ANALYSIS OF HEAT GAIN AGAINST COOLING CAPACITY AT OCCUPIED BUILDING

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

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Date	:

STUDENT’S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature : …………………………
Name : Koh Kelvin
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Date : …………………………

Dedicated to my beloved:

Father,

Mother,

Elder sister,

Younger sister

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I would like to express my sincere gratitude to my parents for their unconditional love and care. They consistently encourage me to attempt for higher goal in life. I also would like to thanks all my colleagues for their constructive comments and assistances during completing this thesis.

ABSTRACT

This project is carried out to indentify whether the existing cooling capacity is suffice for an occupied building. The first objective of this project is to determine the heat gain of Block W when it's fully occupied. The second objective of this project is to compare the calculated heat gain against the existing cooling capacity. In this project, Block W, UMP was chosen as the case study. The floor plan of Block W is first studied to review the building specifications. The building specification is used in the calculation of heat gain, and therefore to identify the cooling load required for Block W. When Block W is fully occupied, the number of occupant will be around 1500 people. There are two types of air-conditioning system used in Block W which are split unit and air handling unit and the total existing cooling load is observed to be 852.74 kW. The peak heat gain is calculated as 1172.43 kW using Cooling Load Factor/ Cooling Load Temperature Difference (CLF/CLTD) method at 3pm. Therefore, the existing cooling load is observed to be undersized in design. However, the peak heat gain will only happen occasionally throughout the year. In order to overcome the undersized design cooling capacity problem, the cooling capacity should increase 27.3%.

ABSTRAK

Projek ini dijalankan untuk menentukan kesesuaian kekuatan sistem penyejukan yang sedia ada dalam bangunan. Objektif pertama untuk projek ini adalah menentukan jumlah haba gandaan semasa bangunan dipenuhi oleh pengguna. Objektif kedua bagi projek ini adalah membanding antara jumlah haba gandaan dengan kekuatan sistem penyejukan yang sedia ada. Dalam projek ini, Blok W, UMP dipilih sebagai kes pengajian. Pengajian atas pelan lantai Blok W dibuat untuk mendapatkan butiran bangunan. Butiran bangunan akan dipakai dalam pengiraan jumlah haba gandaan and jumlah beban penyejukan yang diperlukan di Blok W. Blok W dibina untuk menanggung lebih kurang 1500 orang. Sistem penyaman udara yang dipakai di Blok W adalah *split unit* dan *package unit* dan jumlah kekuatan sistem penyejukan adalah 852.74 kW. Haba gandaan puncak berlaku pada jam pukul 3 petang dan nilainya ialah 1172.43 kW dengan menggunakan kaedah *Cooling Load Factor/ Cooling Load Temperature Difference (CLF/CLTD)*. Oleh demikian, kekuatan sistem penyejukan yang sedia ada didapati kekurangan kekuatan. Walaubagaimanapun, situasi sebegini cuma akan berlaku sekali sekala dalam setahun. Untuk mengatasi masalah tersebut, kekuatan sistem penyejukan perlu dinaikan sebanyak 27.3%.

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LIST OF SYMBOLS

	Humidity ratio
	Mass of dry air
	Mass of water vapor where are is saturated
	Mass of water vapor
°F	Degree Fahrenheit
℃	Degree Celsius
′	Outdoor humidity ratio
′	Inside humidity ratio
	Sensible heat gain
	Latent heat gain

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BF	Ballast factor
CFM	Cubic feet per minute
CLF	Cooling load factor
CLTD	Cooling load temperature difference
CLTDc	Corrected cooling load temperature difference
HVAC	Heating, Ventilating, and Air-conditioning
LM	Correction for latitude and month
RH	Relative humidity
SC	Shading factor
SHGF	Solar heat gain factor
WBK	Lecture room in Block W
WDK	Lecture hall in Block W
WDKU	Main lecture hall in Block W

CHAPTER 1

INTRODUCTION

The title of this project is Analysis of Heat Gain against Cooling Capacity at Occupied Building. The contents of this proposal are organized into five sections namely: (1) introduction, (2) literature review, (3) methodology, (4) results and discussions, and (5) conclusion and recommendations.

1.1 Background of the study

Air conditioning is the air cooling process in a building in order to provide a comfortable temperature. An air-conditioning system is the equipment that produces a refrigeration effect and distributes cool air or water to occupied spaces. Air-conditioning system can be classified by medium, physical arrangement, and cooling capacity (Swenson, 2004).

The project is carried out to identify whether the existing cooling capacity in the case study is suffice. There are generally few kinds of possible situation where the cooling capacity is suitable for the occupied building, or the existing cooling capacity is undersized or oversized.

1.2 Problem Statement

In an occupied building, there are many power consumers for example lights, computers, LCDs, and air-conditioning system. Among the power consumers, air-conditioning system is one of the major power consumers in an occupied building. Excessive power consumption for air-conditioning system may lead to high electricity cost. Whereas, low cooling capacity will makes occupants thermally uncomfortable.

1.3 Project Objectives

The aim of this project is to indentify whether the existing cooling capacity is suffice for an occupied building. As such, the proposed project seeks to fulfill the following objectives:

i) To determine the cooling load required for a case study. (Block W is chosen as the case study in the project),

ii) To compare the calculated heat gain against the existing cooling capacity in the case study.

1.4 Scopes of Project

Based on the aim and objectives of this project, the scopes of the project are:

i) Determine the building material to obtain the overall heat transfer coefficient, U ($W/m^2.°C$)

ii) Calculate the overall building heat gain, Q (kW)

iii) Identify the cooling capacity (kW) used in Block W

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to human thermal comfort, humidity ratio and relative humidity, psychrometric chart, and thermal comfort zone. In this literature review, we will have further study about the building heat gain and the cooling load of an occupied building. The main source of reference for this literature review is from Ogulata (2007) and Pita (1998).

2.2 HISTORY OF THERMAL COMFORT

Human beings come into this world with little protection against the harsh environment conditions unlike animals such as a fox or a bear that are born with built-in furs. For that reason, we can claim that the search for thermal comfort dates back to the beginning of human history. During early stage, human being lived in caves that provided shelter as well as protection from extreme thermal conditions. Means that it is likely the first form of heating system used in human history was open fire, followed by fire in dwellings through the use of a chimney to vent out the combustion gases. The concept of central heating dates back to the times of the Romans, who heated homes by making use the double-floor construction techniques and passing the fire's fumes through the opening between the two floor layers. Transparent windows which were made of mica or glass were also used by the Romans to keep the wind and rain out while letting the light in. The primary energy sources for heating were wood and coal, and oil and candles were used for lighting. The ruins of south-facing houses indicate that the value of solar heating was recognized early in the history (Cengel, 2006).

2.3 HUMAN THERMAL COMFORT

Human beings spend most of their lifetime in buildings for various activities. Uncomfortable indoor-air conditions in terms of thermal comfort and indoor air quality will directly affect human performance and also human health. The essential element in an occupied building is heating, ventilating, and air-conditioning (HVAC) system, which will provide a comfortable indoor climate and less polluted air for the occupants. However, these requirements to HVAC system reflect a large amount of energy consumption in building. Without proper process of finding out the indoor-air condition, it may not feasible that the HVAC system efficiently consumes energy for it to achieve such requirements at the same time (Atthajariyakul and Leephakpreeda, 2004).

Kavgic et al. (2008) also stated that indoor air quality and thermal comfort are both important factors during the design of high quality building. They also mentioned that although innovations in air-conditioning and other forms of cooling or ventilation can be viewed as technological solutions to the problem of maintaining and producing energy efficient environment conditions that will be beneficial for human comfort, performance, and health, there is often a conflict between reducing energy consumption and creating comfortable and healthy buildings.

Prek (2005) described human acts as a heat engine and thermodynamically could be considered as an open system. The energy and mass for the human body's vital processes are taken from external sources which are food and liquids and then exchanged with the environment. These exchanges are very important since they are defined as thermal sensation, i.e. thermal comfort. Ogulata (2007) also mentioned that human body converts the chemical energy of its food into work and heat, producing through its processes of metabolism a great deal of heat.

Generally, human body will keeps its body temperature constant at $37 \pm 0.5°C$ under different climatic conditions (Ogulata, 2007; Cengel, 2006). According to Cengel (2006), at a state of thermal comfort, $33°C$ will be the observed average skin temperature of the human body. There will be no discomfort experienced as the skin temperature is varying by$\pm 1.5°C$.

2.4 HUMIDITY RATIO AND RELATIVE HUMIDITY

One of the several measures of air humidity is the humidity ratio. It can be defined as the mass of the water vapor in a specific volume of humid air divided by the mass of the dry air in the same volume. The humidity ratio can be expressed as (Watson and Chapman, 2001):

$$\omega = \frac{m_v}{m_a} \tag{2.1}$$

The relative humidity is the ratio of the mass of water vapor actually present to the mass that would be present if the air were saturated at the same temperature. The relationship can be expressed as (Iynkaran and Tandy, 2004):

$$RH = \frac{m_v}{m_g} \tag{2.2}$$

2.5 PSYCHROMETRIC CHART AND COMFORT ZONE

According to Iynkaran and Tandy (2004), there are several types of psychrometric charts have been devised to show the graphical relationship between the various properties of moist air. One type of the chart is dry and wet bulb temperature lines. When the dry bulb and wet bulb temperature have been measured for an occupied space, the state point on the psychrometric chart can be found by the intersection of the dry and wet bulb temperature lines as shown in Figure 2.1. From the state point established, several other properties such as humidity ratio and relative humidity can be easily determined.

As mentioned by Grondzik (2007), the design space temperature and humidity for both heating and cooling seasons should be based on Standard 55 for most applications. Figure 2.2 shows the acceptable ranges of operative temperature and RH for human comfort from Standard 55.

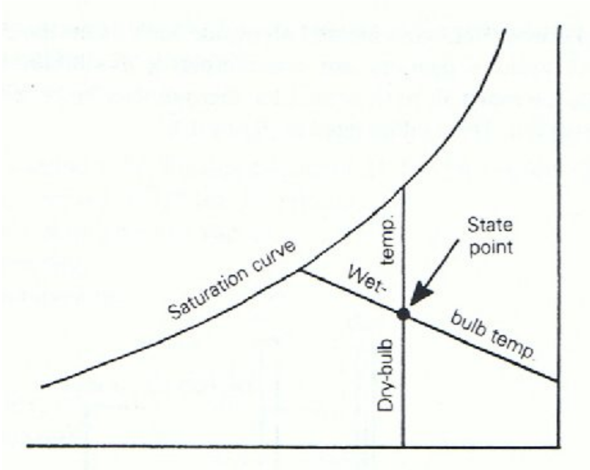

Figure 2.1: Dry and wet bulb temperature lines

Source: Iynkaran and Tandy 2004

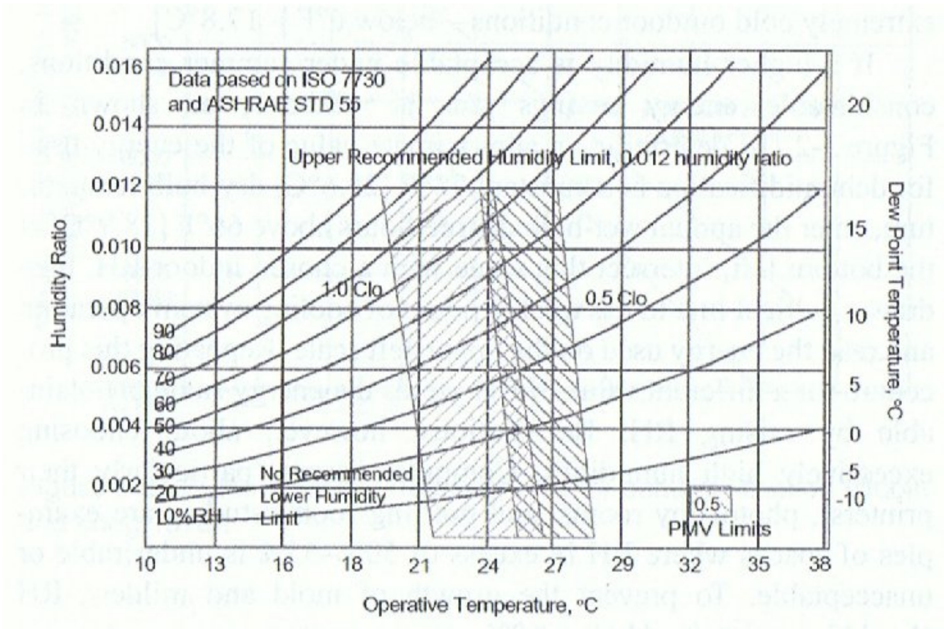

Figure 2.2: Acceptable ranges of operative temperature and RH for human comfort from Standard 55

Source: Grondzik 2007

2.6 BUILDING HEAT GAINS

The heat gain components which contribute to the building cooling load consist of the following (Pita, 1998):

i. Conduction through exterior wall, roof, and glass
ii. Conduction through interior partitions, ceilings, and floors
iii. Solar radiation through glass
iv. Lighting
v. People
vi. Equipment
vii. Heat from infiltration of outside air through openings

Figure 2.3 shows the components which contribute heat to a room.

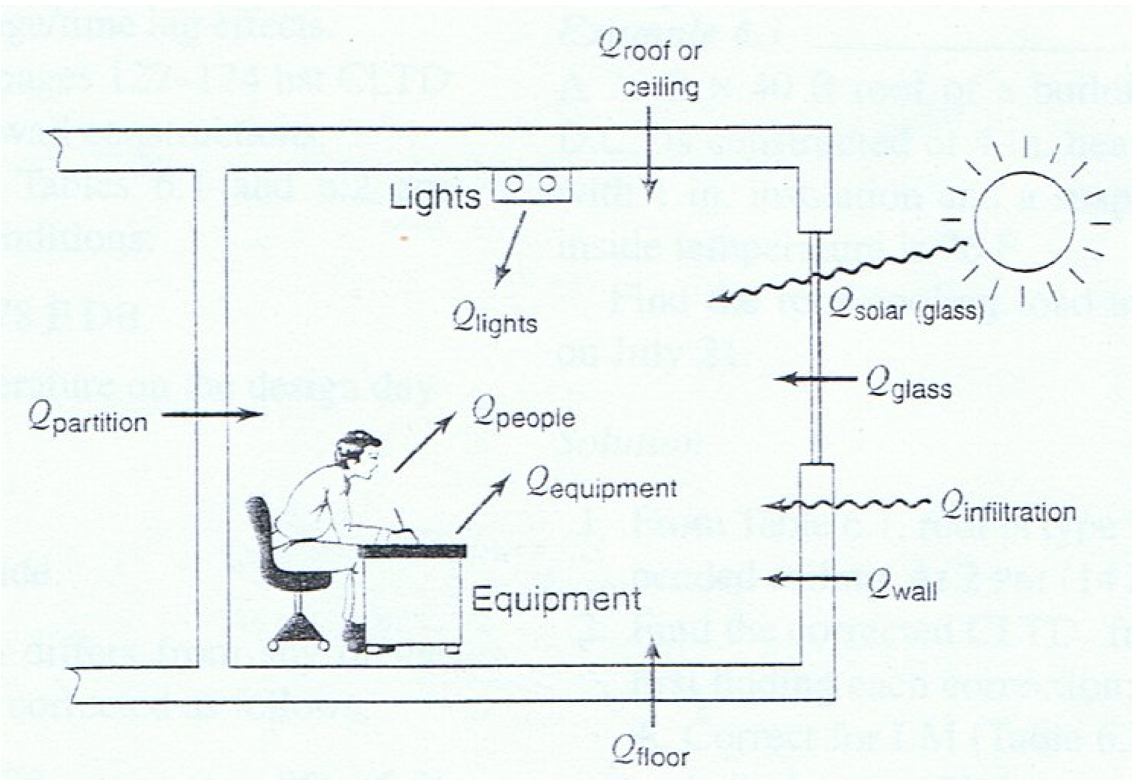

Figure 2.3: Room heat gain components

Source: Pita 1998

Heat gain can be arranged into two groups as those from external sources outside the building and those internally generated. From the previous description, items i. through iii. are external heat gains, whereas items iv. through vi. are internal heat gain. The infiltration can be considered as a separate class.

Heat gain can be also arranged into sensible and latent heat gains. Sensible heat gain results in increasing the air temperature, whereas latent heat gains are due to addition of water vapor, thus increasing humidity. Heat gains of conduction through exterior wall, roof, and glass, conduction through interior partitions, ceilings, and floors, solar radiation through glass, and lighting are solely sensible gains. Heat gains from people and infiltration of outside air through openings are part sensible and part latent. Equipment heat gain can fall in either category or both. The separation of sensible and latent heat gain is important due to the selection of cooling equipment depends on their relative values (Pita, 1998).

2.7 COOLING LOAD

According to Pita (1998), the air inside a building receives heat from a number of sources during the cooling season. Heat must be removed in order to maintain the temperature and humidity of the air at a comfortable level. The amount of heat that must be removed to achieve comfortable level is called the cooling load. The cooling load must be determine due to it is the basis for selection of proper size of air-conditioning equipment and distribution system. Cooling load calculation also used to analyze energy use and conservation.

Pita (1998) also mentioned that, with cooling, the situation is more complex. The amount of heat that must be removed or the cooling load is not always equal to the amount of heat received at a given time. This difference is a result of the heat storage and time lag effects. Only a portion of the total amount of heat entering the building heats the room air immediately. The rest of it will heat other parts such as roof, wall, floors, and furnishings. This is called the heat storage effect. Only at a later time does the stored heat portion contribute to heating the room air. This is called the time lag effect. Figure 2.4 shows the heat flow diagram of building heat gain, heat storage, and cooling load. The room cooling load can be defined as the rate at which heat must be removed from the room air to maintain it at the design temperature and humidity.

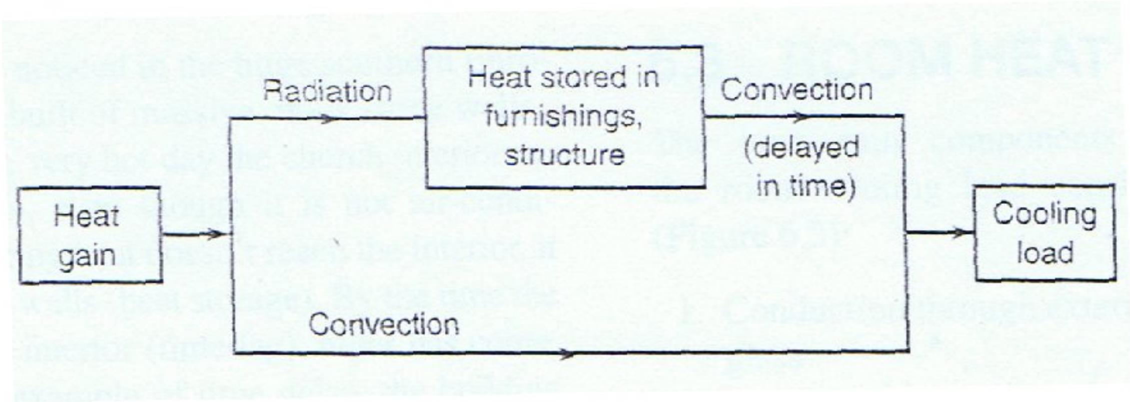

Figure 2.4: Time lag effect

Source: Pita 1998

The thermal storage effect and resulting time lag effect cause the cooling load to often be different in value from the entering heat (called the instantaneous heat gain). Figure 2.5 shows the example of difference between instantaneous heat gain and cooling load as a result of heat storage effect.

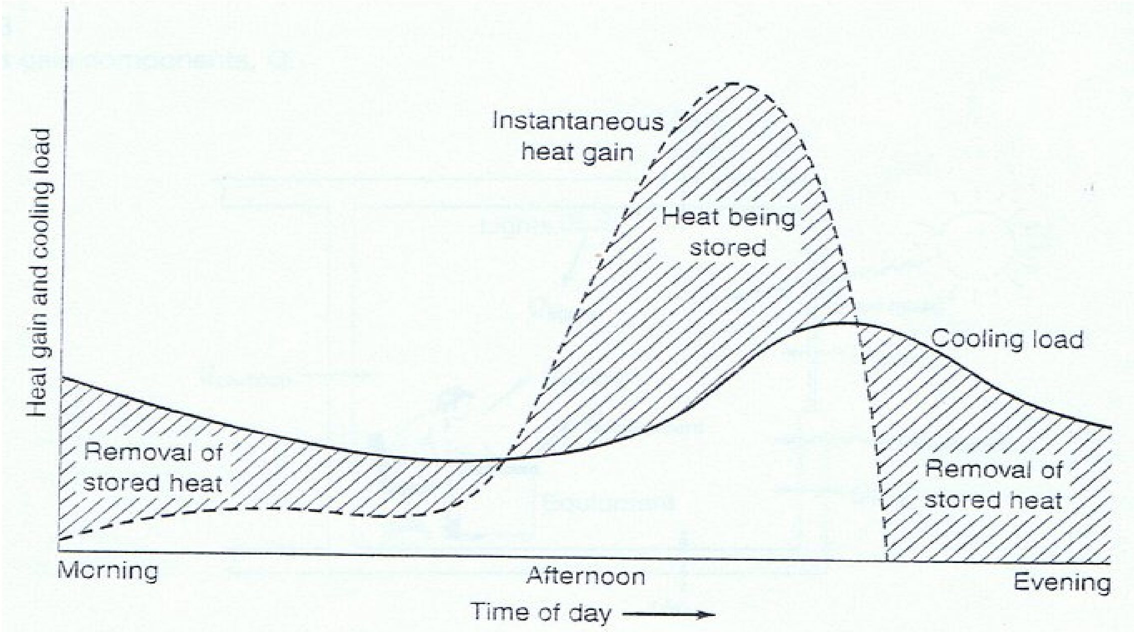

Figure 2.5: Heat gain and cooling load against time of day

Source: Pita 1998

From Figure 2.5, during the time of day at which the instantaneous heat gain is the highest (the afternoon), the cooling load is less than the instantaneous heat gain. This happen due to some of this heat is stored in the building mass and is not heating the room air. Later in the day, the stored heat plus some of the new entering heat is release to the room air, and therefore the cooling load becomes greater than the instantaneous heat gain (Pita, 1998).

2.8 CLF/CLTD METHOD

Cooling Load Factor/Cooling Load Temperature Difference (CLF/CLTD) Method is a method to calculate building heat gain which is developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). The CLF/CLTD method can be carried out manually or using a computer (Pita, 1998).

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) is an international technical society for all individuals and organizations interested in heating, ventilation, air-conditioning, and refrigeration. The Society, organized into Regions, Chapters, and Student Branches, allows exchange of heating, ventilation, air-conditioning, and refrigeration knowledge and experiences for the benefit of the field's practitioners and the public. ASHRAE provides many opportunities to participate in the development of new knowledge via, for example, research and its many Technical Committees. These committees meet typically twice per year at the ASHRAE Annual and Winter Meetings. A popular product show, the AHR Expo, is held in conjunction with each Winter Meeting. The Society has approximately 50,000 members and has headquarters at Atlanta, Georgia, USA (Wikipedia, n.d.).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The purpose of this chapter is to explain the flow and sequence of the project. Figure 3.1 shows the flow chart of the project. The flow chart shown facilitates readers to understand the flow of the project. From the flow chart, there are eight processes to accomplish the project. All the processes will be discussed in the following section.

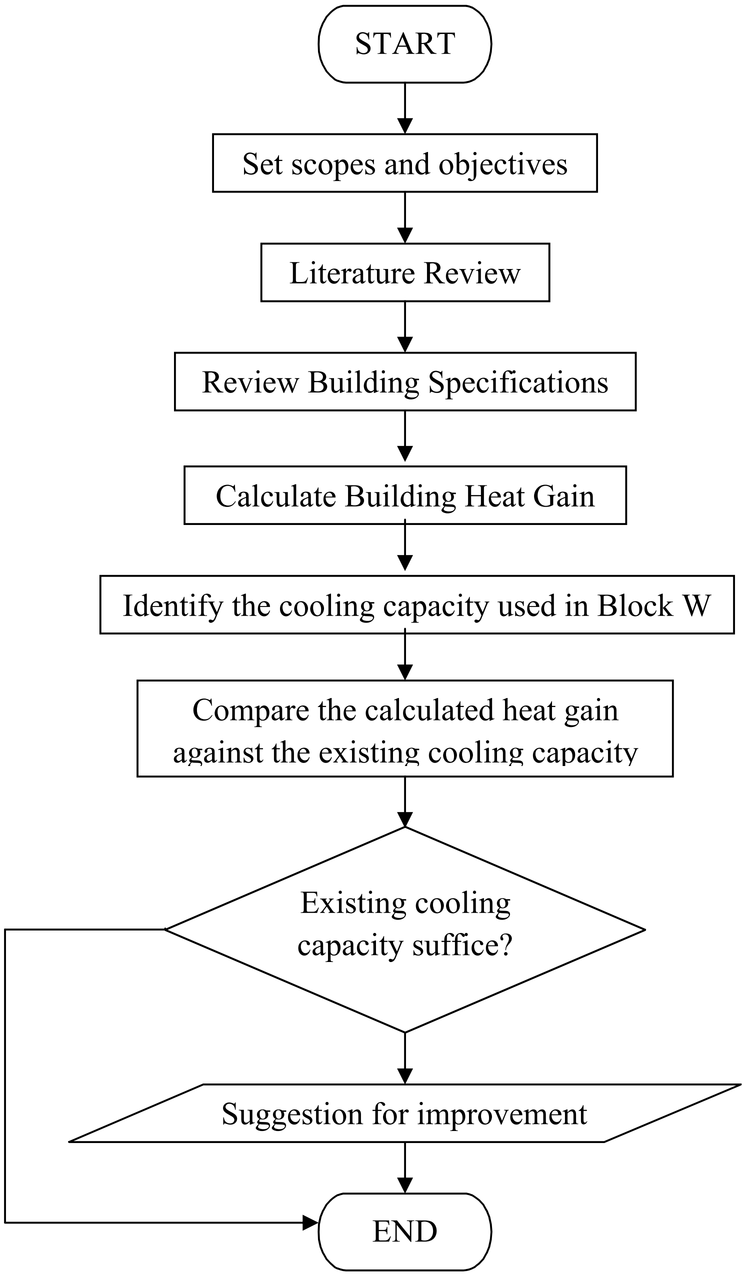

Figure 3.1: Project flow chart

3.2 SET SCOPES AND OBJECTIVES

Discussion and meetings have to be carried out with supervisor in order to set the appropriate scopes and objectives for the project. This is the important process where the direction of the project will be determined by the scopes and objectives.

3.3 LITERATURE REVIEW

In literature review, relevant materials such as journal, books, and articles are needed as the references for the project. The key words for the project included heat gain, cooling load required, and cooling capacity. These should be fully understood in order to run the project smoothly.

3.4 REVIEW BUILDING SPECIFICATIONS

Reviewing the building specification of Block W can be carried out by obtaining the floor plan and other relevant resources from JPPH, UMP. Building specification including structure material, exposure area, and exposure direction will be used in the calculation of building heat gain. The purpose of review building specification is to obtain the information needed such as the overall heat transfer coefficient, U in the building heat gain calculation.

3.5 CALCULATE BUILDING HEAT GAIN

Calculating the building heat gain will be divided mainly into two parts which are external heat gain and internal heat gain. External heat gain will vary according to time and internal heat gain will vary according to the number of occupants, equipment, and lighting used. The purpose of heat gain calculation is to determine the total cooling load required to remove heat in Block W to provide thermal comfort.

3.6 IDENTIFY THE COOLING CAPACITY USED IN BLOCK W

This process is to determine the type of air-conditioning system used in Block W and also the cooling capacity. The value of the cooling capacity will be used in the next process to compare with the calculated heat gain in Block W.

3.7 COMPARISON OF HEAT GAIN AGAINST COOLING CAPACITY

This process is the main objective of this project. Comparison will be carried out among the calculated heat gain and the cooling capacity in Block W. This process will determine whether the cooling capacity in Block W is undersized, oversized, or suitable for Block W.

3.8 DECISION ON WHETHER THE EXISTING COOLING CAPACITY SUFFICES

This process will determine whether the existing cooling capacity in Block W is suffice or not. The decision will be based on the comparison done in the previous process. If the cooling capacity is much higher than calculated heat gain, then the air-conditioning system in Block W can be said is oversized. If the cooling capacity is much lesser than the calculated heat gain, then the air-conditioning system in Block W is undersized in design.

3.9 SUGGESTION FOR IMPROVEMENT

Suggestion for improvement is always important for a project. If the air-conditioning system is oversized in design, the cooling capacity should reduce. If the air-conditioning system is undersized in design, then the cooling capacity should increase by adding more split unit and air handling unit depends on the situation.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter shows the calculations of total heat gain of Block W, UMP. The specification of the building will be incorporated together in order to complete the calculation. The observation of the existing cooling capacity in Block W will also shown in this chapter in order to do comparison among the calculated heat gain against the existing cooling capacity.

4.2 HEAT GAIN CALCULATION

Calculation of heat gain is to determine the total heat gain of Block W during day time. Therefore compare the calculated heat gain with the existing cooling capacity. The calculation method used in this project is called the Cooling Load Factor/Cooling Load Temperature Difference (CLF/CLTD) Method, which is developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). The heat gain calculation can be divided into four parts which are heat gain caused by solar radiation through glass, heat gain caused by conduction through exterior structure, heat gain caused by conduction through interior structure, and heat gain caused by internal heat sources (Pita, 1998).

4.2.1 Heat Gain Caused by Solar Radiation through Glass

Solar radiation process is the process that receives heat transfer directly from the sun to the occupied building through glasses. For the calculation of solar radiation heat gain, the month that has the highest solar heat gain can be determined by identifying the direction of the largest glass area is facing. Figure 4.1 shows the floor plan drawing of Block W.

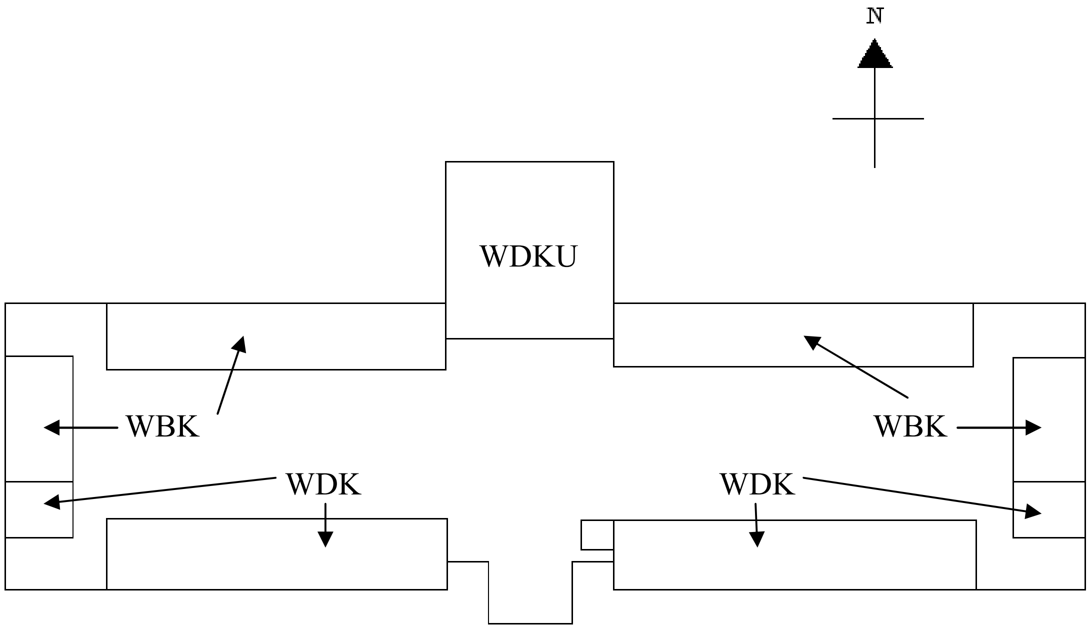

Figure 4.1: Floor plan drawing of Block W

Table 4.1 shows the total area of glass which facing the North, South, East, and West direction.

Table 4.1: Total area of glass facing various directions

Direction	Glass Area, A (m^2)
North	39.60
South	91.44
East	21.60
West	23.76

From table 4.1, South direction has the largest glass area. Referring to Appendix A1, the highest value of maximum solar heat gain factor, SHGF is in December. However, Block W would not fully occupied during December since that is the month of holiday, therefore the second highest SHGF which is in January is chosen. Thus, the day of the case study for this project is on 21st January (Pita, 1998).

The parameters involve in the calculation of heat gain caused by solar radiation through glass are maximum solar heat gain factor, SHGF, shading coefficient, SC, cooling load factor, CLF, and area, A. The CLF value can be obtained from Appendix A2 and Appendix A3. The formula for calculation of heat gain caused by solar radiation is shown in equation (4.1).

$$= \quad \times \quad \times \quad \times \qquad (4.1)$$

Where

Q= solar radiation heat gain, W

SHGF = maximum solar heat gain factor, W/m²

A= area of glass, m²

SC= shading coefficient

CLF = cooling load factor for glass

4.2.2 Heat Gain Caused by Conduction through Exterior Structure

Heat gain caused by conduction through exterior structure is the cooling loads caused by conduction heat gains through the exterior roof, walls, glass, and doors. The parameters involve in the calculation of heat gain caused by conduction through exterior structure are the overall heat transfer coefficient, U, the area, A, and the corrected cooling load temperature difference, CLTDc (Pita, 1998). The formula for the calculation is shown in equation (4.2).

$$= \times \times \tag{4.2}$$

Where

Q = cooling load for roof, wall, glass, or door, W

U = overall heat transfer coefficient for roof, wall, glass, or door, $W/m^2.°C$

A = area of roof, wall, glass, or door, m^2

CLTDc = corrected cooling load temperature difference, °C

4.2.2.1 Overall Heat Transfer Coefficient, U, W/m².°C

The value of the overall heat transfer coefficient, U for certain types of structures can be found using equation (4.3) by first determine the resistance, R for every layer of the structure (Pita, 1998).

$$= 1/\sum \tag{4.3}$$

Where

U = overall heat transfer coefficient, $W/m^2.°C$

$\sum R$ = summation of all layer resistance, $m^2.°C/W$

The calculations to determine the overall heat transfer coefficient, U for roof, wall, glass, and door are shown below.

i. Roof structure

The roof is made from sheet metal roof with ceiling. Figure 4.2 shows the element layers of a roof structure.

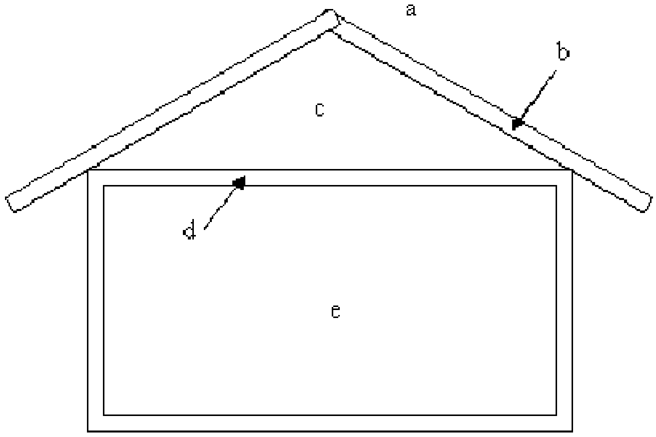

Figure 4.2: Roof structure element layers

The elements layers are as follows:

a) Outdoor air film,
b) Metal roof,
c) Roof space (vent, low emit),
d) Gypsum board,
e) Indoor air

Table 4.2 shows the calculation of total resistance of roof and the value can be obtained from Appendix A4.

Table 4.2: Total resistance, R of roof

Element Layer	R (m^2.°C/W)
Outdoor air film	0.04
Metal roof	0.11
Roof space (vent, low emit)	1.36
Gypsum board	0.08
Indoor air	0.11
Total	1.70

By using equation (4.3),

$U = 1/1.70$

$= 0.588$ W/m^2.°C

Therefore, the overall heat transfer coefficient, U for roof is 0.588 W/m^2.°C.

ii. Wall structure

The wall structure of Block W consists of numbers of layer. The element layers are shown as follows:

a) Outside air film
b) 2 layer of 19mm cement plaster
c) 115mm brick wall
d) Indoor air

Table 4.3 shows the total resistance and the mass of the wall structure.

Table 4.3: Total resistance, R and mass of wall

Element Layer	R (m^2.°C/W)	Mass (kg/m^2)
Outdoor air film	0.040	-
19mm cement plaster	0.026	35.5
115mm brick wall	2.860	197.6
19mm cement plaster	0.026	35.5
Indoor air	0.110	-
	Total = 3.062	**Total = 268.6**

By using equation (4.3),

U = 1/3.062

= 0.327 W/m^2.°C

Therefore, the overall heat transfer coefficient, U for wall is 0.327 W/m^2.°C.

Mass (kg/m^2) = 268.6 kg/m^2

= 58.71 lb/ft^2

The mass value is determined in order to find the group type of Block W wall. Referring to Appendix A5, the Block W wall is best in group E.

iii. Glass structure

The glass structure used in Block W is clear single glass type. The overall heat transfer coefficient, U for glass is 6.1 W/m².°C (Double glazing, n.d.).

iv. Door structure

The type of door used in Block W is timber door type. Therefore, the overall heat transfer coefficient, U for timber door is 0.9 W/m².°C. Referring to Appendix A5, the Block W door is best in group G.

4.2.2.2 Corrected Cooling Load Temperature Difference, CLTDc

The cooling load temperature difference, CLTD can be obtained from Appendix A6, Appendix A7, and Appendix A8. CLTD in Appendix A6 is mainly for roof with suspended ceiling, Appendix A7 for wall and door structure, and Appendix A8 for glass structure. However, the cooling load temperature difference obtained from appendixes is based on the following conditions:

1. Indoor temperature is 25.6°C or 78°F.
2. Outdoor average temperature on the design day is 29.4°C or 85°F.
3. Date is July 21st.
4. Location is 40°N latitude.

For this project, the conditions are:

1. Indoor temperature is 23°C or 73.4°F.
2. Outdoor average temperature on the design day is 33.3°C or 91.94°F.
3. Date is January 21st.
4. Location is 4°N latitude.

Therefore, the cooling load temperature difference should be corrected to suite the conditions of this project. Equation (4.4) shows the formula used to determine the corrected cooling load temperature difference, CLTDc.

$$= \quad + \quad + (25.6 - \quad) + (\quad - 29.4) \tag{4.4}$$

Where

CLTDc = corrected value of CLTD, °C

CLTD = temperature from Appendix A6, A7 or A8

LM = correction for latitude and month, from Appendix A9

Tr = room temperature or indoor temperature, °C

Ta = average outside temperature on a design day, °C

The temperature Ta can be found as follows:

$$= \quad - (\quad /2) \tag{4.5}$$

Where

To = outside design dry bulb temperature, °C. The value is 33.3°C

DR = daily temperature range, °C. The value is 11.1°C

Therefore, Ta = 33.3°C – (11.1°C/2)

= 27.75°C

LM is Latitude Month and its value can be obtained from Appendix A9. The calculation to determine the LM value for 4°N latitude for North exposure is as follows:

Latitude 0°N, LM = -3°F

= -1.67°C

Latitude 8°N, LM = -3°F

= -1.67°C

Since the desired latitude in this project is 4°N, interpolation needs to be carried out.

Latitude 4°N LM for North;

$$\frac{(4-0)}{(8-0)} = \frac{\quad - (-1.67)}{(-1.67 — 1.67)}$$

$$= -1.67°C$$

The LM value for South, East, and West of 4°N latitude can be determined by follow the steps above. Table 4.4 shows the LM value at 4°N latitude at various exposures.

Table 4.4: LM value at 4°N Latitude

Exposure	0°N Latitude, LM	8°N Latitude, LM	4°N Latitude, LM
North	-1.67	-1.67	-1.67
South	3.89	5.56	4.72
East	-0.56	-1.11	-0.83
West	-0.56	-1.11	-0.83
Horizontal	-0.56	-2.22	-1.39

4.2.3 Heat Gain Caused by Conduction through Interior Structure

The heat that flows from interior unconditioned spaces to the conditioned space through wall can be determined using equation 4.6.

$$= \times \times \qquad (4.6)$$

Where

Q = heat gain, W

U = overall heat transfer coefficient for wall, $W/m^2.°C$

A = area of wall, m^2

TD = temperature difference between unconditioned and conditioned space, °C

In this project, the overall heat transfer coefficient for wall was calculated in the earlier section where the value is 0.327 $W/m^2.°C$. The temperature difference between unconditioned and conditioned space can be calculated as follows:

$$= 30°C - 23°C$$

$$= 7°C$$

4.2.4 Heat Gain Caused by Internal Heat Sources

In Block W, there are mainly five internal heat sources which cause heat gain to the occupied space. Among that included lights, people, equipment, fan, and ventilation. The calculations of heat gain caused by internal heat sources are shown as follows:

i. Lights

Lights in Block W especially in lecture hall and lecture room are always occupied. Therefore, heat gain from lights will be considered exist throughout the project. Equation 4.7 shows the formula to determine the heat gain caused by lighting.

$$= \times \times \times \qquad (4.7)$$

Where

Q = heat gain from lighting, W
n = number of lights
W = lighting capacity, Watts
BF = ballast factor
CLF = cooling load factor of lighting

The lighting capacity used in Block W is 40 watts. The typical value of ballast factor for fluorescent lighting is 1.25. The CLF value in this project will be equal to 1.0.

ii. People

The number of people in Block W is 1505 people when it is fully occupied. Table 4.5 shows the distribution of number of people in Block W when fully occupied.

Table 4.5: Number of people occupied Block W

Room	Number of rooms	People per room	Total
Lecture Room (WBK)	20	30	600
Lecture Hall (WDK)	10	60	600
Main Lecture Hall (WDKU)	2	150	300
Guest Room	1	5	5
		TOTAL	1505

The heat gain from people is composed of two parts which are sensible heat and latent heat. Equation 4.8 and 4.9 shows the formula for calculation of sensible and latent heat gains.

$$= \quad \times \quad \times \qquad (4.8)$$

$$= \quad \times \qquad (4.9)$$

Where

, = sensible and latent heat gains, W

, = sensible and latent heat gains per person, W

= number of people

= cooling load factor for people

The sensible and latent heat gains per person can be obtained from Appendix A10. The degree of activity of occupants in Block W is seated and very light work. Therefore, the sensible and latent heat is as follows:

$$= 245 \quad /\mathrm{h} = 71.8095$$

$$= 155 \quad /\mathrm{h} = 45.4305$$

iii. Equipment

The equipment that release heat in Block W is the computer. There are total 32 computers used in Block W. Equation 4.10 shows the formula to calculate the heat gain caused by equipment.

$$= \quad \times \qquad (4.10)$$

Where

Q = heat gain, W

q = heat gain per equipment, W

n = number of equipment

The value of heat gain per equipment, q can be obtained from Appendix A11.

iv. Supply Air Fan Gain

The heat gain from supply air fan will be 5% of the total sensible building heat gain.

v. Ventilation

Ventilation involves both the exchange of air to the outside as well as circulation of air within the building. To determine the heat gain through ventilation, psychrometric chart in Appendix A12 will be used to determine the outdoor and inside humidity ratio. Outdoor relative humidity is 90% and relative humidity for indoor is 50%. Table 4.6 shows the outdoor and inside humidity ratio.

Table 4.6: Outdoor and inside humidity ratio

Condition	Relative Humidity	Temperature	Humidity Ratio, gr w./lb d.a.
Outdoor	90%	33.3°C or 91.94°F	203.18
Indoor	50%	23°C or 73.40°F	61.00

Equation 4.11 and 4.12 shows the formula to calculate the heat gain through ventilation.

$$= 1.1 \times \quad \times \quad \times \tag{4.11}$$

$$= 0.68 \times \quad \times \quad ' - \quad ' \times \tag{4.12}$$

Where

, = sensible and latent heat gain, Btu/h

= air ventilation rate, ft^3/min

= temperature change between outdoor and inside air, °F

', ' = outdoor and inside humidity ratio, gr w./lb d.a.

= number of people

The total heat gain will be equal to the summation of sensible heat gain and latent heat gain through ventilation. The air ventilation rate, CFM is recommended by ASHRAE as 15 CFM per person.

4.3 PEAK LOAD TIME

Peak load time is the time where the highest heat gains occur in Block W. The peak load time can be determined by calculate the heat gain caused by solar radiation and conduction process through the structure of Block W excluding the internal heat gain. Only Block W building structures are involved to find the peak load time possibilities. For solar radiation process, the highest CLF value can be determined from Appendix A2 for glass without shading and Appendix A3 for glass with interior shading. While for conduction process, the highest value of CLTD can be obtained from Appendix A6, A7, and A8. Table 4.7 shows the possibilities of peak load time for Block W.

Table 4.7: Peak load time possibilities

Process	Building Structure	Possible Peak Load Time (hr)					
		12pm	1pm	2pm	3pm	4pm	5pm
Radiation	Without Shading		■				
	With Shading	■					
Conduction	Roof				■		
	Wall						■
	Glass				■	■	
	Door			■			

The possible peak load time is observed to be in the range from 12pm until 5pm. Therefore, the heat gain will be calculated for every hour starting from 12pm until 5pm. Table 4.8 shows the structure heat gain from 12pm until 5pm.

Table 4.8: Peak load time

Process	Structure	Cooling Load (kW) at Time (hr)					
		12pm	1pm	2pm	3pm	4pm	5pm
Radiation	Without Shading	34.23	36.98	37.44	35.09	31.43	27.69
	With Shading	0.81	0.85	0.86	0.79	0.71	0.64
Conduction	Roof	59.98	68.80	74.68	75.66	71.74	64.88
	Wall	5.81	6.92	7.80	8.84	9.65	10.51
	Glass	6.40	8.20	8.79	9.39	9.39	8.79
	Door	3.91	4.29	4.39	4.24	3.87	3.53
Total Cooling Load (kW)		111.15	126.03	133.97	134.01	126.80	116.04

From the result, the peak heat gain occurs at 3.00pm. Thus, the peak load time is at 3.00pm for daily basis.

4.3.1 Calculation at Peak Load Time

Below are the sample calculations for every heat gain process.

i. Roof Structure,

Roof information

- Roof Area, A = 3000 m²
- Overall Heat Transfer Coefficient for roof, U = 0.588 W/m².°C.
- CLTD at 3pm, CLTD = 78°F = 43.33°C

Using equation 4.4,

$$= \quad + \quad + (25.6 - \quad) + (\quad - 29.4)$$

$$= 43.33 + (-1.39) + (25.6 - 23) + (27.75 - 29.4)$$

$$= 42.89℃$$

Using equation 4.2,

Heat Gain, $= 0.588 \times 3000 \times 42.89℃$

$= 75.66$

ii. Wall Structure,

Wall information

- South exposure area, A = 647.94 m²
- Overall Heat Transfer Coefficient for wall, U = 0.327 W/m².°C.
- CLTD at 3pm, CLTD = 29°F = 16.11°C

Using equation 4.4,

$$= 16.11 + (4.72) + (25.6 - 23) + (27.75 - 29.4)$$

$$= 21.78℃$$

Using equation 4.2,

Heat Gain, $= 0.327 \times 647.94 \times 21.78$

$= 4.61$

iii. Glass,

Glass information

- Total glass area of all exposure, A = 176.4 m²
- Overall Heat Transfer Coefficient for glass, U = 6.1 W/m².°C.
- CLTD at 3pm, CLTD = 14°F = 7.78°C
- LM for glass in not included

Using equation 4.4,

$$= 7.78 + (0) + (25.6 - 23) + (27.75 - 29.4)$$

$$= 8.73℃$$

Using equation 4.2,

Heat Gain, $= 6.1 \times 176.4 \times 8.73$

$= 9.39$

iv. Door

Door information

- South exposure area, A = 96.72 m²
- Overall Heat Transfer Coefficient for door, U = 0.9 W/m².°C.
- CLTD at 3pm, CLTD = 43°F = 23.89°C

Using equation 4.4,

$$= 23.89 + (4.72) + (25.6 - 23) + (27.75 - 29.4)$$

$$= 29.56℃$$

Using equation 4.2,

Heat Gain, $= 0.9 \times 96.72 \times 29.56$

$= 2.57$

v. Solar Radiation

Without Shading

- South exposure
- Area, A = 87.84 m²
- Shading Coefficient, SC = 0.69
- Solar Heat Gain Factor, SHGF = 214 BTU/Hr.ft² = 675.17 W/m²
- Cooling Load Factor, CLF = 0.63

Using equation 4.1,

Heat Gain, $= 675.17 \times 87.84 \times 0.69 \times 0.63$

$= 25.78$

With Shading

- South exposure
- Area, A = 3.6 m²
- Shading Coefficient, SC = 0.36
- Solar Heat Gain Factor, SHGF = 214 BTU/Hr.ft² = 675.17 W/m²
- Cooling Load Factor, CLF = 0.5

Using equation 4.1,

Heat Gain, $= 675.17 \times 3.6 \times 0.36 \times 0.5$

$= 0.44$

vi. Lights

Lights information

- Number of lights, n = 780
- Lighting capacity, W = 40 W
- Ballast factor, BF = 1.25
- Cooling Load Factor, CLF = 1

Using equation 4.7,

Heat Gain, $= 780 \times 40 \times 1.25 \times 1$

$= 39$

vii. People

People information

- Number of people, n = 1505
- Cooling Load Factor for people, CLF = 1

Using equation 4.8 & 4.9,

Sensible Heat Gain, $= 71.8095 \times 1505 \times 1$

$= 108.07$

Latent Heat Gain, $= 45.4305 \times 1505$

$= 68.37$

Total Heat Gain Caused by People,

$= 108.07 + 68.37$

$= 176.4$

viii. Equipment

Using equation 4.10,

Heat Gain, $= 996.54 \times 32 = 31.89$

ix. Ventilation

Using equation 4.11 & 4.12,

Sensible Heat Gain,

$= 15 \times (91.94 - 73.4) \times 1505$

$= 460394.55 \quad /h$

$= 134.94$

Latent Heat Gain,

$= \quad = 15 \times (203.18 - 61) \times 1505$

$= 2182605.2 \quad /h$

$= 639.71$

Total Heat Gain Caused by Ventilation,

$= 134.94 + 639.71$

$= 774.65$

4.4 ANALYSIS FROM CALCULATED HEAT GAIN

From the heat gain calculation, analysis can be carried out. For this project, the first analysis is the comparison of heat gain caused by conduction through roof, wall, glass, and door. The analysis will be based on the heat gain at 3pm since the peak heat gain occurred at that time. Figure 4.3 shows the pie chart of conduction through roof, wall, glass, and door of Block W during 3pm.

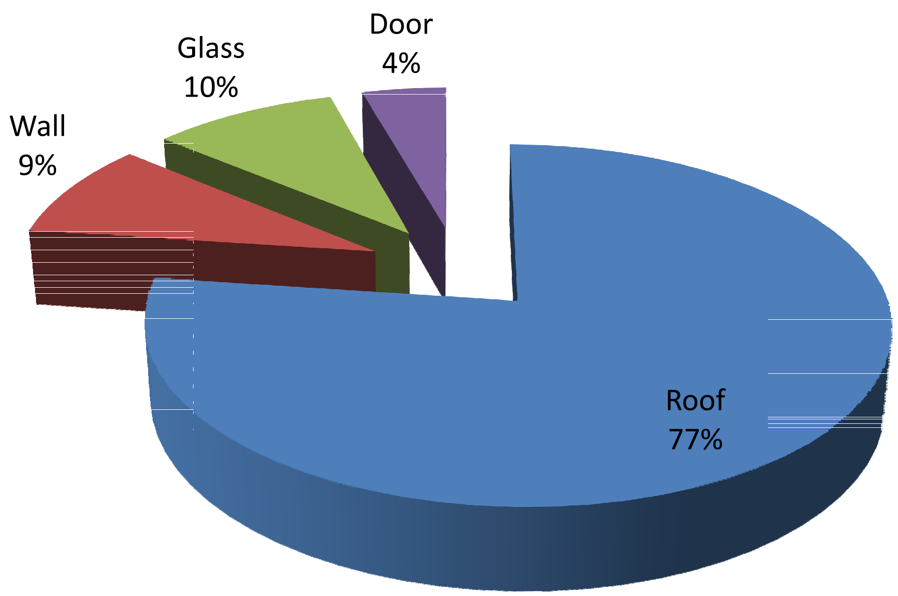

Figure 4.3: Heat gain through conduction

From Figure 4.3, the roof structure contributes the highest heat gain to Block W followed by glass, wall, and door. Roof structure contributes most of the heat gain due to the exposure area is very large. While door structure provides the fewest heat gain to Block W since its exposure surface area and the heat transfer coefficient is the small. Although wall structure has larger exposure surface area than glass structure, but the heat transfer coefficient of wall structure is much fewer than glass structure, therefore glass structure has higher heat gain compared to wall structure. However, the percentage of conduction through wall and glass is also the same.

The second analysis that carried out in this project is the comparison of total heat gain caused by solar radiation process and conduction process through roof, wall, glass, and door. The analysis carried out which included the heat gain from 8am until 7pm. The graph in Figure 4.4 shows the external heat gain through roof, wall, glass, door, and solar radiation.

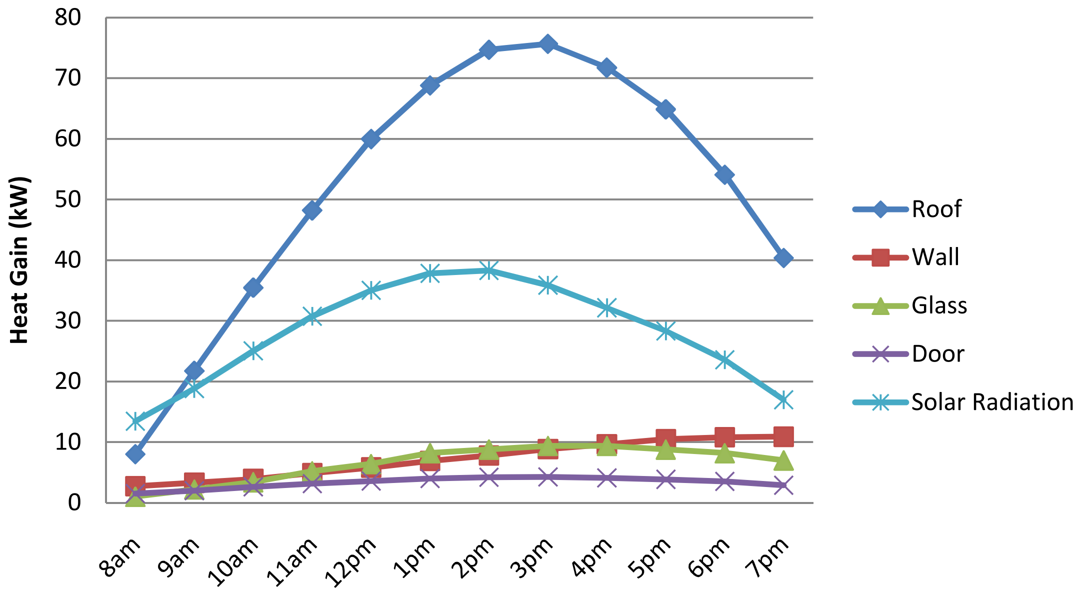

Figure 4.4: External heat gain through building structure

From the graph above, the highest heat gain at 8am is caused by solar radiation through glass. The heat gain is followed by roof conduction, wall conduction, door conduction and glass conduction. At 3pm where the peak heat gain occurred, roof conduction is the highest heat gain and followed by solar radiation through glass. Heat gain through roof conduction still is the highest heat source among all at 7pm. The heat gain followed by solar radiation, wall conduction, glass conduction, and door conduction. From the graph, the main heat gain contributors are roof conduction and solar radiation through glass during the peak heat gain. The other heat gain contributor such as wall conduction, door conduction and glass conduction only contribute small portion from the total heat gain.

Figure 4.5 shows graph of the total calculated heat gain of Block W. The graph can be plotted by combining the result obtained from Appendix B1 to Appendix B12.

The calculated heat gain included all the heat sources which are external heat gain and internal heat gain.

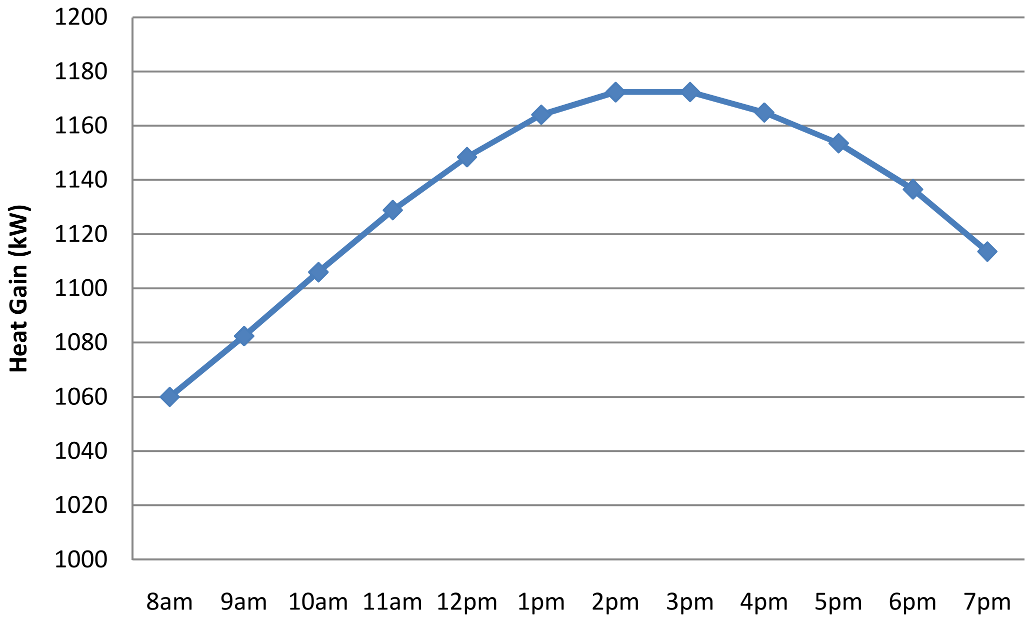

Figure 4.5: Total calculated heat gain of Block W

From the graph in Figure 4.5, the peak heat gain occurred at 3pm which had been identified in the earlier topic. At the beginning of the graph, the heat gain increased until 3pm. The heat gain then decreased due to the sun is immersing.

4.5 EXISTING COOLING CAPACITY IN BLOCK W

There are four types of cooling capacity used in Block W which included 1 horsepower split unit, 3.5 horsepower split unit, 4 horsepower split unit, and package unit. Table 4.9 shows the calculation on existing cooling capacity in Block W.

Table 4.9: Existing cooling capacity in Block W

Location	Air-Conditioning Type	Units	Cooling Capacity/unit (kW)	Cooling Capacity (kW)
Guest Room	Split Unit	1	2.78	2.78
Lecture Room (WBK)	Split Unit	40	10.26	410.40
Lecture Hall (WDK)	Split Unit	20	11.72	234.40
Main Lecture Hall (WDKU)	Package Unit	2	102.58	205.16
			TOTAL	**852.74**

The total existing cooling capacity at Block W is 852.74 kW. The existing cooling capacity will be compared with the cooling load required in order to fulfill the objectives of this project. Figure 4.6 to 4.8 shows the split units and air handling unit used at Block W.

Figure 4.6: Split unit at WBK

Figure 4.7: Split unit at WDK

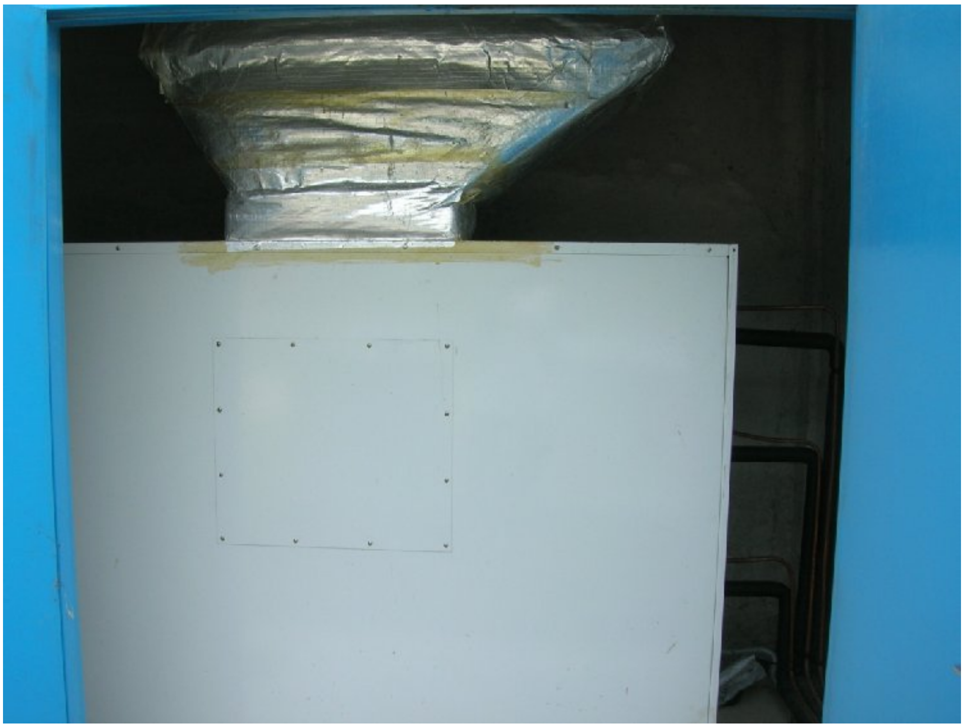

Figure 4.8: Package unit at WDKU

4.6 COMPARISON BETWEEN CALCULATED HEAT GAINS AGAINST EXISTING COOLING CAPACITY

The calculated heat gain and the existing cooling capacity were obtained from the previous topic. The calculated heat gain in Block W will be compared with its existing cooling capacity in order to indentify whether the existing cooling capacity is suffice. Table 4.10 shows the comparison between calculated heat gains against the existing cooling capacity.

Table 4.10: Calculated heat gain vs. existing cooling capacity

Calculated Heat Gain (kW)	Existing Cooling Capacity	Difference (kW)	Percentage of Difference
1172.43	852.74	-319.69	-27.3%

From the table above, the difference between existing cooling capacity with calculated heat gain is -319.69kW. In other word, the cooling capacity is 319.69kW less than the calculated heat gain, means 27.3% less. From the table above, it shows that the existing cooling capacity cannot support the cooling load required when Block W is fully occupied. However, the peak heat gain will only happen occasionally throughout the year since the calculation of peak heat gain was based on the highest solar heat gain factor which is on January 21st.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

In this project, both the objectives were successfully achieved. The cooling load required for Block W was determined to be 1172.43 kW. The heat gain calculation is done by using the CLF/CLTD method. The heat gain is to calculate the total cooling load required to remove heat from Block W. The highest heat gain occurs at 3pm on January 21st for daily basis.

The existing cooling capacity in Block W which is 852.74 kW was compared with the calculated heat gain. The air-conditioning system in Block W is observed to be undersize in design. At the moment when the peak heat gain occurs, the occupants in Block W will feel thermally uncomfortable. In order to overcome this situation, the cooling capacity should increase 27.3%. However, this situation will only happen occasionally where the weather is hot and Block W is fully occupied.

5.2 RECOMMENDATIONS FOR FURTHER WORK

There are few recommendations for further work for this project. First recommendation is to review the air flow in the lecture hall by using computational fluid dynamics (CFD) to map the distribution of cooling capacity.

Second recommendation is to use available software in the market for example ESP-r or TRNSYS in order to calculate building heat gain. By using software in building heat gain calculation, it can be a validation on the manual calculation.

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APPENDIX A1

MAXIMUM SOLAR HEAT GAIN FACTOR (SHGF) BTU/HR.FT² FOR SUNLIT GLASS, NORTH LATITUDES

20° N. Lat

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	29	29	48	138	201	243	253	233	214	232
Feb.	31	31	88	173	226	244	238	201	174	263
Mar.	34	49	132	200	237	236	206	152	115	284
Apr.	38	92	166	213	228	208	158	91	58	287
May	47	123	184	217	217	184	124	54	42	283
June	59	135	189	216	210	173	108	45	42	279
July	48	124	182	213	212	179	119	53	43	278
Aug.	40	91	162	206	220	200	152	88	57	280
Sep.	36	46	127	191	225	225	199	148	114	275
Oct.	32	32	87	167	217	236	231	196	170	258
Nov.	29	29	48	136	197	239	249	229	211	230
Dec.	27	27	35	122	187	238	254	241	226	217

24° N. Lat

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	27	27	41	128	190	240	253	241	227	214
Feb.	30	30	80	165	220	244	243	213	192	249
Mar.	34	45	124	195	234	237	214	168	137	275
Apr.	37	88	159	209	228	212	169	107	75	283
May	43	117	178	214	218	190	132	67	46	282
June	55	127	184	214	212	179	117	55	43	279
July	45	116	176	210	213	185	129	65	46	278
Aug.	38	87	156	203	220	204	162	103	72	277
Sep.	35	42	119	185	222	225	206	163	134	266
Oct.	31	31	79	159	211	237	235	207	187	244
Nov.	27	27	42	126	187	236	249	237	224	213
Dec.	26	26	29	112	180	234	247	247	237	199

28° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	25	25	35	117	183	235	251	247	238	196
Feb.	29	29	72	157	213	244	246	224	207	234
Mar.	33	41	116	189	231	237	221	182	157	265
Apr.	36	84	151	205	228	216	178	124	94	278
May	40	115	172	211	219	195	144	83	58	280
June	51	125	178	211	213	184	128	68	49	278
July	41	114	170	208	215	190	140	80	57	276
Aug.	38	83	149	199	220	207	172	120	91	272
Sep.	34	38	111	179	219	226	213	177	154	256
Oct.	30	30	71	151	204	236	238	217	202	229
Nov.	26	26	35	115	181	232	247	243	235	195
Dec.	24	24	24	99	172	227	248	251	246	179

32° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	24	24	29	105	175	229	249	250	246	176
Feb.	27	27	65	149	205	242	248	232	221	217
Mar.	32	37	107	183	227	237	227	195	176	252
Apr.	36	80	146	200	227	219	187	141	115	271
May	38	111	170	208	220	199	155	99	74	277
June	44	122	176	208	214	189	139	83	60	276
July	40	111	167	204	215	194	150	96	72	273
Aug.	37	79	141	195	219	210	181	136	111	265
Sep.	33	35	103	173	215	227	218	189	171	244
Oct.	28	28	63	143	195	234	239	225	215	213
Nov.	24	24	29	103	173	225	245	246	243	175
Dec.	22	22	22	84	162	218	246	252	252	158

36° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	22	22	24	90	166	219	247	252	252	155
Feb.	26	26	57	139	195	239	248	239	232	199
Mar.	30	33	99	176	223	238	232	206	192	238
Apr.	35	76	144	196	225	221	196	156	135	262
May	38	107	168	204	220	204	165	116	93	272
June	47	118	175	205	215	194	150	99	77	273
July	39	107	165	201	216	199	161	113	90	268
Aug.	36	75	138	190	218	212	189	151	131	257
Sep.	31	31	95	167	210	228	223	200	187	230
Oct.	27	27	56	133	187	230	239	231	225	195
Nov.	22	22	24	87	163	215	243	248	248	154
Dec.	20	20	20	69	151	204	241	253	254	136

40° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	20	20	20	74	154	205	241	252	254	133
Feb.	24	24	50	129	186	234	246	244	241	180
Mar.	29	29	93	169	218	238	236	216	206	223
Apr.	34	71	140	190	224	223	203	170	154	252
May	37	102	165	202	220	208	175	133	113	265
June	48	113	172	205	216	199	161	116	95	267
July	38	102	163	198	216	203	170	129	109	262
Aug.	35	71	135	185	216	214	196	165	149	247
Sep.	30	30	87	160	203	227	226	209	200	215
Oct.	25	25	49	123	180	225	238	236	234	177
Nov.	20	20	20	73	151	201	237	248	250	132
Dec.	18	18	18	60	135	188	232	249	253	113

44° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	17	17	17	64	138	189	232	248	252	109
Feb.	22	22	43	117	178	227	246	248	247	160
Mar.	27	27	87	162	211	236	238	224	218	206
Apr.	33	66	136	185	221	224	210	183	171	240
May	36	96	162	201	219	211	183	148	132	257
June	47	108	169	205	215	203	171	132	115	261
July	37	96	159	198	215	206	179	144	128	254
Aug.	34	66	132	180	214	215	202	177	165	236
Sep.	28	28	80	152	198	226	227	216	211	199
Oct.	23	23	42	111	171	217	237	240	239	157
Nov.	18	18	18	64	135	186	227	244	248	109
Dec.	15	15	15	49	115	175	217	240	246	89

48° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	15	15	15	53	118	175	216	239	245	85
Feb.	20	20	36	103	168	216	242	249	250	138
Mar.	26	26	80	154	204	234	239	232	228	188
Apr.	31	61	132	180	219	225	215	194	186	226
May	35	97	158	200	218	214	192	163	150	247
June	46	110	165	204	215	206	180	148	134	252
July	37	96	156	196	214	209	187	158	146	244
Aug.	33	61	128	174	211	216	208	188	180	223
Sep.	27	27	72	144	191	223	228	223	220	182
Oct.	21	21	35	96	161	207	233	241	242	136
Nov.	15	15	15	52	115	172	212	234	240	85
Dec.	13	13	13	36	91	156	195	225	233	65

APPENDIX A2

COOLING LOAD FACTOR (CLF) FOR GLASS WITHOUT INTERIOR SHADING

N	L	.00	.00	.00	.00	.01	.64	.73	.74	.81	.88	.95	.98	.98	.94	.88	.79	.79	.55	.31	.12	.04	.02	.01	.00
	M	.12	.09	.07	.06	.05	.33	.45	.53	.61	.69	.76	.82	.85	.86	.85	.81	.80	.70	.60	.43	.32	.24	.19	.15
	H	.24	.21	.19	.18	.16	.43	.48	.51	.56	.61	.66	.71	.73	.74	.73	.71	.71	.62	.52	.42	.36	.32	.29	.26
NE	L	.00	.00	.00	.00	.01	.51	.83	.88	.72	.47	.33	.27	.24	.23	.20	.18	.14	.09	.03	.01	.00	.00	.00	.00
	M	.03	.02	.02	.02	.02	.24	.45	.57	.58	.49	.41	.36	.32	.29	.27	.24	.21	.17	.13	.10	.07	.06	.05	.04
	H	.08	.07	.07	.06	.06	.27	.43	.49	.45	.37	.32	.29	.28	.27	.26	.24	.22	.19	.16	.14	.12	.11	.10	.09
E	L	.00	.00	.00	.00	.00	.42	.76	.91	.90	.75	.51	.30	.22	.18	.16	.13	.11	.07	.02	.01	.00	.00	.00	.00
	M	.03	.02	.02	.02	.01	.20	.41	.57	.65	.64	.55	.44	.36	.31	.26	.23	.19	.16	.12	.09	.07	.06	.04	.04
	H	.08	.08	.07	.06	.06	.24	.40	.50	.53	.50	.41	.33	.30	.28	.26	.24	.22	.19	.16	.14	.13	.11	.10	.09
SE	L	.00	.00	.00	.00	.00	.27	.58	.81	.93	.93	.81	.59	.37	.27	.21	.18	.14	.09	.03	.01	.00	.00	.00	.00
	M	.04	.03	.02	.02	.02	.13	.31	.48	.62	.69	.69	.61	.50	.41	.35	.30	.25	.20	.15	.12	.09	.07	.06	.05
	H	.10	.09	.08	.08	.07	.18	.32	.45	.53	.56	.54	.47	.39	.35	.32	.29	.26	.23	.19	.17	.15	.14	.12	.11
S	L	.00	.00	.00	.00	.00	.07	.15	.23	.39	.62	.82	.94	.93	.80	.59	.38	.26	.16	.06	.02	.01	.00	.00	.00
	M	.05	.04	.04	.03	.02	.05	.09	.14	.24	.38	.53	.65	.72	.71	.63	.52	.42	.33	.24	.18	.14	.11	.09	.07
	H	.13	.12	.10	.09	.09	.11	.14	.17	.25	.36	.47	.55	.58	.56	.49	.41	.36	.30	.25	.21	.19	.17	.16	.14
SW	L	.00	.00	.00	.00	.00	.04	.09	.13	.16	.19	.23	.39	.62	.82	.94	.94	.81	.54	.19	.07	.03	.01	.00	.00
	M	.08	.07	.05	.04	.03	.05	.07	.09	.12	.15	.17	.26	.40	.54	.66	.73	.72	.61	.43	.31	.23	.17	.13	.10
	H	.15	.14	.12	.11	.10	.11	.12	.14	.15	.17	.18	.26	.37	.48	.56	.59	.57	.47	.33	.27	.23	.21	.19	.17
W	L	.00	.00	.00	.00	.00	.03	.07	.10	.13	.15	.16	.18	.31	.55	.78	.92	.93	.73	.25	.10	.04	.01	.01	.00
	M	.08	.07	.05	.04	.04	.04	.06	.08	.10	.12	.13	.15	.21	.35	.50	.63	.71	.67	.46	.33	.24	.18	.14	.11
	H	.14	.13	.12	.11	.10	.10	.11	.12	.13	.14	.15	.16	.21	.33	.45	.54	.58	.52	.33	.26	.22	.19	.18	.16
NW	L	.00	.00	.00	.00	.00	.04	.09	.14	.17	.20	.22	.23	.24	.31	.53	.78	.92	.81	.28	.10	.04	.02	.01	.00
	M	.08	.06	.05	.04	.03	.05	.07	.10	.13	.15	.17	.19	.20	.24	.36	.51	.64	.66	.46	.32	.23	.17	.13	.10
	H	.13	.12	.11	.10	.09	.10	.12	.13	.15	.16	.17	.18	.19	.23	.33	.46	.55	.53	.33	.25	.21	.18	.16	.15
Hor.	L	.00	.00	.00	.00	.00	.08	.25	.45	.64	.80	.91	.97	.97	.91	.80	.64	.44	.23	.08	.03	.01	.00	.00	.00
	M	.07	.06	.05	.04	.03	.06	.14	.26	.40	.53	.64	.73	.78	.80	.77	.70	.59	.45	.33	.24	.19	.14	.11	.09
	H	.16	.15	.13	.12	.11	.13	.20	.29	.39	.48	.56	.61	.65	.65	.63	.57	.49	.40	.32	.28	.25	.22	.20	.18

APPENDIX A3

COOLING LOAD FACTOR (CLF) FOR GLASS WITH INTERIOR SHADING

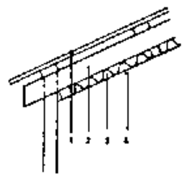
Fenes-tration Facing	Solar Time, h																							
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
N	0.08	0.07	0.06	0.06	0.07	0.73	0.66	0.65	0.73	0.80	0.86	0.89	0.89	0.86	0.82	0.75	0.78	0.91	0.24	0.18	0.15	0.13	0.11	0.10
NNE	0.03	0.03	0.02	0.02	0.03	0.64	0.77	0.62	0.42	0.37	0.37	0.37	0.36	0.35	0.32	0.28	0.23	0.17	0.08	0.07	0.06	0.05	0.04	0.04
NE	0.03	0.02	0.02	0.02	0.02	0.56	0.76	0.74	0.58	0.37	0.29	0.27	0.26	0.24	0.22	0.20	0.16	0.12	0.06	0.05	0.04	0.04	0.03	0.03
ENE	0.03	0.02	0.02	0.02	0.02	0.52	0.76	0.80	0.71	0.52	0.31	0.26	0.24	0.22	0.20	0.18	0.15	0.11	0.06	0.05	0.04	0.04	0.03	0.03
E	0.03	0.02	0.02	0.02	0.02	0.47	0.72	0.80	0.76	0.62	0.41	0.27	0.24	0.22	0.20	0.17	0.14	0.11	0.06	0.05	0.05	0.04	0.03	0.03
ESE	0.03	0.03	0.02	0.02	0.02	0.41	0.67	0.79	0.80	0.72	0.54	0.34	0.27	0.24	0.21	0.19	0.15	0.12	0.07	0.06	0.05	0.04	0.04	0.03
SE	0.03	0.03	0.02	0.02	0.02	0.30	0.57	0.74	0.81	0.79	0.68	0.49	0.33	0.28	0.25	0.22	0.18	0.13	0.08	0.07	0.06	0.05	0.04	0.04
SSE	0.04	0.03	0.03	0.03	0.02	0.12	0.31	0.54	0.72	0.81	0.81	0.71	0.54	0.38	0.32	0.27	0.22	0.16	0.09	0.08	0.07	0.06	0.05	0.04
S	0.04	0.04	0.03	0.03	0.03	0.09	0.16	0.23	0.38	0.58	0.75	0.83	0.80	0.68	0.50	0.35	0.27	0.19	0.11	0.09	0.08	0.07	0.06	0.05
SSW	0.05	0.04	0.04	0.03	0.03	0.09	0.14	0.18	0.22	0.27	0.43	0.63	0.78	0.84	0.80	0.66	0.46	0.25	0.13	0.11	0.09	0.08	0.07	0.06
SW	0.05	0.05	0.04	0.04	0.03	0.07	0.11	0.14	0.16	0.19	0.22	0.38	0.59	0.75	0.83	0.81	0.69	0.45	0.16	0.12	0.10	0.09	0.07	0.06
WSW	0.05	0.05	0.04	0.04	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.23	0.44	0.64	0.78	0.84	0.78	0.55	0.16	0.12	0.10	0.09	0.07	0.06
W	0.05	0.05	0.04	0.04	0.03	0.06	0.09	0.11	0.13	0.15	0.16	0.17	0.31	0.53	0.72	0.82	0.81	0.61	0.16	0.12	0.10	0.08	0.07	0.06
WNW	0.05	0.05	0.04	0.03	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.18	0.22	0.43	0.65	0.80	0.84	0.66	0.16	0.12	0.10	0.08	0.07	0.06
NW	0.05	0.04	0.04	0.03	0.03	0.07	0.11	0.14	0.17	0.19	0.20	0.21	0.22	0.30	0.52	0.73	0.82	0.69	0.16	0.12	0.10	0.08	0.07	0.06
NNW	0.05	0.05	0.04	0.03	0.03	0.11	0.17	0.22	0.26	0.30	0.32	0.33	0.34	0.34	0.39	0.61	0.82	0.76	0.17	0.12	0.10	0.08	0.07	0.06
HOR.	0.06	0.05	0.04	0.04	0.03	0.12	0.27	0.44	0.59	0.72	0.81	0.85	0.85	0.81	0.71	0.58	0.42	0.25	0.14	0.12	0.10	0.08	0.07	0.06

APPENDIX A4
ROOF STRUCTURE RESISTANCE

	Construction	Resistance, R $(m^2\cdot{}^\circ K)/W$	Thermal Capacity $kJ/(m^2\cdot{}^\circ K)$
Sheet. Metal roof and Insulation Plastic and Chicken Wire	Outdoor air	0.04	0
	1. Metal roof	0.11	0
	2. *Air space, 200mm	1.36	0
	3. Coffeehulls, 50,	0.83	10
	4. Indoor air	0.11	0
metal roof 0.11	Total resistance, R_T	2.45	10

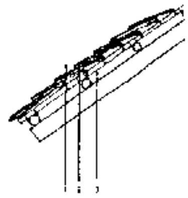
* Low emittance, shiny metal

$U = 1/2.45 = 0.41\ W/(m^2\cdot{}^\circ K)$ heat flow down



	Construction	Resistance, R $(m^2\cdot{}^\circ K)/W$	Thermal Capacity $kJ/(m^2\cdot{}^\circ K)$
Thatch + Plastic Sheet 150mm	1. Outdoor air	0.04	0
	2. Thatch, 150mm	3.72	16
	3. Indoor air	0.11	0
	Total resistance, R_T	3.87	16

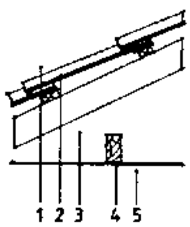
$U = 1/3.87 = 0.26\ W/(m^2\cdot{}^\circ K)$



	Construction	Heat flow Up	Heat flow Down	Thermal Capacity
Tiled Roof Gypsum Board	1. Outdoor air film	0.04	0.04	0
	2. 19mm tiles, clay roofing	0.023	0.023	34
	3. Roof space (ventilated)		0.46	0
	4. 13mm gypsum board	0.077	0.077	12
	5. Indoor air film	0.11	0.11	0
	Total resistance, R_T	0.250	0.710	46

$U = 1/0.250 = 4.0\ W/(m^2\cdot{}^\circ K)$ heat flow up

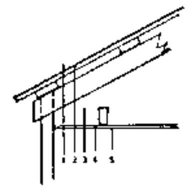
$U = 1/0.710 = 1.4\ W/(m^2\cdot{}^\circ K)$ heat flow down



	Construction	Heat flow Up	Heat flow Down	Thermal Capacity
Sheet Metal Roof, Ceiling	1. Outdoor air film	0.04	0.04	0
	2. Metal roof	0.11	0.11	0
	3. Roof space (Vent, low emit.)	0.34	1.36	0
	4. Gypsum board	0.08	0.08	3
	5. Indoor air	0.11	0.11	0
	Total resistance, R_T	0.68	1.70	3

$U = 1/0.68 = 1.47\ W/(m^2\cdot{}^\circ K)$ heat flow up

$U = 1/1.70 = 0.59\ W/(m^2\cdot{}^\circ K)$ heat flow down



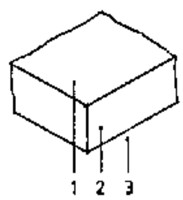
	Construction	Resistance, R $(m^2\cdot{}^\circ K)/W$	Thermal Capacity $kJ/(m^2\cdot{}^\circ K)$
Concrete Slab on soil	1. Indoor air film	0.11	0
	2. 100mm concrete ($2400 kg/m^3$)	0.069	210
	Total resistance, R_T	0.179	210

$U = 1/0.179 = 5.59\ W/(m^2\cdot{}^\circ K)$

With 2mm Vinyl Tiles

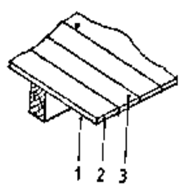
$R_T = 0.179 + 0.003 = 0.182$

$U = 1/0.182 = 5.49\ W/(m^2\cdot{}^\circ K)$



	Construction	Resistance, R $(m^2\cdot{}^\circ K)/W$	Thermal Capacity $kJ/(m^2\cdot{}^\circ K)$
Timber	1. Indoor air film (upper)	0.11	0
	2. 19mm T. & G. flooring (hardwood)	0.120	19
	3. Indoor air film (lower)	0.11	0
	Total resistance, R_T	0.340	19

$U = 1/0.340 = 2.94\ W/(m^2\cdot{}^\circ K)$



APPENDIX A5

WALL CONSTRUCTION GROUP DESCRIPTION

Group No.	Description of Construction	Weight (lb/ft²)	*U*-Value (BTU/h•ft²•°F)
4-in. Face brick + (brick)			
C	Air space + 4-in. face brick	83	0.358
D	4-in. common brick	90	0.415
C	1-in. insulation or air space + 4-in. common brick	90	0.174–0.301
B	2-in. insulation + 4-in. common brick	88	0.111
B	8-in. common brick	130	0.302
A	Insulation or air space + 8-in. common brick	130	0.154–0.243
4-in. Face brick + (heavyweight concrete)			
C	Air space + 2-in. concrete	94	0.350
B	2-in. insulation + 4-in. concrete	97	0.116
A	Air space or insulation + 8-in. or more concrete	143–190	0.110–0.112
4-in. Face brick + (light or heavyweight concrete block)			
E	4-in. block	62	0.319
D	Air space or insulation + 4-in. block	62	0.153–0.246
D	8-in. block	70	0.274
C	Air space or 1-in. insulation + 6-in. or 8-in. block	73–89	0.221–0.275
B	2-in. insulation + 8-in. block	89	0.096–0.107
4-in. Face brick + (clay tile)			
D	4-in. tile	71	0.381
D	Air space + 4-in. tile	71	0.281
C	Insulation + 4-in. tile	71	0.169
C	8-in. tile	96	0.275
B	Air space or 1-in. insulation + 8-in. tile	96	0.142–0.221
A	2-in. insulation + 8-in. tile	97	0.097
Heavyweight concrete wall + (finish)			
E	4-in. concrete	63	0.585
D	4-in. concrete + 1-in. or 2-in. insulation	63	0.119–0.200
C	2-in. insulation + 4-in. concrete	63	0.119
C	8-in. concrete	109	0.490
B	8-in. concrete + 1-in. or 2-in. insulation	110	0.115–0.187
A	2-in. insulation + 8-in. concrete	110	0.115
B	12-in. concrete	156	0.421
A	12-in. concrete + insulation	156	0.113
Light and heavyweight concrete block + (finish)			
F	4-in. block + air space/insulation	29	0.161–0.263
E	2-in. insulation + 4-in. block	29–37	0.105–0.114
E	8-in. block	47–51	0.294–0.402
D	8-in. block + air space/insulation	41–57	0.149–0.173
Clay tile + (finish)			
F	4-in. tile	39	0.419
F	4-in. tile + air space	39	0.303
E	4-in. tile + 1-in. insulation	39	0.175
D	2-in. insulation + 4-in. tile	40	0.110
D	8-in. tile	63	0.296
C	8-in. tile + air space/1-in. insulation	63	0.151–0.231
B	2-in. insulation + 8-in. tile	63	0.099
Metal curtain wall			
G	With/without air space + 1- to 3-in. insulation	5–6	0.091–0.230
Frame wall			
G	1-in. to 3-in. insulation	16	0.081–0.178

APPENDIX A6

COOLING LOAD TEMPERATURE DIFFERENCES (CLTD) FOR ROOF

Roof No	Description of Construction	Weight, lb/ft²	BTU / h•ft²•°F	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Maxi-mum CLTD	Mini-mum CLTD	Maxi-mum CLTD	Differ-ence CLTD
				Solar Time																											
	With Suspended Ceiling																														
1	Steel Sheet with 1-in. (or 2-in.) insulation	9 (10)	0.134 (0.092)	2	0	−2	−3	−4	−4	−1	9	23	37	50	62	71	77	78	74	67	56	42	28	18	12	8	5	15	−4	78	82
2	1-in. wood with 1-in. ins.	10	0.115	20	15	11	8	5	3	2	3	7	13	21	30	40	48	55	60	62	61	58	51	44	37	30	25	17	2	62	60
3	4-in. lightweight concrete	20	0.134	19	14	10	7	4	2	0	0	4	10	19	29	39	48	56	62	65	64	61	54	46	38	30	24	17	0	65	65
4	2-in. heavyweight concrete with 1 in. insulation	30	0.131	28	25	23	20	17	15	13	13	14	16	20	25	30	35	39	43	46	47	46	44	41	38	35	32	18	13	47	34
5	1-in. wood with 2-in. ins	10	0.083	25	20	16	13	10	7	5	5	7	12	18	25	33	41	48	53	57	57	56	52	46	40	34	29	18	5	57	52
6	6-in. lighweight concrete	26	0.109	32	28	23	19	16	13	10	8	7	8	11	16	22	29	36	42	48	52	54	54	54	47	42	37	20	7	54	47
7	2.5-in. wood with 1-in. insulation	15	0.096	34	31	29	26	23	21	18	16	15	15	16	18	21	25	30	34	38	41	43	44	44	42	40	37	21	15	44	29
8	8-in. lighweight concrete	33	0.093	39	36	3	3	29	26	23	20	18	15	14	14	15	17	20	25	29	34	38	42	45	46	44	42	21	14	46	32
9	4-in. heavyweight concrete with 1-in. (or 2-in.) ins.	53 (54)	0.128 (0.090)	30	29	27	26	24	22	21	20	20	21	22	24	27	29	32	34	36	38	38	38	37	36	34	33	19	20	38	18
10	2.5-in. wood with. 2-in. ins	15	0.072	35	33	30	28	26	24	22	20	18	18	18	20	22	25	28	32	35	38	40	41	41	40	39	37	21	18	41	23
11	Roof terrace system	77	0.082	30	29	28	27	26	25	24	23	22	22	22	23	23	25	26	28	29	31	32	33	33	33	33	32	22	22	33	11
12	6-in. heavyweight concrete with 1-in. (or 2-in.) insulation	77 (77)	0.125 (0.088)	29	28	27	26	25	24	23	22	21	21	22	23	25	26	28	30	32	33	34	34	34	33	32	31	20	21	34	13
13	4-in. wood with 1-in. (or 2-in.) insulation	19 (20)	0.082 (0.064)	35	34	33	32	31	29	27	26	24	23	22	21	22	22	24	25	27	30	32	34	35	36	37	36	23	21	37	16

APPENDIX A7

COOLING LOAD TEMPERATURE DIFFERENCES (CLTD) FOR WALL

North Latitude Wall Facing	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hr of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD
	Solar Time, h																											
Group A Walls																												
N	14	14	14	13	13	13	12	12	11	11	10	10	10	10	10	10	11	11	12	12	13	13	14	14	2	10	14	4
NE	19	19	19	18	17	17	16	15	15	15	15	15	16	16	17	18	18	18	19	19	20	20	20	20	22	15	20	5
E	24	24	23	23	22	21	20	19	19	18	19	19	20	21	22	23	24	24	25	25	25	25	25	25	22	18	25	7
SE	24	23	23	22	21	20	20	19	18	18	18	18	18	19	20	21	22	23	23	24	24	24	24	24	22	18	24	6
S	20	20	19	19	18	18	17	16	16	15	14	14	14	14	14	15	16	17	18	19	19	20	20	20	23	14	20	6
SW	25	25	25	24	24	23	22	21	20	19	19	18	17	17	17	17	18	19	20	22	23	24	25	25	24	17	25	8
W	27	27	26	26	25	24	24	23	22	21	20	19	19	18	18	18	18	19	20	22	23	25	26	26	1	18	27	9
NW	21	21	21	20	20	19	19	18	17	16	16	15	15	14	14	14	15	15	16	17	18	19	20	21	1	14	21	7
Group B Walls																												
N	15	14	14	13	12	11	11	10	9	9	9	8	9	9	9	10	11	12	13	14	14	15	15	15	24	8	15	7
NE	19	18	17	16	15	14	13	12	12	13	14	15	16	17	18	19	19	20	20	21	21	21	20	20	21	12	21	9
E	23	22	21	20	18	17	16	15	15	15	17	19	21	22	24	25	26	26	27	27	26	26	25	24	20	15	27	12
SE	23	22	21	20	18	17	16	15	14	14	15	16	18	20	21	23	24	25	26	26	26	26	25	24	21	14	26	12
S	21	20	19	18	17	15	14	13	12	11	11	11	11	12	14	15	17	19	20	21	22	22	22	21	23	11	22	11
SW	27	26	25	24	22	21	19	18	16	15	14	14	13	13	14	15	17	20	22	25	27	28	28	28	24	13	28	15
W	29	28	27	26	24	23	21	19	18	17	16	15	14	14	14	15	17	19	22	25	27	29	29	30	24	14	30	16
NW	23	22	21	20	19	18	17	15	14	13	12	12	12	11	12	12	13	15	17	19	21	22	23	23	24	11	23	9
Group C Walls																												
N	15	14	13	12	11	10	9	8	8	7	7	8	8	9	10	12	13	14	15	16	17	17	17	16	22	7	17	10
NE	19	17	16	14	13	11	10	10	11	13	15	17	19	20	21	22	22	23	23	23	23	22	21	20	20	10	23	13
E	22	21	19	17	15	14	12	12	14	16	19	22	25	27	29	29	30	30	30	29	28	27	26	24	18	12	30	18
SE	22	21	19	17	15	14	12	12	12	13	16	19	22	24	26	28	29	29	29	29	28	27	26	24	19	12	29	17
S	21	19	18	16	15	13	12	10	9	9	9	10	11	14	17	20	22	24	25	26	25	25	24	22	20	9	26	17
SW	29	27	25	22	20	18	16	15	13	12	11	11	11	13	15	18	22	26	29	32	33	33	32	31	22	11	33	22
W	31	29	27	25	22	20	18	16	14	13	12	12	12	13	14	16	20	24	29	32	35	35	35	33	22	12	35	23
NW	25	23	21	20	18	16	14	13	11	10	10	10	10	11	12	13	15	18	22	25	27	27	27	26	22	10	27	17
Group D Walls																												
N	15	13	12	10	9	7	6	6	6	6	6	7	8	10	12	13	15	17	18	19	19	19	18	16	21	6	19	13
NE	17	15	13	11	10	8	7	8	10	14	17	20	22	23	23	24	24	25	25	24	23	22	20	18	19	7	25	18
E	19	17	15	13	11	9	8	9	12	17	22	27	30	32	33	33	32	32	31	30	28	26	24	22	16	8	33	25
SE	20	17	15	13	11	10	8	8	10	13	17	22	26	29	31	32	32	32	31	30	28	26	24	22	17	8	32	24
S	19	17	15	13	11	9	8	7	6	6	7	9	12	16	20	24	27	29	29	29	27	26	24	22	19	6	29	23
SW	28	25	22	19	16	14	12	10	9	8	8	8	10	12	16	21	27	32	36	38	38	37	34	31	21	8	38	30
W	31	27	24	21	18	15	13	11	10	9	9	9	10	11	14	18	24	30	36	40	41	40	38	34	21	9	41	32
NW	25	22	19	17	14	12	10	9	8	7	7	8	9	10	12	14	18	22	27	31	32	32	30	27	22	7	32	25
Group E Walls																												
N	12	10	8	7	5	4	3	4	5	6	7	9	11	13	15	17	19	20	21	23	20	18	16	14	20	3	22	19
NE	13	11	9	7	6	4	5	9	15	20	24	25	25	26	26	26	26	26	25	24	22	19	17	15	16	4	26	22
E	14	12	10	8	6	5	6	11	18	26	33	36	38	37	36	34	33	32	30	28	25	22	20	17	13	5	38	33
SE	15	12	10	8	7	5	5	8	12	19	25	31	35	37	37	36	34	33	31	28	26	23	20	17	15	5	37	32
S	15	12	10	8	7	5	4	3	4	5	9	13	19	24	29	32	34	33	31	29	26	23	20	17	17	3	34	31
SW	22	18	15	12	10	8	6	5	5	6	7	9	12	18	24	32	38	43	45	44	40	35	30	26	19	5	45	40
W	25	21	17	14	11	9	7	6	6	6	7	9	11	14	20	27	36	43	49	49	45	40	34	29	20	6	49	43
NW	20	17	14	11	9	7	6	5	5	5	6	8	10	13	16	20	26	32	37	38	36	32	28	24	20	5	38	33
Group F Walls																												
N	8	6	5	3	2	1	2	4	6	7	9	11	14	17	19	21	22	23	24	23	20	16	13	11	19	1	23	23
NE	9	7	5	3	2	1	5	14	23	28	30	29	28	27	27	27	27	26	24	22	19	16	13	11	11	1	30	29
E	10	7	6	4	3	2	6	17	28	38	44	45	43	39	36	34	32	30	27	24	21	17	15	12	12	2	45	43
SE	10	7	6	4	3	2	4	10	19	28	36	41	43	42	39	36	34	31	28	25	21	18	15	12	13	2	43	41
S	10	8	6	4	3	2	1	1	3	7	13	20	27	34	38	39	38	35	31	26	22	18	15	12	16	1	39	38
SW	15	11	9	6	5	3	2	2	4	5	8	11	17	26	35	44	50	53	52	45	37	28	23	18	18	2	53	48
W	17	13	10	7	5	4	3	3	4	6	8	11	14	20	28	39	49	57	60	54	43	34	27	21	19	3	60	57
NW	14	10	8	6	4	3	2	2	3	5	8	10	13	15	21	27	35	42	46	43	35	28	22	18	19	2	46	44
Group G Walls																												
N	3	2	1	0	−1	2	7	8	9	12	15	18	21	23	24	24	25	26	22	15	11	9	7	5	18	−1	26	27
NE	3	2	1	0	−1	9	27	36	39	35	30	26	26	27	27	26	25	22	18	14	11	9	7	5	9	−1	39	40
E	4	2	1	0	−1	11	31	47	54	55	50	40	33	31	30	29	27	24	19	15	12	10	8	6	10	−1	55	56
SE	4	2	1	0	−1	5	18	32	42	49	51	48	42	36	32	30	27	24	19	15	12	10	8	6	11	−1	51	52
S	4	2	1	0	−1	0	1	5	12	22	31	39	45	46	43	37	31	25	20	15	12	10	8	5	14	−1	46	47
SW	5	4	3	1	0	0	2	5	8	12	16	26	38	50	59	63	61	52	37	24	17	13	10	8	16	0	63	63
W	6	5	3	2	1	1	2	5	8	11	15	19	27	41	56	67	72	67	48	29	20	15	11	8	17	1	72	71
NW	5	3	2	1	0	0	2	5	8	11	15	18	21	27	37	47	55	55	41	25	17	13	10	7	18	0	55	55

APPENDIX A8

COOLING LOAD TEMPERATURE DIFFERENCES (CLTD) FOR GLASS CONDUCTION

Solar time, h	CLTD °F	Solar time, h	CLTD °F
0100	1	1300	12
0200	0	1400	13
0300	−1	1500	14
0400	−2	1600	14
0500	−2	1700	13
0600	−2	1800	12
0700	−2	1900	10
0800	0	2000	8
0900	2	2100	6
1000	4	2200	4
1100	7	2300	3
1200	9	2400	2

APPENDIX A9

CLTD CORRECTION FOR LATITUDE AND MONTH

Lat.	Month	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	HOR
0	Dec	−3	−5	−5	−5	−2	0	3	6	9	−1
	Jan/Nov	−3	−5	−4	−4	−1	0	2	4	7	−1
	Feb/Oct	−3	−2	−2	−2	−1	−1	0	−1	0	0
	Mar/Sept	−3	0	1	−1	−1	−3	−3	−5	−8	0
	Apr/Aug	5	4	3	0	−2	−5	−6	−8	−8	−2
	May/Jul	10	7	5	0	−3	−7	−8	−9	−8	−4
	Jun	12	9	5	0	−3	−7	−9	−10	−8	−5
8	Dec	−4	−6	−6	−6	−3	0	4	8	12	−5
	Jan/Nov	−3	−5	−6	−5	−2	0	3	6	10	−4
	Feb/Oct	−3	−4	−3	−3	−1	−1	1	2	4	−1
	Mar/Sept	−3	−2	−1	−1	−1	−2	−2	−3	−4	0
	Apr/Aug	2	2	2	0	−1	−4	−5	−7	−7	−1
	May/Jul	7	5	4	0	−2	−5	−7	−9	−7	−2
	Jun	9	6	4	0	−2	−6	−8	−9	−7	−2
16	Dec	−4	−6	−8	−8	−4	−1	4	9	13	−9
	Jan/Nov	−4	−6	−7	−7	−4	−1	4	8	12	−7
	Feb/Oct	−3	−5	−5	−4	−2	0	2	5	7	−4
	Mar/Sept	−3	−3	−2	−2	−1	−1	0	0	0	−1
	Apr/Aug	−1	0	−1	−1	−1	−3	−3	−5	−6	0
	May/Jul	4	3	3	0	−1	−4	−5	−7	−7	0
	Jun	6	4	4	1	−1	−4	−6	−8	0	−7
24	Dec	−5	−7	−9	−10	−7	−3	3	9	13	−13
	Jan/Nov	−4	−6	−8	−9	−6	−3	9	3	13	−11
	Feb/Oct	−4	−5	−6	−6	−3	−1	3	7	10	−7
	Mar/Sept	−3	−4	−3	−3	−1	−1	1	2	4	−3
	Apr/Aug	−2	−1	0	−1	−1	−2	−1	−2	−3	0
	May/Jul	1	2	2	0	0	−3	−3	−5	−6	1
	Jun	3	3	3	1	0	−3	−4	−6	−6	1
32	Dec	−5	−7	−10	−11	−8	−5	2	9	12	−17
	Jan/Nov	−5	−7	−9	−11	−8	−15	−4	2	9	12
	Feb/Oct	−4	−6	−7	−8	−4	−2	4	8	11	−10
	Mar/Sept	−3	−4	−4	−4	−2	−1	3	5	7	−5
	Apr/Aug	−2	−2	−1	−2	0	−1	0	1	1	−1
	May/Jul	1	1	1	0	0	−1	−1	−3	−3	1
	Jun	1	2	2	1	0	−2	−2	−4	−4	2
40	Dec	−6	−8	−10	−13	−10	−7	0	7	10	−21
	Jan/Nov	−5	−7	−10	−12	−9	−6	1	8	11	−19
	Feb/Oct	−5	−7	−8	−9	−6	−3	3	8	12	−14
	Mar/Sept	−4	−5	−5	−6	−3	−1	4	7	10	−8
	Apr/Aug	−2	−3	−2	−2	0	0	2	3	4	−3
	May/Jul	0	0	0	0	0	0	0	0	1	1
	Jun	1	1	1	0	1	0	0	−1	−1	2
48	Dec	−6	−8	−11	−14	−13	−10	−3	2	6	−25
	Jan/Nov	−6	−8	−11	−13	−11	−8	−1	5	8	−24
	Feb/Oct	−5	−7	−10	−11	−8	−5	1	8	11	−18
	Mar/Sept	−4	−6	−6	−7	−4	−1	4	8	11	−11
	Apr/Aug	−3	−3	−3	−3	−1	0	4	6	7	−5
	May/Jul	0	−1	0	0	1	1	3	3	4	0
	Jun	1	1	2	1	2	1	2	2	3	2

APPENDIX A10

RATES OF HEAT GAIN FROM OCCUPANTS

Seated at theater	Theater—Matinee	390	330	225	105
Seated at theater	Theater—Evening	390	350	245	105
Seated, very light work	Offices, hotels, apartments	450	400	245	155
Moderately active office work	Offices, hotels, apartments	475	450	250	200
Standing, light work: walking	Department store, retail store	550	450	250	200
Walking; standing	Drug store, bank	550	500	250	250
Sedentary work	Restaurant[e]	490	550	275	275
Light bench work	Factory	800	750	275	475
Moderate dancing	Dance hall	900	850	305	545
Walking 3 mph: light machine work	Factory	1000	1000	375	625
Bowling[f]	Bowling alley	1500	1450	580	870
Heavy work	Factory	1500	1450	580	870
Heavy machine work; lifting	Factory	1600	1600	635	965
Athletics	Gymnasium	2000	1800	710	1090

APPENDIX A11

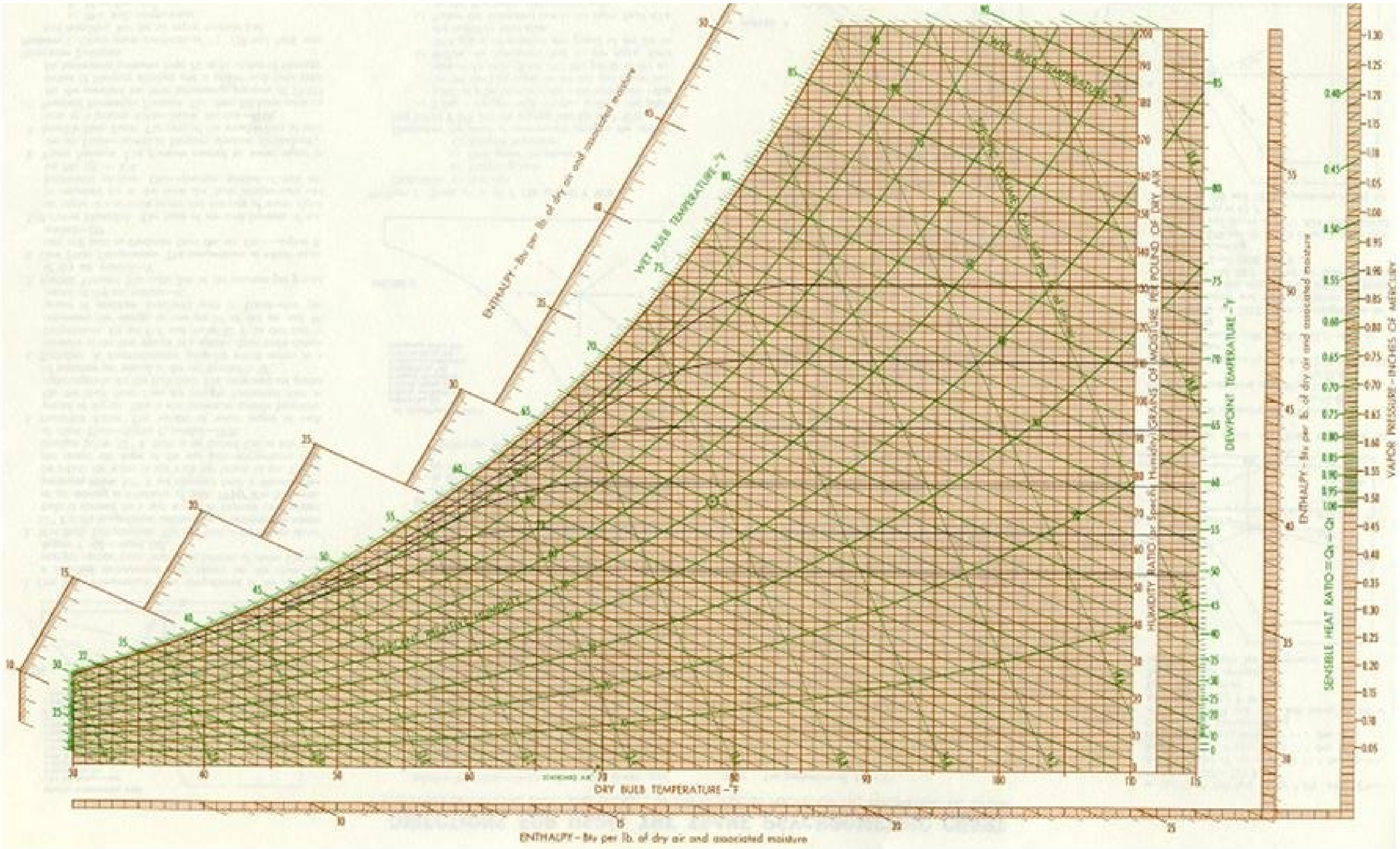
HEAT GAIN FROM EQUIPMENT

Appliance	Size	Recommended Rate of Heat Gain, BTU/hr — Without Hood: Sens.	Without Hood: Latent	Without Hood: Total	With Hood: Sensible
Restaurant, electric blender, per quart of capacity	1 to 4 qt	1000	520	1520	480
Coffee brewer	12 cups/2 brnrs	3750	1910	5660	1810
Coffee heater, per warming burner	1 to 2 brnrs	230	110	340	110
Display case (refrigerated), per ft^3 of interior	6 to 67 ft^3	62	0	62	0
Hot plate (high-speed double burner)		7810	5430	13,240	6240
Ice maker (large)	220 lb/day	9320	0	9320	0
Microwave oven (heavy-duty commercial)	0.7 ft^3	8970	0	8970	0
Toaster (large pop-up)	10 slice	9590	8500	18,080	5800

Appliance	Size		Recommended Rate of Heat Gain, BTU/hr
Computer Devices			
Communication/transmission			5600–9600
Disk drives/mass storage			3400–22,400
Microcomputer/word processor	16–640 kbytes		300–1800
Minicomputer			7500–15,000
Printer (laser)	8 pages/min		1000
Printer (line, high-speed)	5000 or more pages/min		2500–13,000
Tape drives			3500–15,000
Terminal			270–600
Copiers/Typesetters			
Blue print			3900–42,700
Copiers (large)	30–67 copies/min		1700–6600
Copiers	6–30 copies/min		460–1700
Miscellaneous			
Cash register			160
Cold food/beverage			1960–3280
Coffee maker	10 cup	sensible	3580
		latent	1540
Microwave oven	1 ft^3		1360
Paper shredder			680–8250
Water cooler	8 gal/hr		6000

APPENDIX A12

PSYCHROMETRIC CHART



APPENDIX B1

TOTAL COOLING LOAD REQUIRED AT 8AM

[redacted]

APPENDIX B2

TOTAL COOLING LOAD REQUIRED AT 9AM

[redacted]

APPENDIX B3

TOTAL COOLING LOAD REQUIRED AT 10AM

[redacted]

APPENDIX B4

TOTAL COOLING LOAD REQUIRED AT 11AM

[redacted]

APPENDIX B5

TOTAL COOLING LOAD REQUIRED AT 12PM

[redacted]

APPENDIX B6

TOTAL COOLING LOAD REQUIRED AT 1PM

[redacted]

APPENDIX B7

TOTAL COOLING LOAD REQUIRED AT 2PM

[redacted]

APPENDIX B8

TOTAL COOLING LOAD REQUIRED AT 3PM

[redacted]

APPENDIX B9

TOTAL COOLING LOAD REQUIRED AT 4PM

[redacted]

APPENDIX B10

TOTAL COOLING LOAD REQUIRED AT 5PM

[redacted]

APPENDIX B11

TOTAL COOLING LOAD REQUIRED AT 6PM

[redacted]

APPENDIX B12

TOTAL COOLING LOAD REQUIRED AT 7PM

[redacted]