room is shown in Figure 3.8 below. Only two walls are subjected to solar radiation at all time as the main entrance is located at the centre of the building which is shaded by the roof and the other wall separates the room and an Electrical & Electronics Lab.

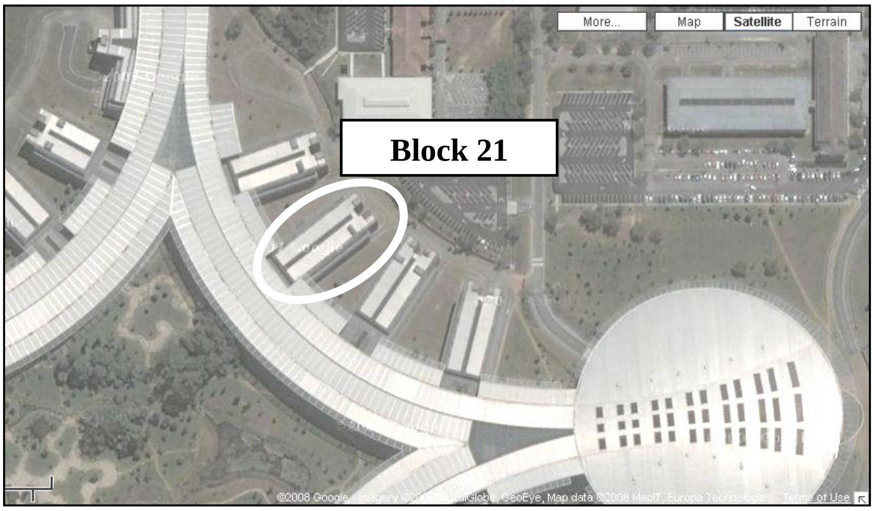

Figure 3.7 : Top view of Block 21, UTP Academic Building (Google Maps, 2008)

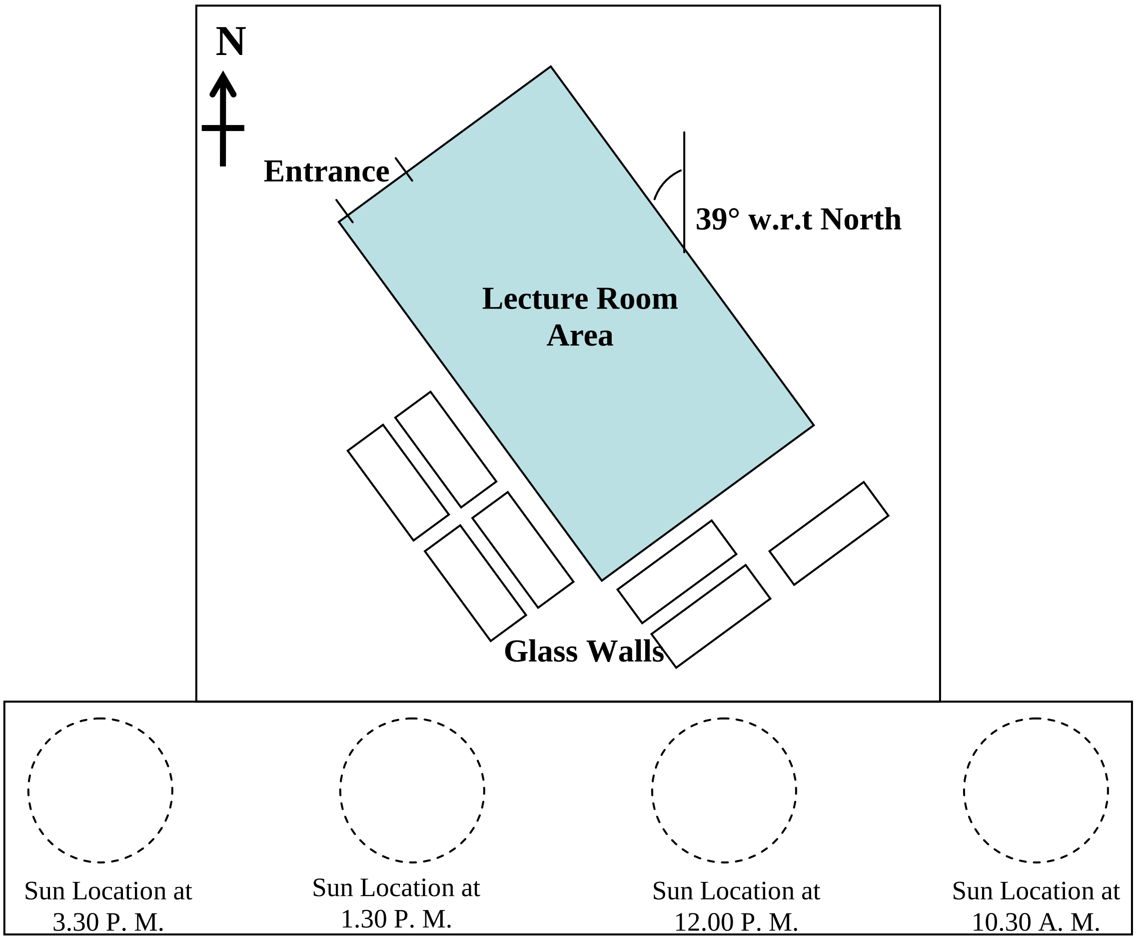

Figure 3.8 : Layout of Room 21-02-07

This room has two sides which are exposed to direct sunlight. The glass walls on the South East side are directly exposed to the sun on the morning, while the glass walls on the South West side are barely exposed to solar radiance. The three glass panes on the South East side are identical in size. Each measures 3.30 m in length and 0.82 m in height. The glass panes on the South West side are relatively different in length with two of the glass panes having 1.90 m and the other two with 2.92 m. All four glass panes however have identical heights of 0.82 m.

As given by the Property, Management & Maintenance Department of UTP, the materials that are used for the glass panes are double glazing glass with emissivity, e = 0.05 on surface and thickness of 12.7 mm. From Table 4 in ASHRAE Fundamentals Handbook 9 (2001), the U-value for this glazing type is given as 1.67 W m^{-2} K^{-1}. The clear type of the glass gives the value of 0.81 for the shading coefficient.

3.4 Solar Radiation Measurement

Calculation is done in order to get the preliminary data of the buildings' cooling load with respect to solar radiation and conduction. However, some parameters in the calculation may be inaccurate at certain time as a lot of factors need to be consider apart from equations and coefficient. Apart from that the measurement must also be done in order to see the results from the introduction of the shading devices.

Solarimeter is a weather instrument used widely for measuring the flux of solar radiation through a surface. This type of measuring device is also known as 'pyranometer'. It measures the intensity of the entire global solar radiation on the surface of the earth in both direct and defused sunlight. In the present project, the solarimeter was manufactured by Kipp & Zonen with model number HD 9221. The accuracy of this solarimeter was reported by the manufacturer as ± 0.02 W/m^2 (HD 9221 Instruction Manual).

The solar radiation derived from the absorption of heat by a black body is developed into energy that is measured by the solarimeter. The voltage output provided by the solarimeter is read by a data logger or other related reading device. The reading is then converted into watts per square meter (W/m^2) to get the final result. The solarimeter has a weatherproof body with an aluminium coat. The sensor based upon a silicon photo detector is placed within this body. This body condition is suitable for long term outdoor operation.

Figure 3.9 : Solarimeter

CHAPTER 4
RESULTS

4.1 Calculation of Heat Gain by Conduction

Using earlier equation, the total cooling load with regards to the solar radiation and conduction for room 21-02-07 were calculated in Microsoft Excel. In this calculation, the solar radiation is assumed to be at the peak hour.

For South East walls the total area for the glass panes are 8.12 m^2 and for the South West walls are 7.90 m^2. *U*-values for the glass is 1.67 W m^{-2} K^{-1}. Using Table 6.5 from ASHRAE Handbook – Fundamentals (1993), the peak value for Cooling Load Temperature Difference (CLTD) is 14 °F. Table 6.4 from 1989 ASHRAE Handbook – Fundamentals gives -6 °F for CLTD correction with regards to the altitude of the room. Using equation from (4.1):

$$Q = U \times A \times CLTD_C \tag{4.1}$$

Inserting all the appropriate value into the excel file gives a value of 214 W.

4.2 Calculation of Cooling Load by Solar Radiation

For South East walls the total area for the glass panes are 8.12 m^2 and for the South West walls are 7.90 m^2. Using Table 6.6 from ASHRAE Handbook – Fundamentals (1989), the Maximum Solar Heat Gain Factor (SGHF) is 110 BTU h^{-1} ft^{-2}. Converting to SI unit gives the value of 346.83 W m^{-2}. Shading Coefficient (SC) is obtained from Table 6.7 from ASHRAE Handbook – Fundamentals (1993) which gives the value of 0.81. Cooling Load Factor (CLF) is also determined from Table 6.9 which is 0.35 for South East walls and 0.66 for South West walls. Using equation from (4.2):

$$Q = SHGF \times A \times SC \times CLF \tag{4.2}$$

Inserting all the appropriate value into the excel file gives a value of 2263 W.

4.3 Total Room Cooling Load

The total cooling load of the room with respect to the sun radiation is the summation of the conduction and solar radiation values. For this particular room, the total cooling load is 2477 Watts. Shown in Figure 4.1 is the total cooling calculated for the room.

Cooling Load Calculations								
Month	**August**							
Location	**21-02-07**							
Altitude	**4° 23', 100° 58' East to West**							
							SCL = Sensible Cooling Load	
Conduction	Direction	Colour	*U*	Area (m^2)	CLTD (F)	CLTD Corrected	**SCL (W)**	
	N						0.00	
Glass	SW	Transparent	1.67	7.9	14	8	105.54	
	W						0.00	
	SE	Transparent	1.67	8.118	14	8	108.46	
								214.00
Solar	Direction	Shading	SHGF	Area	SC	CLF		
Glass	N						0.00	
	SW	No	346.83	7.9	0.81	0.66	1464.78	
	W						0.00	
	SE	No	346.83	8.118	0.81	0.35	798.21	
								2262.99
							Total	**2476.99**

Figure 4.1 : Excel Spreadsheet of Overall Calculation

4.4 Sun Movement and Radiation

By monitoring the sun movement according to time, the exact sun radiation directed to the building can be calculated. The behaviour of the sunlight when it rises cause the overall building to be directed by sun radiation. Early in the morning at 8:30 am the sun radiation is observed to be covering the whole of Block 21. However, only one side of the building is subjected to the radiation which is on the South West side.

The unique characteristic of Block 21 also made the sun radiation to vary according to each level. The top two level which is the lecturers' office at Level 03 and also lecture rooms at Level 02 experiencing full radiation as the wall is at the most outer part of the building. Level 03 which has some roof at the upper side does not give much protection from the sun radiation at early morning as the location of the sun which is far below made the roof ineffective to block the sunlight. There are 27 glass panes on that side of the building on Level 02 and 26 glass panes on Level 03 that are exposed to the sun radiation.

Figure 4.2 : South East Walls of Block 21

For Level 00 and Level 01 which house a Mechanical Engineering Lab, the layout for the floor is totally different from Level 02. It has outer corridors and projected roofs to protect it from directly exposed to the sun radiation at any time of the day. However, the sun movement from early morning to evening has an effect on glass walls that is subjected to sun radiation.

In the afternoon the sun movement is getting higher and the area that are exposed to the sun radiation has decreased as the upper roof at Level 03 and Level 02 which being the roof for Level 01 and Level 00 starts to block the sunlight from penetrating through the glass walls. The area that is subjected to full sun radiation is only at Level 02 as the outer walls do not have any protection from the sunlight.

At the evening the sun closes to dawn and going towards the East and the sun radiation subjected to the building has also change side. However the trend is still the same with the roof proved to be useful in blocking the sunlight which reduces the sun radiation. Furthermore the existence of canopy above the building has a greater impact in blocking the sunlight. It can be seen from Figure 4.3 below that the canopy has a major role in reducing the sun radiation.

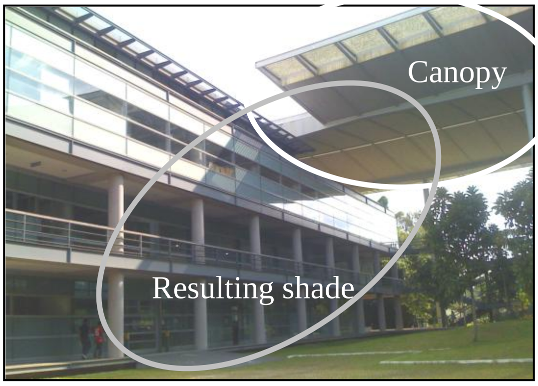

Figure 4.3 : North West Walls of Block 21

Late in the afternoon the canopy started to block more than half of the building thus reducing the total solar radiation subjected to the glass walls. As the sun closes to dawn the canopy has completely covering the building thus preventing the sun radiation.

4.5 Solar Radiation in Block 21

The behaviour of the sun movement which has a great impact on the total solar radiation subjected to the building has been observed and the value is calculated. Each of the glass panes which became the wall material for Block 21 measures 2.38m in length and 0.88m in height. The observation was done on the 4th March 2009 and started at 0830 in the morning until 1730 in the evening. Table 4.1 accumulates the data for the whole day.

Table 4.1 : Solar radiation calculation of Block 21 for whole day

Time	Glass Panel Affected by Solar Radiation		Cooling Load According to Time (W)
	North West Walls	South East Walls	
8.30am	5	78	16498
9.30am	5	50	10932
10.30am	4	45	9740
11.30am	4	35	7752
12.30pm	3	23	5168
1.30pm	4	4	1590
2.30pm	25	4	5765
3.30pm	23	3	5168
4.30pm	17	5	4373
5.30pm	15	3	3578
TOTAL	105	250	**70565**

4.6 Cooling Load due to Solar Heat Gain for Block 21

Inserting all the values to the Microsoft Excel Spreadsheet, the total cooling load for each hour can be calculated. Figure 4.4 shows the variation of the solar radiation for Block 21 throughout the day.

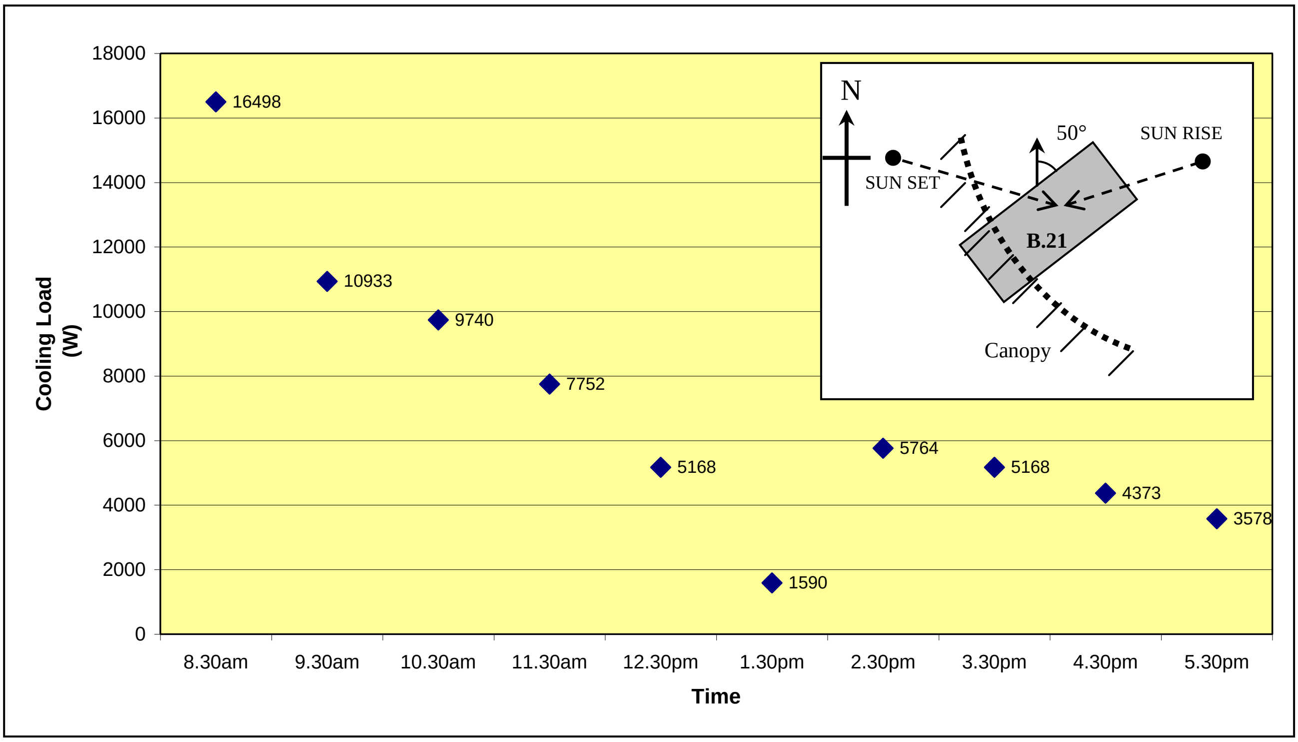

Figure 4.4 : Cooling Load Pattern According to Time on 4th March 2009. The inset pictures shows the diagram of Block 21

The solar radiation is very high in the morning because the sun rises from North East of the building which later radiated the building without any blockage hence the high solar radiation being observed until the afternoon.

4.7 Cooling Load for UTP Academic Building According to Zones

Block 21 which is in Zone 1 shares the same variation with other buildings in the same zone. The trend is similar because the buildings in the area share the same profiles and orientation. Table 4.2 shows the data for each of the building in Zone 1.

4.7.1 Zone 1

Table 4.2 : Cooling Load data for buildings in Zone 1

Time (hours)	Block 20		Block 21		Block 22		Block 23	
	North West	South East	North West	South East	North West	South East	North West	South East
0830	7	65	5	78	6	54	5	53
0930	6	45	5	50	5	50	5	47
1030	6	41	4	45	5	38	4	43
1130	5	39	4	35	4	33	3	39
1230	5	21	3	23	4	26	3	35
1330	4	7	4	4	4	6	3	6
1430	24	7	25	4	34	6	27	6
1530	20	8	23	3	30	6	26	5
1630	19	5	17	5	25	4	26	5
1730	18	5	15	3	21	3	24	5
TOTAL	114	243	105	250	138	226	126	244
Cooling Load (W)	70963		70565		72354		73546	

The total cooling load for each building is different because of the small angle differences of the buildings. However the trend for the solar radiation throughout the day is still the same as Block 21. Figure 4.5 below shows the chart for each building to observe the differences.

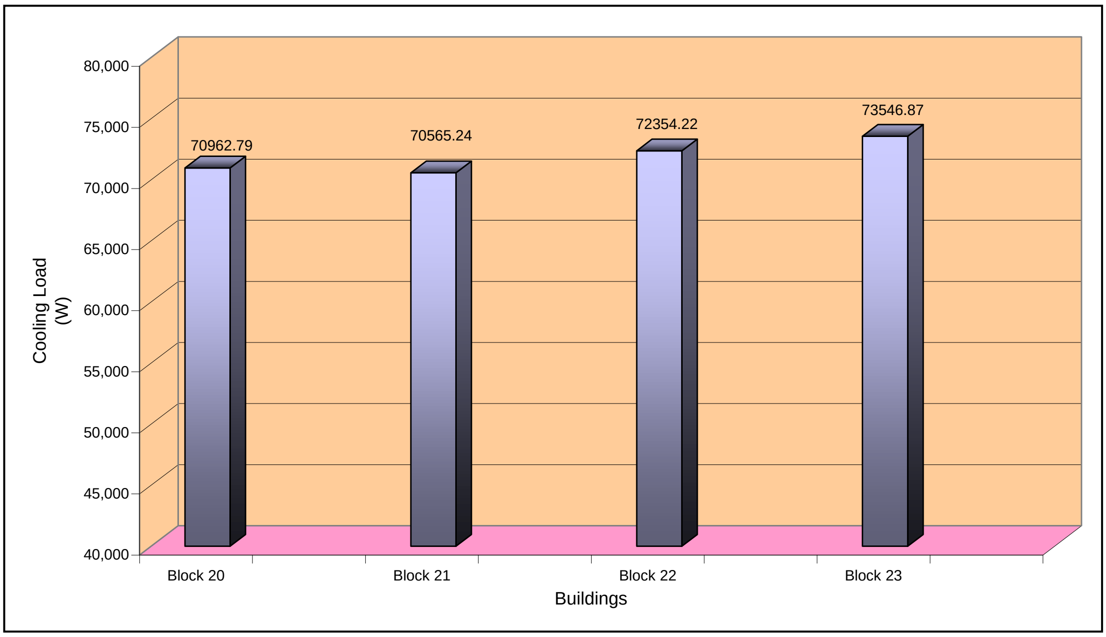

Figure 4.5 : Total cooling load for each buildings in Zone 1

4.7.2 Zone 2

For buildings in Zone 2, the solar radiation is very much different from Zone 1. Because of the canopy that existed in between the sun direction towards the buildings, the solar radiation is smaller at early morning but gradually increases until the afternoon when the buildings' roof takes effect to block the sunlight. Table 4.3 tabulates the data variation.

Table 4.3 : Cooling Load data for buildings in Zone 2

Time (hours)	Block 15		Block 16		Block 17		Block 18		Block 19	
	North East	South West	North East	South West	North East	South West	North East	South West	North East	South West
0830	30	6	35	5	26	6	33	7	34	7
0930	34	5	38	5	31	6	34	6	36	7
1030	41	5	43	4	38	5	40	6	40	6
1130	38	4	39	3	33	5	32	4	34	6
1230	27	4	35	3	26	4	27	4	32	5
1330	7	4	6	3	6	4	5	4	4	5
1430	7	44	6	43	6	40	5	40	4	40
1530	8	38	5	34	6	38	4	39	4	33
1630	5	29	4	29	4	35	4	33	3	24
1730	5	25	4	24	3	29	4	25	3	21
TOTAL	202	164	215	153	179	172	188	168	194	154
Cooling Load (W)	72752		73149		69770		70764		69174	

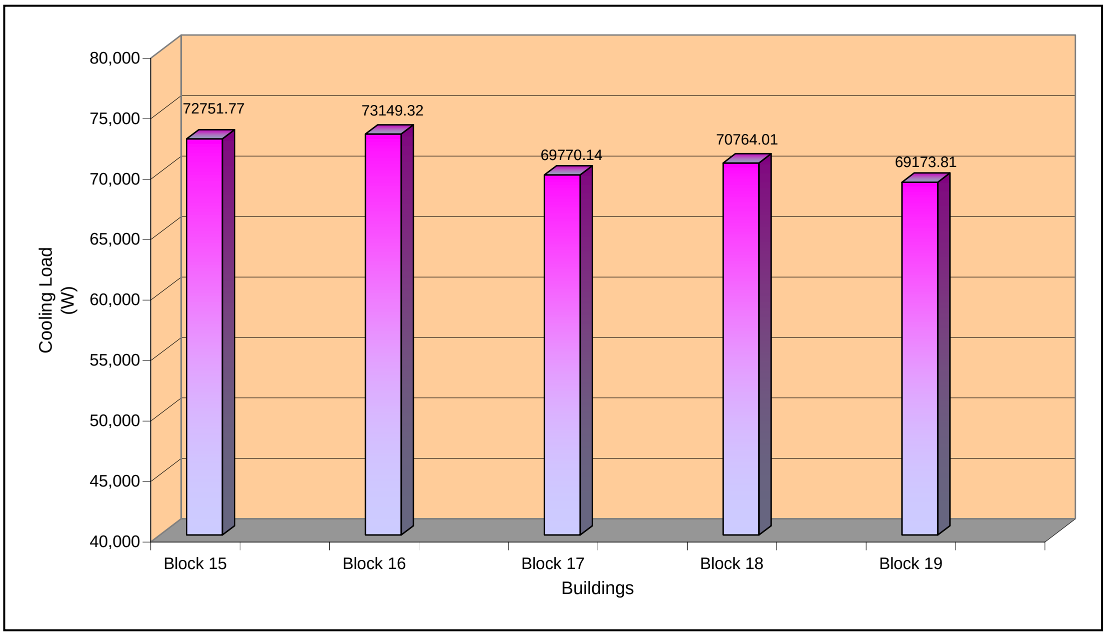

Figure 4.6 : Total cooling load for each buildings in Zone 2

4.7.3 Zone 3

For Zone 3 it is quite the same as Zone 2. Although the location of the canopy is now on the exact opposite, the variation of the solar radiation is similar. This is because only small amount of the glass are being shaded by the canopy at any given time. As the sun proceeds to dawn, the number of glass panes affected decreased following the same trend as buildings in Zone 2.

Table 4.4 : Cooling Load data for buildings in Zone 3

Time (hours)	Block 1		Block 2		Block 3		Block 4		Block 5	
	North East	South West	North East	South West	North East	South West	North East	South West	North East	South West
0830	28	4	29	5	33	6	32	7	34	7
0930	34	4	39	5	39	6	38	6	39	7
1030	40	5	43	4	40	5	32	6	43	6
1130	38	5	40	3	30	5	30	4	40	6
1230	29	5	35	3	24	4	25	4	37	5
1330	5	6	4	3	4	4	5	4	4	5
1430	5	45	6	43	6	41	5	43	4	39
1530	5	39	5	34	6	37	4	41	4	36
1630	4	30	4	29	4	32	4	37	3	28
1730	4	27	4	24	3	30	4	33	3	20
TOTAL	192	170	209	153	189	170	179	185	211	159
Cooling Load (W)	71957		71957		71360		72354		73547	

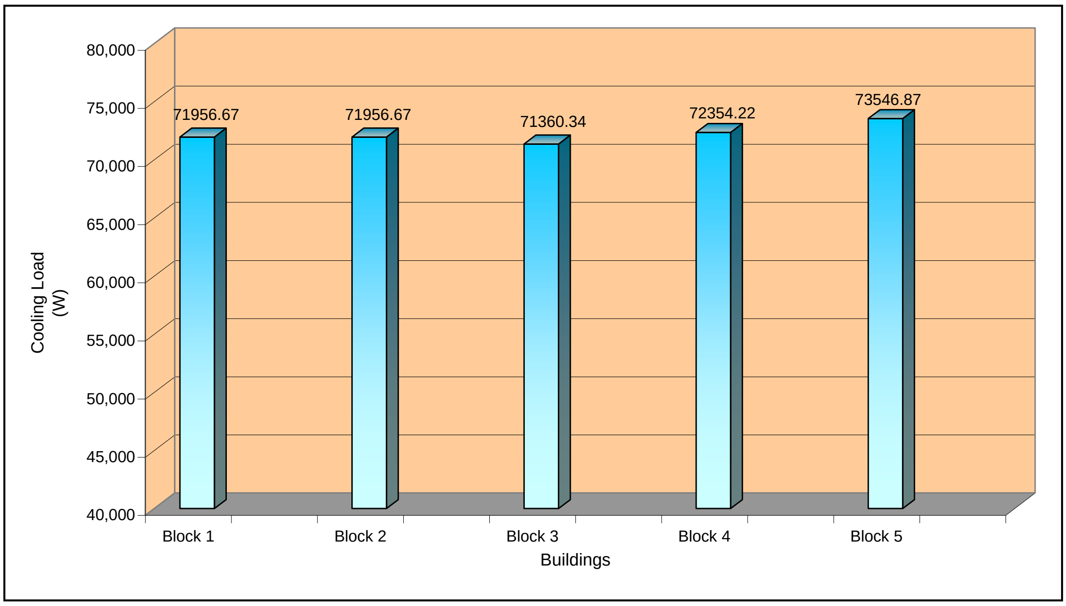

Figure 4.7 : Total cooling load for each buildings in Zone 3

4.7.4 Zone 4

Zone 4 only has two buildings which are Block 13 and Block 14. For this zone, it follows the same characteristic as Zone 1 but at early morning the number of glass panes that is being affected by solar radiation is small due to the canopy that existed which block the direct sunlight. However in the evening the amount of solar radiation increased as there are no elements to block the direct sunlight from the buildings.

Table 4.5 : Cooling Load data for buildings in Zone 4

Time (hours)	Block 13		Block 14	
	North West	South East	North West	South East
0830	4	23	3	21
0930	4	27	3	26
1030	5	33	4	34
1130	5	31	5	33
1230	6	22	6	23
1330	6	7	6	7
1430	35	15	38	8
1530	41	19	42	11
1630	37	13	39	15
1730	20	9	21	8
TOTAL	163	199	167	186
Cooling Load (W)	71957		70168	

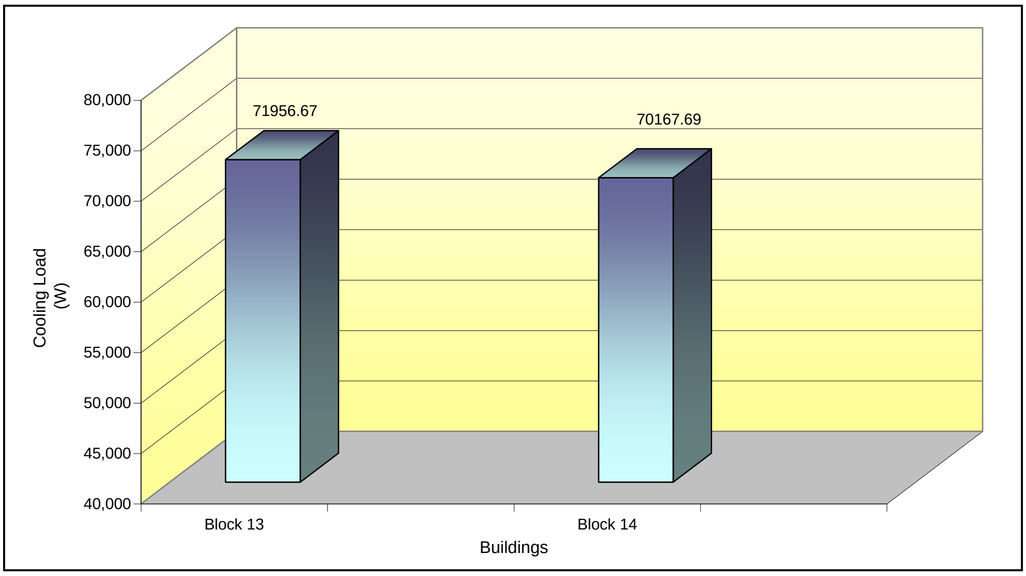

Figure 4.8 : Total cooling load for each buildings in Zone 4

4.7.5 Cooling Load for All the Zones

Comparing all the academic buildings in UTP shows that there is not much difference in terms of total cooling load for the whole day. However the variation of the solar radiation differs according to time and orientation of the buildings. Buildings' canopy plays a major role in this part where the solar radiations from the sunlight are being blocked by the canopy thus reducing the cooling load at a given time.

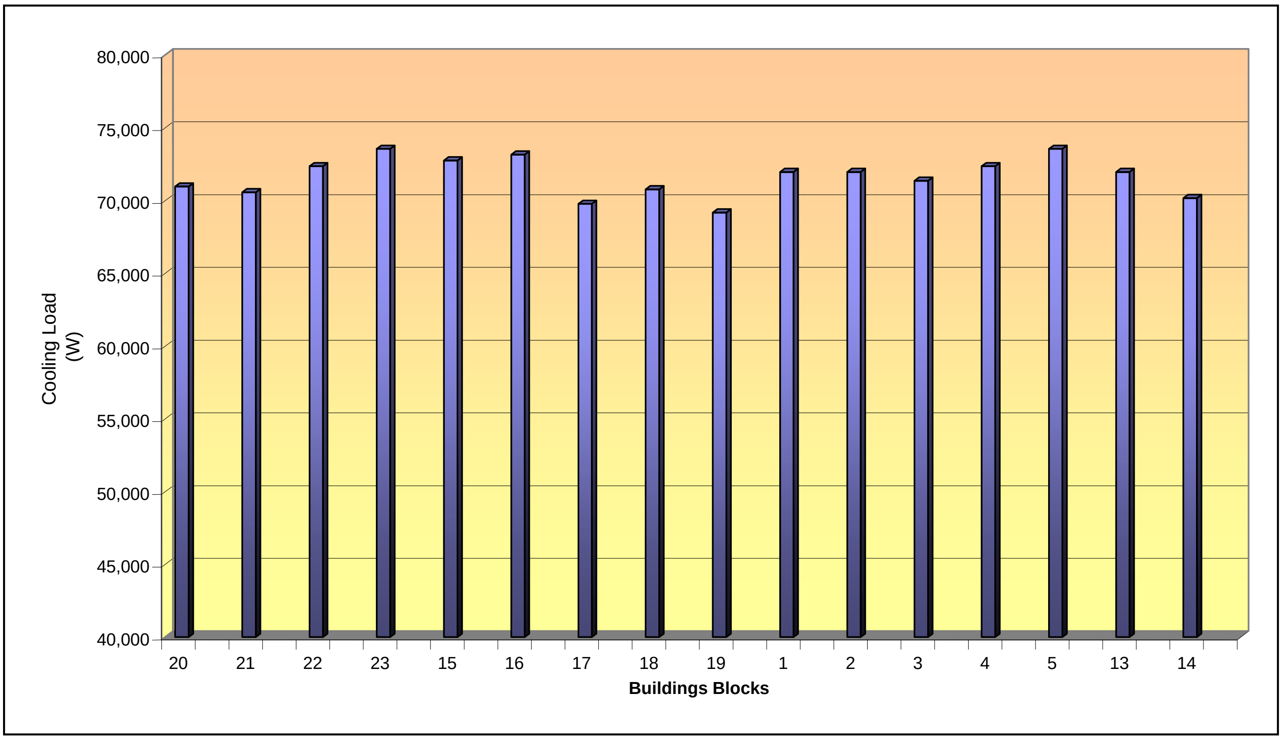

Figure 4.9 : Total cooling load for UTP Academic Buildings

4.8 Solar Radiation Measurement

Apart from calculation, solar measurements were also done using solarimeter. However for this particular measurement it is only done for Block 21. The objectives for the measurement are to validate the data from the calculation and also to see further effects from the buildings orientation as well as the effects from adjacent buildings.

4.8.1 Solar Measurement for Block 21

Wall structure for Block 21 is constructed by glass panes which measures about 2.38 m in length and 0.88 m in height each. The glass panes will then be arranged accordingly before being fixed to a steel beam which holds the glass panes together. Figure 4.10 shows the typical glass wall structure.

Figure 4.10: Typical glass walls structure

The method to evaluate the solar radiation is to equally divide the glass panes to 9 similar points which have equal dimensions. The solar radiation will be measured on each point of the glass pane and a mean value will be calculated. The measurement is taken hourly as the data is needed to be compared with the calculated data. Figure 4.11 shows the schematic diagram of the glass pane with 9 dimension points.

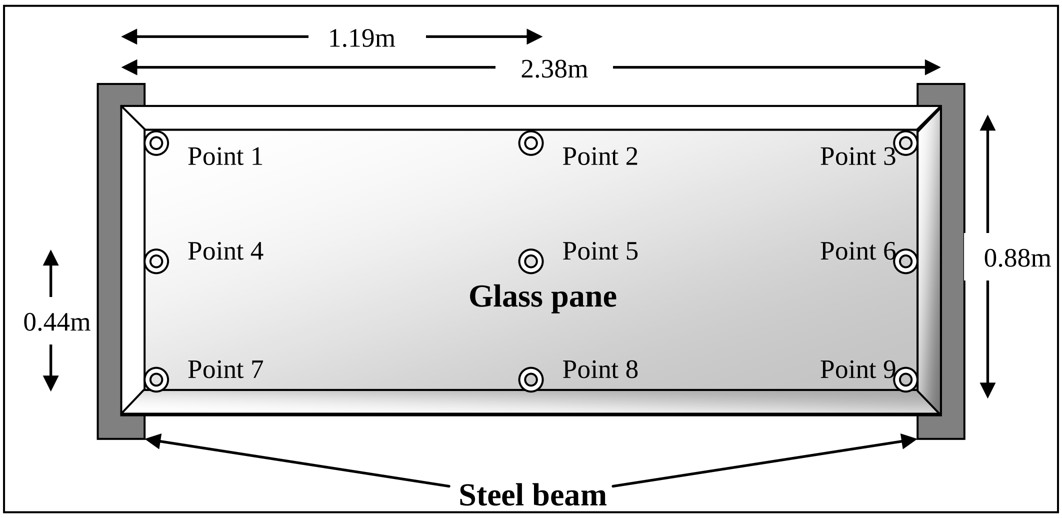

Figure 4.11: Schematic diagram of the glass pane

The measurement started at 8.30 am until 5.30 pm in the evening. Only one side of the wall is being measured and for each glass pane, the mean value is taken for each point. Data gathered were then tabulated to get mean value for each hour. Table 4.6 shows the data accumulated on the 4th March 2009.

Table 4.6: Solar Radiation Measurement of Block 21 on the 4th March 2009

Time (hours)	Point									Mean Value (W/m²)	Total Solar Radiance (W)	Calculated Solar Radiance (W)	Difference (%)
	1	2	3	4	5	6	7	8	9				
0830	178	180	175	176	184	185	190	177	183	181	15014	16498	9.0
0930	165	160	163	156	154	167	171	172	165	164	9002	10933	17.7
1030	171	167	154	170	162	160	168	166	159	164	8206	9740	15.8
1130	177	173	165	171	173	169	172	166	164	170	6630	7752	14.5
1230	154	143	149	152	150	147	157	148	149	150	3897	5168	24.6
1330	144	148	145	151	154	143	147	149	140	147	1174	1590	26.2
1430	152	156	160	161	152	157	166	159	161	158	4588	5764	20.4
1530	171	168	159	174	169	158	170	166	153	165	4299	5168	16.8
1630	178	176	170	169	173	174	179	171	168	173	3808	4373	12.9
1730	156	148	146	151	143	149	150	139	141	147	2646	3578	26.0

It is observed that the value measured is actually less than the value calculated. This is because of several factors. At the time of measurement the movement of the clouds creates a blocking effect which reduces the amount of solar radiance being emitted by the sun at that particular time and this causes the actual value to be lower than calculated value. Besides that the existence of canopy further obstructs the solar radiance at certain time thus contributing to the lesser amount of solar radiance being emitted.

4.8.2 Solar Measurement : Window Blind

The introduction of shading systems has been proven to minimise the effect from the direct sunlight thus reducing solar radiation and improving thermal comfort. However, the amount of illuminance will also be reduced significantly and at some cases the room will need to use lighting equipment to compensate for the loss of illuminance.

The use of shading devices in UTP academic buildings however is not mandatory which means only certain buildings are using these devices. This limits the potential to reduce the amount of energy used at specific time of the day. Hence the effect from the use of these devices are studied and observed thoroughly.

Window blind that is used in academic buildings are Venetian blind which are made from plastic. It measures about 25mm in width and about 1000mm in length. For one glass panes it takes up to two separate windows blind to cover the whole glass area. Figure 4.12 shows the Venetian blind when it is open at maximum angle. The benefit of using this type of blind is that it can be set to be open at different angle according to the need.

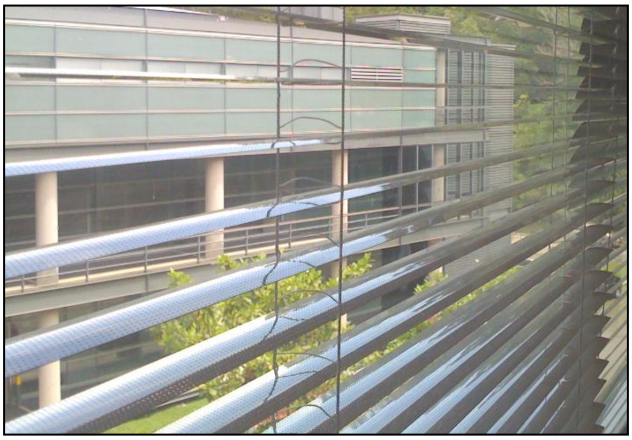

Figure 4.12: Venetian blind opens at maximum angle

When the sun radiation is being emitted for a particular time of the day in such a way that it causes distraction for the occupants, the window blind can be fully closed to block all the radiation thus preventing the heat gain and also improving occupants' visibility for that particular room. Figure 4.13 shows the fully closed window blind.

Figure 4.13 : Venetian blind fully closed

To see the effects from using the Venetian blind, measurement was done using solarimeter to identify how much reduction in solar radiation can be obtained. The experiment being conducted at 10.30 am in the morning to compare with the original data obtained. The method is the same as the measurement for sun radiation of Block 21. But for this particular experiment, a Venetian blind is used as shading device and being placed 15 mm away from the glass panes. Figure 4.14 shows the schematic diagram of the experiment.

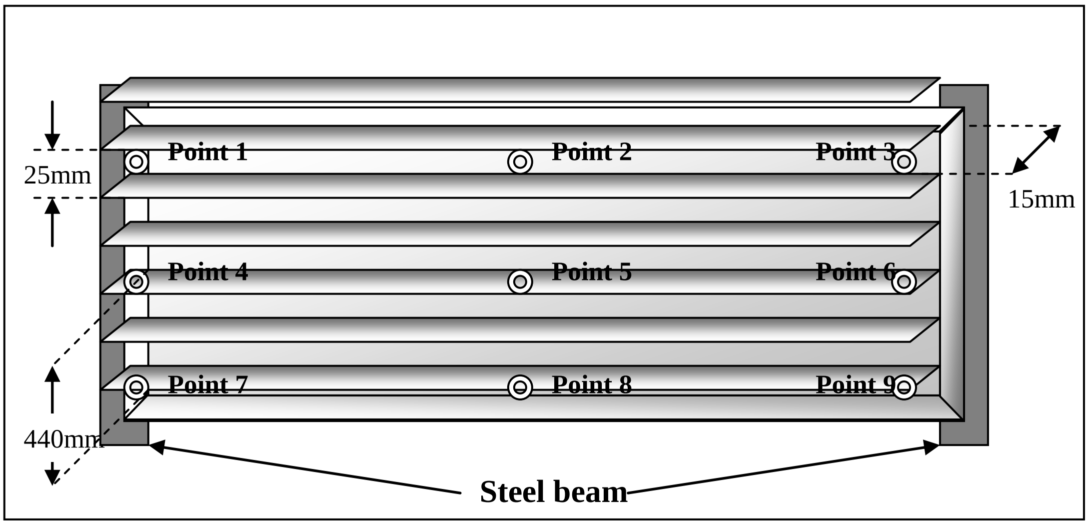

Figure 4.14 : Schematic diagram of the experiment

Solarimeter is placed just above the Venetian blind in order to get optimum result from the use of shading device. Measurement is done for each of the 9 points and the mean value will then be calculated. Table 4.7 shows the variation of the data from the experiment.

Table 4.7 : Reduction in solar radiance from using window blind

Point	Solar radiance for glass panes (W/m²)				Difference in reduction against 90° (W/m²)	Percentage (%)
	Without blind	With blind				
		0°	45°	90°		
1	155	153	116	79	76	49.0
2	157	153	112	81	76	48.4
3	151	150	117	82	69	45.7
4	149	146	109	75	74	49.7
5	153	149	111	73	80	52.3
6	151	148	108	77	74	49.0
7	147	145	104	71	76	51.7
8	147	144	104	73	74	50.3
9	151	144	107	73	78	51.7
Average	151.2	148.0	109.8	76.0	75.2	49.8

From the tabulated results, it is now proven that the window shading devices are really affective in reducing the amount of solar radiation being emitted by the sun. However the amounts of reduction differ for each level and are according to sun movement at any given time. The experiment was conducted when the sun was at direct position to the glass panes hence the maximum amount of reduction obtained.

CONCLUSIONS

The sun radiation for Academic Complex buildings in UTP is very high in the morning but gradually decrease until noon. It is then slightly increase for some time before continue to decrease until dawn. The effect of the canopy and roofs really helps in blocking the sun radiation thus reducing the total cooling load of the building. The building in Zone 1 and Zone 4 share similar depiction of the solar radiance variation for a particular day while buildings in Zone 2 and Zone 3 are quite similar with each other. This is because of the similar building orientation in that said zone hence the same characteristics. From this research the effect of the sun direct contact related to the solar radiation and conduction can be seen clearly. The areas that receive the most direct sunlight have very high radiation and conduction as compared to the area with less surface contact. Furthermore the glass which uses double or triple glazing has better blocking from the radiation than the one without any glazing material. Shading devices are also proven in reducing the amount of solar radiation hence minimizing the energy requirement for the building. The objectives for this research are achieved and suitable method to minimize the solar radiation has also been identified. To ensure low energy use and good thermal comfort, vigilant design is needed especially for highly glazed buildings. Detailed thermal simulations are the needed to ensure on the best design for glazed buildings in which the facade is easily affected by the climatic conditions. Besides, proper combination of control set points, glazing and solar shading are crucial for the energy performance. A thorough sensitivity analysis of the heat transfer through the glazed UTP academic buildings is the main aim of the study.

REFERENCES

Alhomoud, M.S., (1997) Optimum Thermal Design of Office Buildings, International Journal of Energy Research 21 (10) 941–957.

Aleo, F., Sciuto, S., Viadana, R., (1994) Solar transmission measurements in outdoor conditions of non-homogeneous shading devices.

Becker, R., Paciuk, M., (2002) Inter-related Effects of Cooling Strategies and Building Features on Energy Performance of Office Buildings.

Carlson, L. E. and Sullivan, J. F. (1999) Hands-on Engineering: Learning by Doing in the Integrated Teaching and Learning Program.

Dascalaki, E., Santamouris, M., (2002) On the Potential of Retrofitting Scenarios for Offices, Building and Environment 37 (6) 557–567.

Eicker, U., Fux, V., Bauer, U., Mei, L., Infield, D., (2008) Façades and Summer Performance of Buildings, Energy and Buildings 40, 600-611.

Kuhn, E., (2006), Solar control: a general evaluation method for facades with venetian blinds or other solar control systems.

Leung, T.M., Chau, C.K., Lee, W.L., Yik, F.W.H., (2005) Willingness to Pay for Improved Environmental Performance of the Building Envelope of Office Buildings in Hong Kong.

McQuiston, Faye C., Parker, Jerald D., Spitler, Jeffrey D., (2004) Heating, Ventilating, and Air Conditioning: Analysis and Design, 120-163.

Pita, E. G., (2001) Air Conditioning Principles and Systems, 121-163

Poirazis, H., (2005) Single Skin Glazed Office Buildings, Energy Use and Indoor Climate Simulations.

Rea, M., (1984) Window blind occlusion: a pilot study, Building and Environment.

Zimmerman, M., Anderson, J., (1998) Low Energy Cooling-Case Studies Buildings, EMPA ZEN, Dübendorf, Switzerland.