PERFORMANCE EVALUATION OF FKM CENTRAL UNIT AIR CONDITION SYSTEM/CHILLED WATER SYSTEM

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BACHELOR OF ENGINEERING

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Dedicated, truthfully for supports,
encouragements and always be there during hard times, to
my beloved family.

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ABSTRACT

Air conditioning system has been introduced in past several decades in order to serve comfort condition to the humans. Air conditioner is defined as control air movement, temperature, humidity and cleanliness in a needed space. Meanwhile chilled water is to control the movement of water, air, fluid flow and temperature from chiller plant room. There are several types of system where hot air can be removed from a system in the process of refrigeration and air conditioning. Basic air-conditioning systems and chilled water covers four main components including compressor, condenser, throttling valve and evaporator. The process of heat removal can be done by heat transfer directly or indirectly. Since the system been introduced, performance of the system will be the main issues and until now there are many researches still ongoing in order to get the best performance of air conditioning system. Faculty of Mechanical engineering (FKM) in Pekan has started its operation in July 2009 and almost building in the faculty is occupied with air conditioning system. The type of air conditioning system in the faculty is central unit air conditioning system. The performance of the air conditioning system in the faculty becomes an interesting part to be studied to those who are in that field. An informal interview was conducted with officials from the Jabatan Pembangunan dan Pengurusan Harta (JPPH) that is responsible for monitoring this air conditioning system. The problem that arises in the central air conditioning system in the FKM are influences JPPH to cooperate in order to help an individual for analyzing the performance of air conditioning system.The objective of this project is to review the working system and analyze the performance of air conditioners and chilled water system for daily use. In addition, evaluation and review of cooling load is also taken into account for two rooms, specifically name by Computer Lab and Excellent Centre. The heat gain analysis is compulsory conducted in order to estimate performance of central unit air conditioning system. The heat gain for the Computer Lab and Excellent Centre is calculated to be 23.297kW and 39.952kW respectively. Different condition of date were taken and been analyzed which is performances of the system using single chiller running alternately and two chiller running simultaneously. The result shows that when the system is being operated with single chiller simultaneously, the total available cooling capacity can be ranging between 770kW to 810kW. Whereas for two chiller operations, the total available cooling capacity by the chiller is 1246.77kW. The room total load capacity with single chiller in operation alternately, the value load capacity for Computer Lab is ranging from 18.072kW to 20.482kW and for Excellent Centre is 26.746kW to 27.981kW. While for two chiller operations simultaneously, the room total load capacity for Computer Lab is 25.301kW and for Excellent Centre is 42.168kW. It can be conclude that air conditioning system running with single chiller operation is not enough to absorb the heat gain in the particular room in the present of study. Therefore, the system with 2 chiller operation is the best to meet the needs and more systematic guide for the consumer at Faculty of Mechanical Engineering (FKM) in Pekan. Study also emphasizes the relationship between temperature, pressure, flow rate, the amount of cooling and performance of work for each component and total components involved.

ABSTRAK

Sistem penyaman udara telah diperkenalkan dalam beberapa dekad terakhir untuk memberi keselesaan dalam persekitaran kepada manusia. Penghawa dingin ditakrifkan sebagai gerakan kawalan udara, suhu, kelembapan serta kebersihan dalam ruangan yang diperlukan. Sementara itu pendingin air adalah berfungsi untuk mengawal pergerakan air, udara, aliran bendalir dan suhu dari pusat pendingin air. Ada beberapa jenis sistem penghawa dingin dimana udara panas boleh dihilangkan dari sistem melaui proses pendinginan dan penghawa dingin. Dasar penghawa dingin dan pendingin air meliputi empat komponen utama termasuk pemampat, pemeluwap, pengukur injap dan penyejat. Proses pemindahan haba boleh dilakukan dengan *perpindahan haba* secara langsung atau tidak langsung. Sejak sistem ini diperkenalkan, prestasi sistem menjadi isu utama dan sehingga kini masih banyak kajian yang dijalankan untuk mendapatkan prestasi terbaik daripada sistem penghawa dingin. Fakulti Kejuruteraan Mekanikal(FKM) di Pekan telah memulakan operasinya pada bulan Julai 2009 dan hampir keseluruhan bangunan di fakulti ditempati dengan sistem penghawa dingin. Sistem yang diguna pakai oleh fakulti adalah sistem penghawa dingin berpusat. Keupayaan serta prestasi penghawa dingin di fakulti adalah menarik untuk dikaji bagi mereka yang berada dalam bidang itu. Satu temuramah tidak formal telah dilakukan dengan pegawai dari Jabatan Pembangunan dan Pengurusan Harta (JPPH) yang bertanggungjawab memantau sistem penghawa dingin ini. Masalah yang timbul dalam sistem penghawa dingin berpusat di FKM menarik minat JPPH untuk bekerjasama dalam membantu seseorang individu bagi tujuan menganalisa prestasi sistem penghawa dingin tersebut. Tujuan projek ini adalah untuk meninjau sistem kerja dan mempelajari serta menganalisis prestasi sistem pennghawa dingin dan pendingin air bagi penggunaan sehari-hari. Selain itu, penilaian dan peninjauan beban pendinginan juga dihitung untuk dua bilik yang melibatkan Makmal Komputer dan Pusat Kecemerlangan. Analisis *perolehan haba* adalah perlu dilakukan untuk menganggarkan prestasi sistem penghawa dingin berpusat. Perolehan haba untuk Makmal Komputer dan Pusat Kecemerlangan dikira serta nilai yang dihasilkan adalah 23.297kW dan 39.952kW bagi setiap bilik. Tarikh yang berbeza diambil bagi menilai prestasi sistem dengan menggunakan satu pendingin dan dua pendingin yang beroperasi secara bergilir. Keputusan kajian menunjukkan bahawa ketika sistem sedang beroperasi dengan satu pendingin, keseluruhan beban pendinginan yang dihasilkan adalah antara 770kW untuk 810kW. Sedangkan untuk operasi menggunakan dua pendingin, jumalah keseluruhan beban yang dihasilkan oleh pendingin berpusat adalah 1246.77kW. Beban pendinginan yang terhasil dari satu pendingin dalam operasi bergantian adalah sebanyak 18.072kW ke 20.482kW bagi Makmal Komputer dan untuk Pusat Kecemerlangan adalah antara 26.746kW ke 27.981kW. Walhal untuk operasi dua pendingin, jumlah keseluruhan beban pendinginan yang terhasil untuk Makmal Komputer adalah 25.301kW dan untuk Pusat Kecemerlangan adalah 42.168kW. Dapat disimpulkan bahawa sistem penghawa dingin yang beroperasi menggunakan satu pendingin tidak cukup untuk menyerap perolehan haba dalam bilik tertentu pada masa kajian dijalankan. Oleh kerana itu, sistem dengan dua pendingin adalah yang terbaik untuk memenuhi keperluan dan panduan lebih sistematik untuk pengguna di Fakulti Kejuruteraan Mekanikal(FKM) di Pekan. Kajian ini turut menekankan hubungan antara suhu, tekanan, laju alir, jumlah pendinginan dan prestasi kerja untuk setiap komponen dan keseluruhan bahagian yang terlibat.

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A	-	Area, m^2
DR	-	Daily temperature range, ° C
Gr w/kg. d.a	-	Gram wet per kilogram dry air
h	-	Enthalpy, kJ/kg
H	-	Hours
kW	-	Kilowatt
MW	-	Megawatt
m^3/s	-	Meter cubic per second
m^2	-	Meter Square
$\dot{m}$	-	Mass flow rate, kg/s
$\dot{Q}$	-	Volume flow rate, m^3/s
Qevap	-	Evaporator heat absorb/Cooling capacity, W
Qcond	-	Condenser heat reject, W
Q_S, Q_L	-	Sensible and latent cooling loads from ventilation air, kW
R	-	Resistance, m^2.K/W
t	-	Refrigerant temperature, ºC
U	-	Heat transfer coefficient, W/m^2.K
Wcomp	-	Compressor work, W
Wo' – Wi'	-	Outdoor and inside humidity ratio, gr w/kg. d.a
ºC	-	Degree Celsius
%	-	Percentage
W	-	Watt
W/m^2.K	-	Watt per meter square kelvin

LIST OF ABBREVIATIONS

AC	-	Air Conditioning
ACR	-	Air change rate
AHRI	-	Air Conditioning, Heating and Refrigerant Institute
AHU	-	Air Handling Unit
ARI	-	American Refrigeration Institute
ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineer
B.F	-	Ballast factor
BAS	-	Building Automation System
CLF	-	Cooling load factor
CLTD	-	Cooling load temperature difference
COP	-	Coefficient of Performance
CPU	-	Central Processing Unit
CT	-	Cooling Tower
DX	-	Direct Expansion
CHW	-	Chilled Water
EER	-	Energy Efficiency Ratio
FCU	-	Fan Coil Unit
FKM	-	Fakulti Kejuruteraan Mekanikal
HVAC	-	Heating, ventilating and air conditioning
JPPH	-	Jabatan Pembangunan dan Pengurusan Harta
LHG	-	Latent heat gain
RLCL	-	Room latent cooling load
RSCL	-	Room sensible cooling load

RTCL	-	Room total cooling load
SC	-	Shading coefficient
SCL	-	Sensible cooling load
SHG	-	Sensible heat gain
UMP	-	Universiti Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

1.1.1 General Project Background

Air-conditioning is a process that simultaneously conditions air; distributes it combined with the outdoor air to the conditioned space; and at the same time controls and maintains the required space's temperature, humidity, air movement, air cleanliness, sound level, and pressure differential within predetermined limits for the health and comfort of the occupants, for product processing, or both (Shan K. W & Zalman L. 1999). Human comfort which related to air conditioning, heating and ventilating has become one of the most serious issues in the past several decades. These energy consumption issues generally closely related to either in industrial application, residential or transportation. Thus, many research and work have been done in this field to minimize the energy consumption by predicting the humidity and cooling load along with size of the system.

There are many types of air condition system such as central air, hydronics water and air, split, and packages system. All this system is work based on basic vapor compression refrigeration cycle that contains compressor, condenser, metering device and evaporator. Central type air condition usually use for a large cooled area while split and packages system is widely use for residential or for a small office operation. These two major types of air conditioning system have their own advantages and disadvantages based on its power, capacity install, performance factor and working system.

1.1.2 Specific Project Background

This project is carrying out the overview about Faculty of Mechanical Engineering (FKM) building in Pekan. The main purpose is to evaluate the performance of chiller plant at FKM. Generally, Faculty of Mechanical Engineering (FKM) consist of 5 blocks which consists admin block, block 1,block 2,block 3 and block 4. The admin block is fully central air conditioned where are block 1 and block 2 are 80 percent have air condition. While in block 3 and 4, only rooms occupied by staff, preparation room and selected laboratory have the air conditioning. Almost all of rooms, lecture hall, office and laboratory that have air conditioner are supplied by central unit air conditioning system. All the central unit air conditioning system circulated in FKM building has 13 number of system (nos.) of air handling units serving areas like laboratories, lectures hall and administration area. The lectures room, student affair room, labs room are served by 86 nos. of chilled water fan coil units.

In FKM building, an air condition working by using central air conditioning plants which involving the chiller water system and cooling tower. A cooled air is flow regarding to the vapor compression refrigeration cycle which is involve four main components such as compressor, condenser, metering device and evaporator. Chilled water system for FKM building consists of 4 no. of chiller, 4 nos. of cooling towers, 4 nos. of chilled water pumps and 4 nos. of condenser water pumps. The chillers and pumps are located at ground floor chiller plant room and cooling tower is located on top of chiller water plant room.

FKM has started its operation since July 2009; however the system that serves all building in the faculty is not consistent. These problem is occurs by the unstable supply cooled air to the system. As a result, an occupant in the building can’t feel uncomfortable with the performance of air conditioning system. Generally, performance of air conditioning system is depending on the chiller plant capacity supply to the whole space. The air conditioning performance will affect the human comfortable air in the location.

1.2 PROBLEM STATEMENT

The energy consumed in air conditioning and refrigeration systems is sensitive to load changes, ambient condition and etc. The major purpose of air conditioning is to make occupants comfortable with the cooled air in the room. However, the system of air conditioning in FKM building running inconsistent due to the several factor. These problem is occurs by the unstable supply cooled air to the system. As a consequence, the occupants and some location are not receiving a necessary capacity of cooled air.

An interview had been done with the Jabatan Pembangunan dan Pengurusan Harta (JPPH) who involve in the operation of air conditioning system in Pekan campus. As been explained by the person in charge, air conditioning system at Faculty of Mechanical Engineering (FKM) is not operating at optimum condition. Sometime the system was unstable to run according to the design specification. Based on design specification, the chiller requires running at 2 chillers in the same time. However, sometimes the systems are unable running with 2 chillers cause of several factors. From the interview, the conclusion can be made that a research is required to do for analyzing the performance of air conditioning system. The result will be significant to all FKM's to know the level of performance necessary to the system.

1.3 PROJECT OBJECTIVE

The main objectives in this project is to analyze the performance of FKM central unit air condition/chilled water system. This study will be focused on 3 parts:

(i) Required heat gain of particular rooms.
(ii) Performance of chiller plant.
(iii) Room load capacity.

1.4 SCOPE OF PROJECT

There are several scope of work should be considered in these projects which are:

(i) Study and understanding about working system of air conditioning and chiller water system.
(ii) The project focused on measuring the performance of the particular rooms.
(iii) Determine the heat gain for room by using CLTD/CLF method referring to heat coefficient of each component in order to calculate overall heat gain.
(iv) Collect the data from actual condition including from central plant, air handling unit and room.
(v) Cooling load calculation for performance analysis.
(vi) Evaluate the data from the actual working system and justify the factor involving of the performance data.
(vii) Analyze chilled water capacity supplies the buildings.
(viii) Estimation of room total room load capacity receives in the specific location.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Nowadays, the increasing temperature of earth is one of the factors of increasing usage of air conditioning. For example, in Malaysia our average temperature is 30 degrees Celsius and cause of this factor air condition is really important for cooling subject. There are various types of air conditioners in the market according to the desired capacity. For example, central air condition is one of the famous systems devoted to a wide range of places such as supermarket, mall, college, hall and others.

The project is really focus about evaluate and check the performance of central unit. Firstly, the project scope is to mastering the system before making an analysis about the system. To mastering the system there are some methods to do such as study on referring to the journal, articles, lectures and schematic diagram. In this chapter there also show the detail system of central unit air condition / water chiller system. Main component of the system also described details in this chapter. There are including the function of the compressor, condenser, evaporator and throttling valve.

The estimation of cooling load is done by using CLTD/CLF method. This process were done in order to determine the suitable cooling load require for the system. To ensure the room is cool there are various factors should be emphasized including the desired temperature, component in the room, the number of people and also goods that can interfere the cooling room. By consider all these factors we can identify how much air conditioning capacity needed before select the suitable.

2.2 CENTRAL UNIT AIR CONDITION WORKING SYSTEM

Central air conditioner units are energy moving or converted machines that are designed to cool or heat the entire building. This system uses chilled water or hot water from a central plant to cool and heat the air at the coils in an air handling unit (AHU) as shown in Figure 2.1. It does not create heat or cool. (Hundy G.F et al., 2008). It just removes heat from one area, where it is undesirable, to an area where it is less significant or makes no difference. The duct system (air distribution system) has an air handler, air supply system, air return duct and register that circulate warm air from a furnace or cooled air from central air conditioning units to our room.

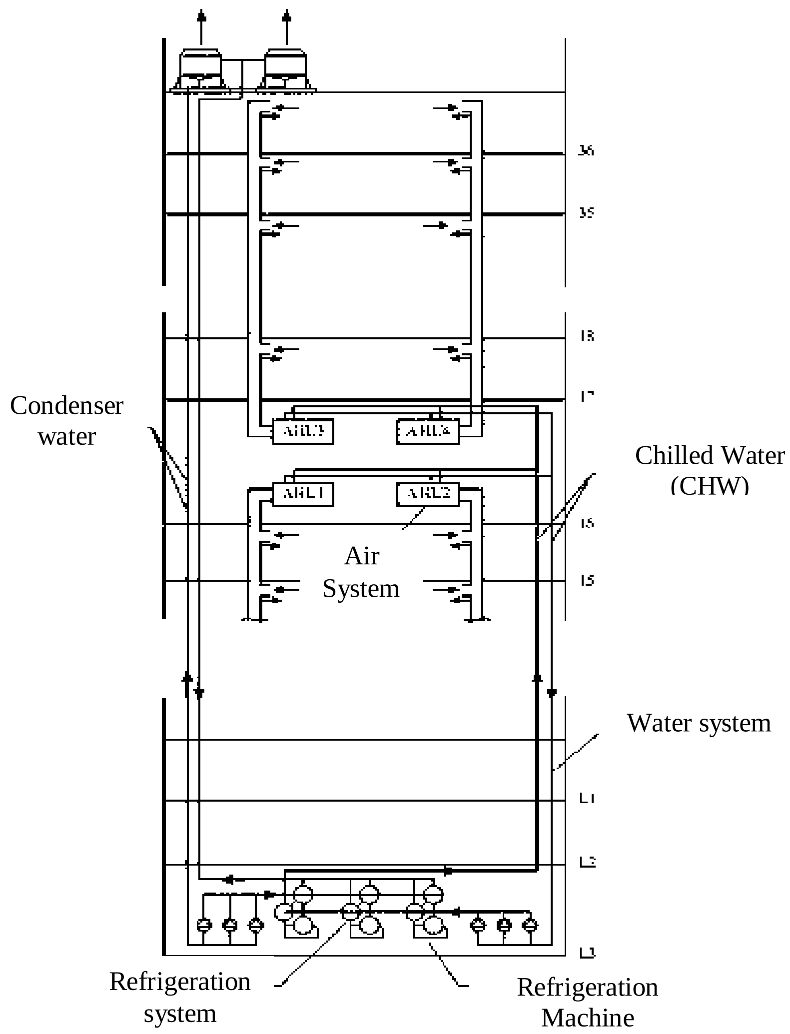

Figure 2.1: Working system of central unit air condition

Source: Hundy G.F, Trott A.R, Welch T.C. (2008)

2.2.1 The Operation Principle

Central air conditioner unit is simply a matter of removing heat from indoor (evaporator coil) to outdoor (condenser unit) by using the four basic mechanical components:

i. Compressor

The purpose of the compressor in the vapor compression cycle is to compress the low-pressure dry gas from the evaporator and raise its pressure to that of the condenser. Compressors may be divided into two types, positive displacement and dynamic. Positive displacement types compress discrete volumes of low-pressure gas by physically reducing the volumes causing a pressure increase, whereas dynamic types raise the velocity of the low-pressure gas and subsequently reduce it in a way which causes a pressure increase. (Hundy G.F et al., 2008). It delivers the refrigerant vapor to the condenser at a pressure and temperature at which the condensing process can be readily accomplished, at the temperature of the air or other fluid used for condensing. Compressor also can push the refrigerant in one cycle continuously. Figure 2.2 shows the compressor.

Figure 2.2: Compressor

Source: McQuay International Company (2009)

ii. Condenser

Typically a condensing coil inside which high temperature high pressure refrigerant gas flows, and over which a fan blows air to cool the refrigerant gas back to a liquid state (thus transferring heat from the refrigerant gas to the air being blown by the fan). The condenser unit is basically a coil of finned tubing and a fan to blow air across the coil. Usually the condenser unit is in the outdoor portion of an air conditioning system and often packaged along with the compressor motor. The change of state of refrigerant from hot high pressure gas to a liquid releases heat including heat collected inside the building to outdoors. Figure 2.3 shows the condenser. (Hundy G.F et al., 2008).

Figure 2.3: Condenser

Source: Wang, S.K. and Lavan, Z. (1999)

iii. Expansion Device

In throttling devices the pressure of the refrigerant drops down suddenly and due to this its temperature also reduces drastically. This low pressure and low temperature liquid refrigerant then enters the evaporator and absorbs heat from the substance or the space to be cooled. This refrigerant flow process through metering device was shown in Figure 2.4. The throttling valve is fitted between the condenser and the evaporator. When refrigerant passes through this small orifice its pressure reduces suddenly due to the friction. The rate of the flow of refrigerant through the throttling device depends on the size and opening of the orifice. It also depends on the difference in pressure on the evaporator and the condenser sides. Throttling valve also controls the amount of liquid refrigerant entering the evaporator coils. (Edward G. P., 1997)The amount of liquid refrigerant entering the evaporator must equal the amount of refrigerant boils in the evaporator coils. Besides that, it’s also maintains a pressure difference between the high and low pressure sides of the system to permit the refrigeration to vaporize. There are two major unit of expansion device which is system capillary tube and thermostatic expansion valve. Differentiation between this two components are the capillary tube are used for small refrigeration system such as wall mount air condition, water cooler and refrigerator while an expansion valve are use in large building with combination of chiller system or central air conditioning system. Thermostatic expansion valve or known as TEV can work in versatile condition. Its can maintaining the proper flow of refrigerant depend upon the heat load in the evaporator. (Jordon R. C. et al., 2007)

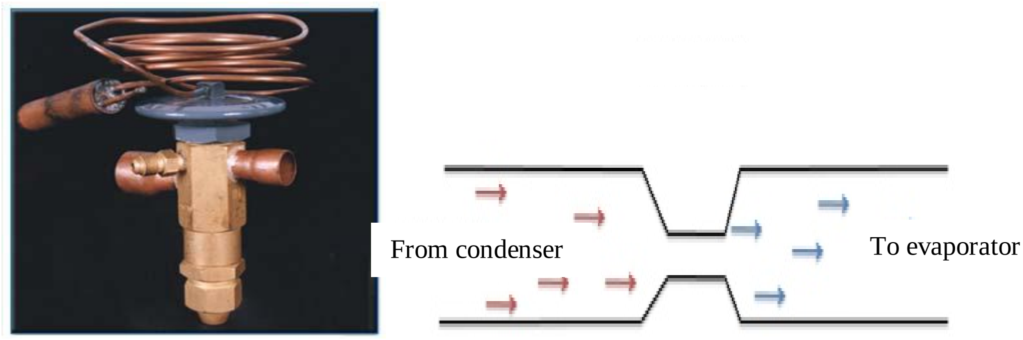

Figure 2.4: Refrigerant flow through metering device

Source: Jordon R. C. & Gayle B.P. (2007)

iv. Evaporator

The evaporator coil is a vital piece of the overall puzzle. It’s a piece of a equipment in a air conditioning system that is useful in sending cold air throughout the ductwork. As air is passed through the system, the coil will absorb the heat and will return get that cold breeze throughout the house. The evaporator coil is usually on top of a furnace and apart from the actual condensing unit as shown in Figure 2.5. Typically the cooling coil is a section of finned tubing (it looks a lot like a car radiator) into which liquid refrigerant is metered and permitted to evaporate from liquid to gas state inside the coil. This state change of the refrigerant, from liquid to gas, absorbs heat, cooling the evaporator coil surface and thus cooling indoor air blown across the cooling coil. Usually the cooling coil is located inside the air handler. (Shan K. W., 2000)

Figure 2.5: Freezing evaporator cooling coil

Source: Shan K. W. (2000)

2.3 TYPE OF CENTRAL UNIT AIR CONDITION

Central air condition is system of cooling the building by using the multi component. This central air condition basically use for large area involving hall, hotel, cinemas, mall and etc. There are two types of central air conditioning plants or systems:

2.3.1 Direct Expansion or DX Central Air Conditioning Plant

In this system the huge compressor and the condenser are housed in the plant room, while the expansion valve and the evaporator or the cooling coil and the air handling unit are housed in separate room. The cooling coil is fixed in the air handling unit, which also has large blower housed in it. The blower sucks the hot return air from the room via ducts and blows it over the cooling coil. The cooled air is then supplied through various ducts and into the spaces which are to be cooled. This type of system is useful for small buildings. In the direct expansion or DX types of air central conditioning plants the air used for cooling space is directly chilled by the refrigerant in the cooling coil of the air handling unit. Since the air is cooled directly by the refrigerant the cooling efficiency of the DX plants is higher. However, it is not always feasible to carry the refrigerant piping to the large distances hence, direct expansion or the DX type of central air conditioning system is usually used for cooling the small buildings or the rooms on the single floor. Figure 2.6 below, show the location of DX system which is consist cooling tower, plant room, direct expansion and space of cooled air supply. (B. Balamugundan., 2008)

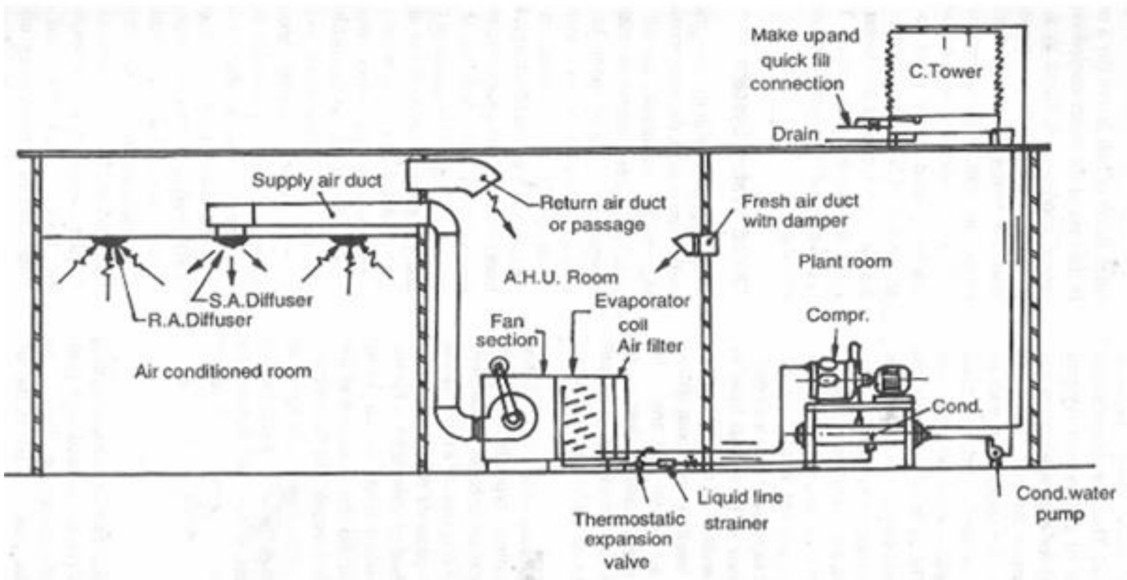

Figure 2.6: Central air conditioning –DX System

Source: Balamugundan. B. (2008)

Direct expansion central air condition had flow into two places such as:

i. The Plant Room:

The plant room comprises of the important parts of the refrigeration system, the compressor and the condenser. The compressor can be either semi-hermetically sealed or open type. The semi-hermetically sealed compressors are cooled by the air, which is blown by the fan, while open type compressor is water cooled. The open compressor can be driven directly by motor shaft by coupling or by the belt via pulley arrangement. The condenser is of shell and tube type and is cooled by the water. The refrigerant flows along the tube side of the condenser and water along the shell side, which enables faster cooling of the refrigerant. The water used for cooling the compressor and the condenser is cooled in the cooling tower kept at the top of the plant room, though it can be kept at other convenient location also.

ii. The Air Handling Unit Room:

The refrigerant leaving the condenser in the plant room enters the thermostatic expansion valve and then the air handling unit, which is kept in the separate room. The air handling unit is a large box type of unit that comprises of the evaporator or the cooling coil, air filter and the large blower. After leaving the thermostatic expansion valve the refrigerant enters the cooling coil where it cools the air that enters the room to be air conditioned. The evaporator in the air handling unit of the DX central air conditioning system is of coil type covered with the fins to increasing the heat transfer efficiency from the refrigerant to the air. There are two types of ducts connected to the air handling unit: for absorbing the hot return air from the rooms and for sending the chilled air to the rooms to be air conditioned. The blower of the air handling unit enables absorbing the hot return air that has absorbed the heat from the room via the ducts. This air is then passed through the filters and then over the cooling coil. The blower then passes the chilled air through ducts to the rooms that are to be air conditioned. Below is the description about air handling unit (AHU) system. (Balamugundan. B., 2008)

2.3.2 Chilled Water Central Air Conditioning Plant

This type of system is more useful for large buildings comprising of a number of floors. It has the plant room where all the important units like the compressor, condenser, throttling valve and the evaporator are housed. The evaporator is a shell and tube. On the tube side the Freon fluid passes at extremely low temperature, while on the shell side the brine solution is passed. After passing through the evaporator, the brine solution gets chilled and is pumped to the various air handling units installed at different floors of the building. The air handling units comprise the cooling coil through which the chilled brine flows, and the blower. The blower sucks hot return air from the room via ducts and blows it over the cooling coil. (Balamugundan. B., 2008) The cool air is then supplied to the space to be cooled through the ducts. The brine solution which has absorbed the room heat comes back to the evaporator, gets chilled and is again pumped back to the air handling unit. Usually these plants are installed in the place where whole large buildings, shopping mall, airport, hotel, etc. While in the direct expansion type of central air conditioning plants, refrigerant is directly used to cool the room air; in the chilled water plants the refrigerant first chills the water, which in turn chills the room air. Figure 2.7 show a chilled water central air condoning plant.

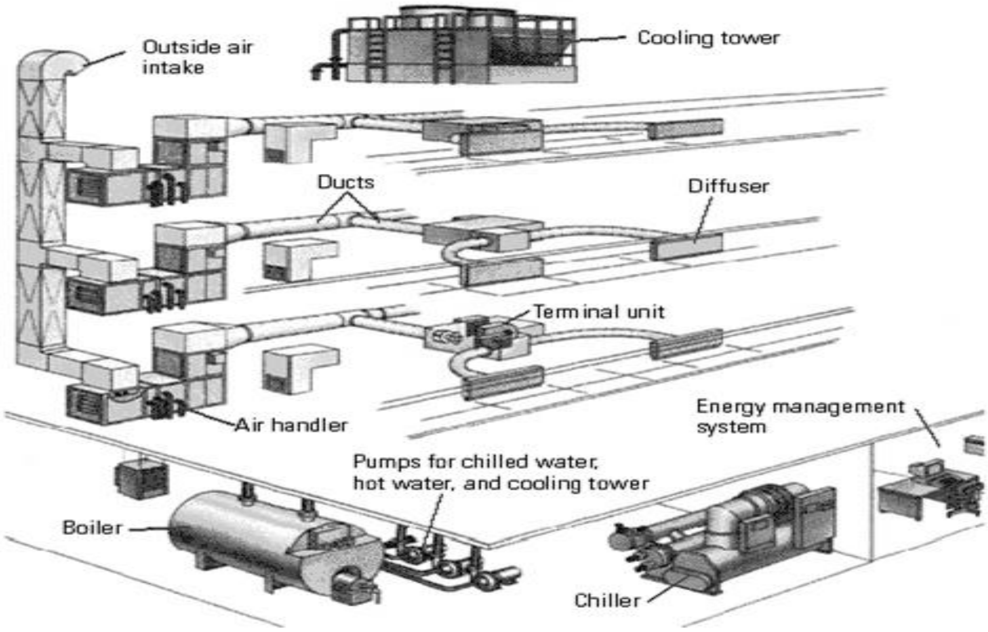

Figure 2.7: Chilled water central air conditioning plant

Source**:** Balamugundan. B. (2008)

This chilled water is pumped to various floors of the building and its different parts. In each of these parts the air handling units are installed, which comprise of the cooling coil, blower and the ducts. The chilled water flows through the cooling coil. The blower absorbs return air from the air conditioned rooms that are to be cooled via the ducts. This air passes over the cooling coil and gets cooled and is then passed to the air conditioned space. In Figure 2.8 shows the movement of chilled water within primary and secondary component.

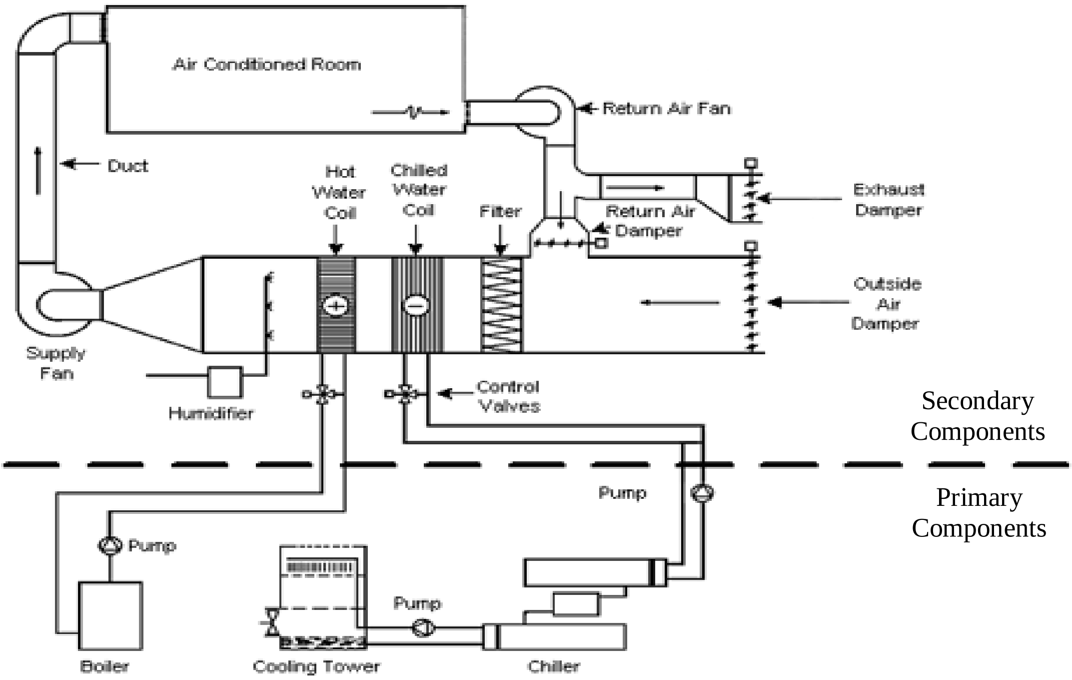

Figure 2.8: Central air conditioning chilled water system

Source: Neil. P. (2002)

2.4 CHILLER PLANT OPERATION

Chilled water is commodity often used to cool a building's air and equipment, especially in situations where many individual rooms must be controlled separately, such as hotel. A chilled-water applied system uses chilled water to transport heat energy between the airside, chillers and the outdoors. These systems are more commonly found in large HVAC installations, given their efficiency advantages. The components of the chiller (evaporator, compressor, an air- or water-cooled condenser, and expansion device) are often manufactured, assembled, and tested as a complete package within the factory. These packaged systems can reduce field labor, speed installation and improve reliability. (Neil. P., 2002)

Alternatively, the components of the refrigeration loop may be selected separately. While water-cooled chillers are rarely installed as separate components, some air cooled chillers offer the flexibility of separating the components for installation in different locations. Another benefit of a chilled-water applied system is refrigerant containment. Having the refrigeration equipment installed in a central location minimizes the potential for refrigerant leaks, simplifies refrigerant handling practices, and typically makes it easier to contain a leak if one does occur. (S.Taylor, P.DuPont, B.Jones, T.Hartman & M.Hydeman, 2000)

Figure 2.9: High efficiency centrifugal chiller

Source: Combined Heating, Cooling & Power Handbook (2002)

2.5 REFRIGERATION CYCLES

The term refrigeration as part of a building HVAC system generally refers to a vapor-compression refrigeration cycle. The process wherein the heat is transfer from a lower temperature region to the higher temperature region is called refrigeration. In the vapor-compression refrigeration cycles, a chemical substance is alternately changes from liquid to gas (vaporized) and from gas to liquid (condensed). Refrigerators are cyclic devices that perform the refrigeration process. The chemical substance (working fluid) used in refrigerators is refrigerants. The refrigerator schematic diagram is shown in Figure 2.10. As shown schematically, Q_L is the magnitude of the heat absorbed to the refrigerator from the cold refrigerated space at a low temperature, T_L and Q_H is the magnitude of the heat rejected to the warm environment at tem a high temperature, T_H, and $W_{net,in}$ is the net work input to the refrigerator that can be obtain from the subtraction of Q_L and Q_H(Cengel Y.A. and Boles M.A. 2007).

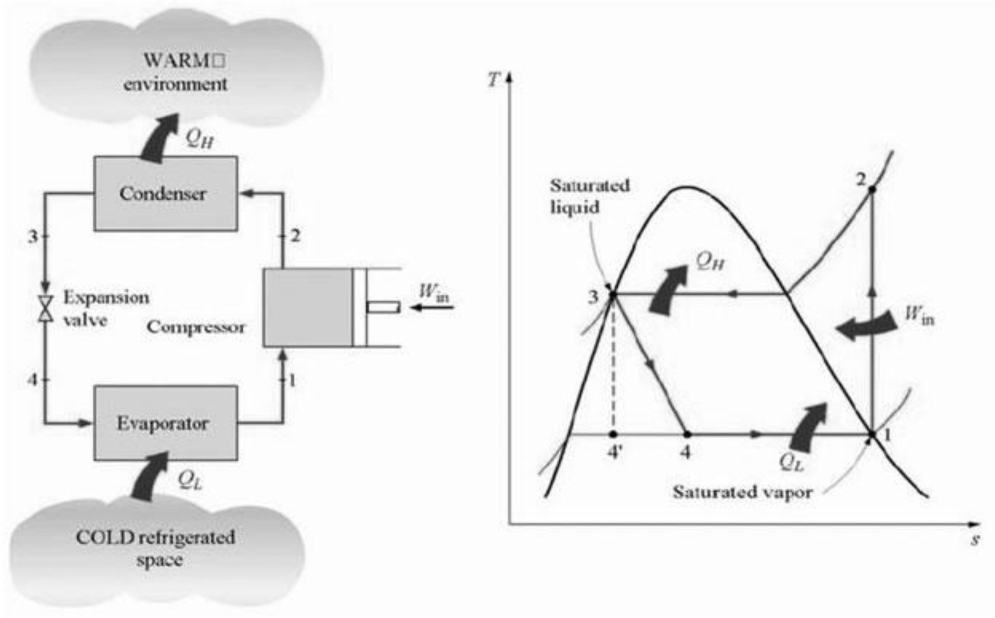

Figure 2.10: Vapor-Compression Refrigeration cycle T-S diagram

Source: Cengel Y.A. and Boles M.A. 2007

2.5.1 Vapor Compression Working System

Compression refrigeration cycles take advantage of the fact that highly compressed fluids at a certain temperature tend to get colder when they are allowed to expand. If the pressure change is high enough, then the compressed gas will be hotter than our source of cooling (outside air, for instance) and the expanded gas will be cooler than our desired cold temperature. In this case, fluid is used to cool a low temperature environment and reject the heat to a high temperature environment. Vapor compression refrigeration cycles have two advantages. First, a large amount of thermal energy is required to change a liquid to a vapor, and therefore a lot of heat can be removed from the air-conditioned space. Second, the isothermal nature of the vaporization allows extraction of heat without raising the temperature of the working fluid to the temperature of whatever is being cooled. This means that the heat transfer rate remains high, because the closer the working fluid temperature approaches that of the surroundings, the lower the rate of heat transfer. The refrigeration cycle is shown in Figure 2.14 and 2.15 and can be broken down into the following stages:

i. 1 – 2. Low-pressure liquid refrigerant in the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

ii. 2 – 3. The superheated vapor enters the compressor where its pressure is raised. The temperature will also increase, because a proportion of the energy put into the compression process is transferred to the refrigerant.

iii. 3 – 4. The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process (3-3a) de-superheats the gas before it is then turned back into liquid (3a-3b). The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b - 4), so that the refrigerant liquid is sub-cooled as it enters the expansion device.

iv. 4 – 1. The high-pressure sub-cooled liquid passes through expansion device, which both reduces its pressure and controls the flow into the evaporator. (Electrical Energy Equipment , 2006)

The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Figure 2.11 provides a schematic diagram of working cycle flow and the component output of the refrigeration vapor compression cycle.

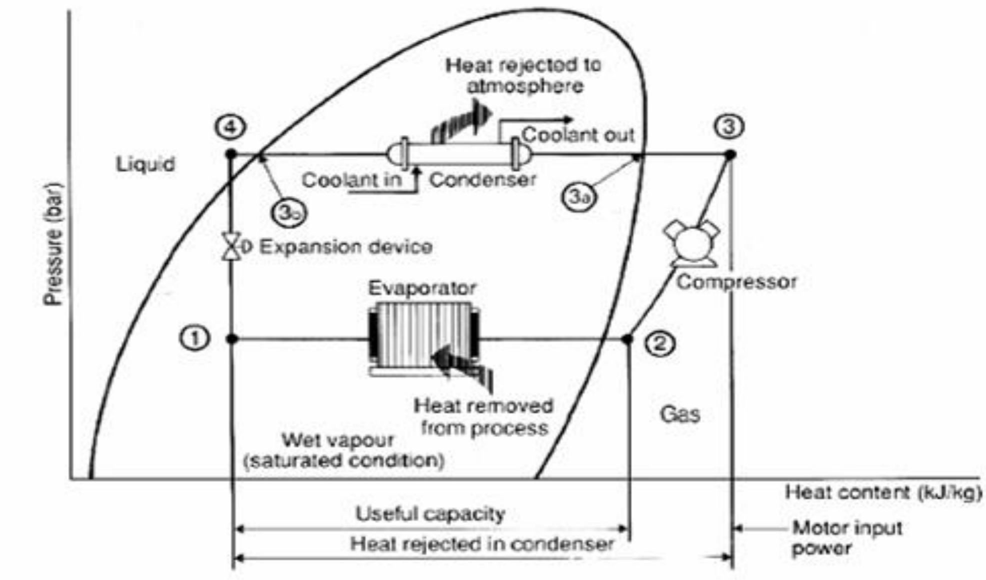

Figure 2.11: Schematic of the refrigeration cycle including pressure changes

Source: Electrical Energy Equipment (2006)

2.6 COOLING TOWERS

Cooling towers come in a variety of shapes and configurations. These towers can be crossflow or counterflow and use axial fans. Most field-erected cooling towers are the induced draft type. “Field-erected” towers mostly serve very large chiller plants and industrial/utility projects. Because the air discharges at a high velocity, they are not as susceptible to recirculation. The large blades of the axial fan can create noise at low frequencies that is difficult to attenuate and, depending on the location on the property, could cause problems. The axial fans have either a belt drive or direct (shaft) drive. Direct drive fans use gear reducers to maintain the low speeds of the fan. Belt drive towers have the disadvantage that the motor and belts are located within the moist air stream of the tower exhaust, making them more susceptible to corrosion and fouling and more difficult to maintain. Belt drive towers usually cost less than towers with direct drives. Belt drive towers allow the use of “pony” motors as a means of speed control. (S.Taylor, P.DuPont, B.Jones, T.Hartman & M.Hydeman, 2000). Figure 2.12 shows working system of induced draft towers.

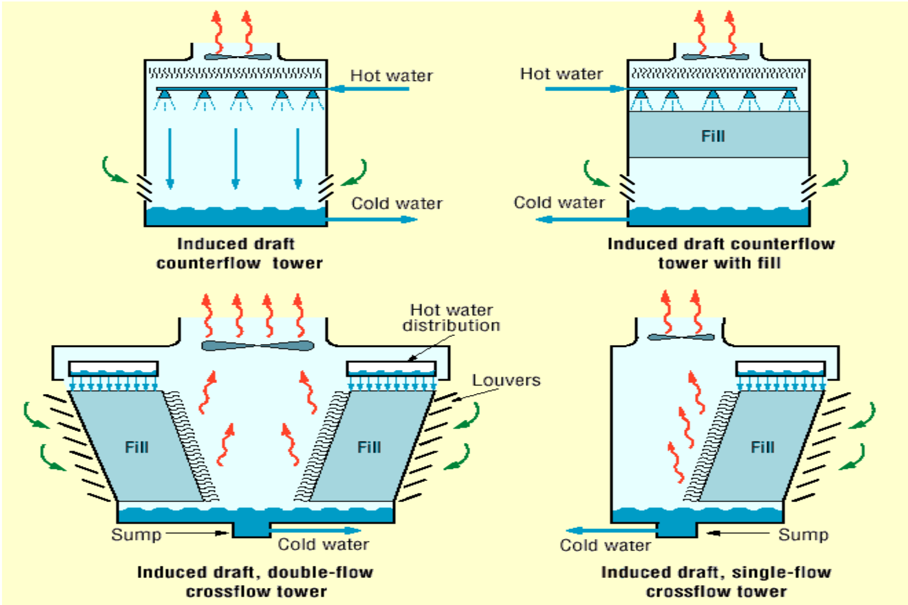

Figure 2.12: Induced draft towers

Source: S.Taylor, P.DuPont, B.Jones, T.Hartman & M.Hydeman (2000)

2.7 COOLING LOAD

The undifferentiated heat flow into a building or space generally are described as 'heat gain' means that, the amount of heat flowing into the building or space resulting from any sources that produce the heat is 'heat gain'. The sources could be building occupants, lights, appliances, and from the environment, mainly solar energy. The portion of heat gain that would affect the air temperature (as opposed to building material and content) at a given point in time is usually known as the cooling load (Pita E.G. 1998). This portion of heat gain will raise the temperature in the space or building, thus gives uncomfortable environment. In other words, cooling load is the amount of heat that must be removed from a building to maintain a comfortable temperature for its occupants. The cooling load is the basis for selection of the proper size air conditioning equipment and distribution system. It is also important in analyzing the energy use and conservation.

In the cooling process, rate of heat received (heat gain) is not equal to the heat removed (cooling load) from a space or building due to the heat storage and time lag effects. Based on Figure 2.13, amount of heat gain entering the building at any time is divided to two parts. A portion of it heats the room air immediately through convection and other part is drawn to furnishings and building structure such as roof, walls and floors through radiation process. This radiation process can be described as heat storage effect. The heat stored in furnishings and structures then heats the room air through convection after delayed time. This is the time lag effect.

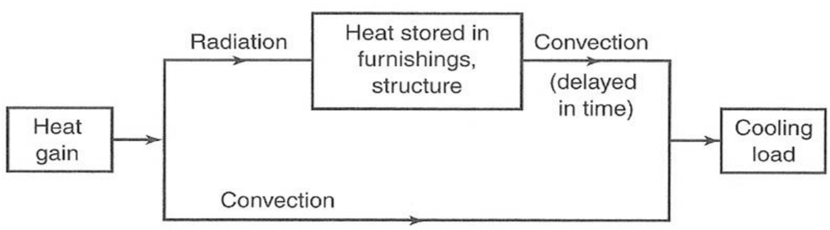

Figure 2.13: Heat flow diagram showing building heat gain, heat storage, and cooling load

Source: Pita E.G. (1998)

The heat storage effect and time lag effect causes the differences between the amount of cooling load and the amount of entering heat (instantaneous heat gain). The instantaneous heat gain is less than cooling load on the morning. The instantaneous heat gain reach a peak value at afternoon and at the same time, the cooling load is less than instantaneous heat gain. This is because of the storage effect wherein a portion of this heat is stored in the building structure and furnishings, and is not heating the room air. Later in the day, the stored heat plus some of the new entering heat is released to the room air, increases the cooling load, thus, the cooling load becomes greater than the instantaneous heat gain. (Pita E.G. 1998)

2.7.1 Sensible Cooling Heat versus Latent Heat

The process of comfort heating and air conditioning is simply a transfer of energy from one substance to another. This energy can be classified as either sensible or latent heat energy. Sensible heat is heat energy that, when added to or removed from a substance, results in a measurable change in dry-bulb temperature. Changes in the latent heat content of a substance are associated with the addition or removal of moisture.

Latent heat can also be defined as the “hidden” heat energy that is absorbed or released when the phase of a substance is changed. For example, when water is converted to steam, or when steam is converted to water. (Pita E.G. 1998)

2.8 FKM COMPONENT SYSTEM

FKM central unit air condition / chiller water system were covered 4 building including administration building, block 1, block 2, block 3 and block 4. Each block of them have 3 storey (Ground, First and Second floor). All of the buildings have the main supply called Air Handling Unit (AHU) as medium for distributed cool air to the room, hall, office or others place. This system function running on the basic air conditioning and refrigeration system contains evaporator, condenser, expansion valve and compressor.

2.8.1 Centrifugal Chiller

Centrifugal chillers have the highest full-load efficiency ratings of all the chillers discussed. They are available in sizes from 80 tons to 10,000 tons but the most common sizes are from 200 to 2000 tons. Centrifugal chillers use high-pressure refrigerants R-22 and R-134a and low-pressure refrigerant R-123. They are available in both air-cooled and water-cooled versions but because of very low COPs and very high initial cost, air-cooled centrifugal chillers are very seldom used. Water-cooled centrifugal chillers have COPs that range from 5.5 to 7.1 (0.64 to 0.49 kW/ton). Centrifugal chillers are usually controlled with inlet guide vanes which allow for full modulation to as low as 10% to 15% capacity (with condenser water relief). Note that chiller efficiency drops off severely at low loads. Variable-speed drives can be added, as discussed above, to enhance the part-load operation characteristics but because of the high cost of the drives, the value of this option must be carefully evaluated. Because of the economics of centrifugal chiller manufacturing, there are product differences among all the major manufacturers. In Figure 2.14 shows centrifugal chiller in FKM chiller plant room.

Figure 2.14: Centrifugal chiller in FKM building

2.8.2 Air Handling Unit (AHU)

Air Handling Unit (AHU) consist of primary filter, chilled water cooling coil and double inlet, double width backward curve centrifugal supply air fan, all of which are housed in insulated sheet metal housing. There is also a return air plenum connected to each of the AHU for air return to the unit. These AHUs are located at various AHU room located at every floor. Conditioned air from AHU is supplied to the space via an insulated of sheet metal reticulation supply ductwork system. The supply air after flowing through the ductwork is distributed and discharged to the space by several 4-way throw diffusers. Return air from air conditioned space is returned to the AHU via the return air grilles, passing through and internally acoustic lined duct which is connected to return air plenum box. The return air is then mixed with fresh air in the plenum before entering the coil. Fresh air is drawn into the air plenum by a volume control damper which is connected to the return air plenum. This damper can be control manually by a driving shaft. Filter is function to remove dust particles prior entering the AHU. On the leaving filters, the air is drawn through a chilled water cooling coil and is cooled before passing through the AHU blower into the supply air duct system. Figure 2.15 shows an actual air handling unit.

Figure 2.15: Air Handling Unit (AHU) in FKM building

2.8.3 Expansion and Make Up Tank

A make up tank is located on the top of chiller water plant. It’s placed near the cooling tower for this system if there any water loss due maintenance or others reason. Due to chilled water piping system is sealed loop, an expansion tank has been incorporated into the system as well to allow water expansion and contraction due to changes in temperature.

2.8.4 Interfacing with HVAC BAS Sub System

Building automation describes the functionality provided by the control system of a building. Building automation system (BAS) is an example of a distributed control system. The control system is a computerized, intelligent network of electronic devices, designed to monitor and control mechanical and lighting systems in a building. The chiller water system for air conditioning is design to operate by BAS. In UMP, BAS system can also read chiller water supply and return temperature, chiller water pressure and water flow rate, running amps and power factor for AHU’s. The BAS functionality reduces building energy and maintenance costs when compared to a non-controlled building. BAS is often referred to as an intelligent building system.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is purposely discussed about the preparation on the actual testing. Its including the basic equation will use for determine the cooling load as well as the performance. Before doing the calculation, there are some method needs to be determined. At this point, an explanation about an actual system had been described. In other words, this chapter on a beginning journey before reaches an objective. The characteristics of the component and the structure also explained here into order to understand the purpose of work for the project. For general methodology, there were started with brain storming before collecting the data from journal, articles, books and other sources. In previous chapter, detailed explanation about the central air condition units. Thus, the information can be used as guidelines to carry out this project.

3.2 RESEARCH FLOWCHART

Research flow chart has been developed as a guide to the project in order to enactive the research is conducted successfully. In Figure 3.1 is showed the detail of testing flow work.

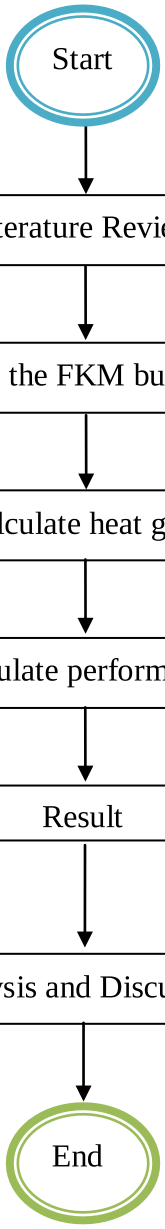

Figure 3.1: Research flowchart

i. Literature Review

Project starts with literature study about the fundamental of the project. Classification of air conditioning/chiller water flow, refrigerant system, heat gain, cooling load, and coefficient of performance need to be study in order to evaluating the system will undergo smoothly. For example study system is differentiation between the large system and small system regarding to the cooling capacity space.

ii. Reviewing FKM building plan

Purpose to review the FKM building is for calculate the dimension of certain room which need to find heat gain. Besides that, the characteristics of building need to be finding before calculating cooling load are made.

iii. Calculate heat gain

To calculate heat gain, some data should be taken from the building automation system (BAS). The data involve ambient temperature, room temperature, relative humidity of specific room and range temperature. From the heat gain calculation, there should determine the total cooling load needed by the room. Hence, the capacity of load from chiller plan need to be higher to cooled the room. There are several formulas used in the Cooling Load Factor (CLF)/Cooling Load Temperature Difference (CLTD) method based on classification of loads.

iv. Calculate performance

To obtain a comfortable temperature for each room, things to be taken into account is the performance of each component. For calculate the performance, there are some parameters should be determined at first as a record for data log taking. The parameters involved in determining the performance of central unit air condition are temperature, pressure, motor power, flow rate, and cooling system working. This parameter is a guideline to calculate efficiency and capacity usage of the central unit air condition. An important thing for this step is to compare the actual data with the manufacture data.

v. Results

There are two calculations before get the performance result. For the 1st calculation, the method use is CLF and CLTD method to determine the cooling load necessary for the specific room that had been selected. While the 2nd calculation is for determine the performance from the chiller by using energy balances equation in order to determine the capacity usage per chiller. In order to get the performance factor of the system, the selected room was test based on combination between cooling load and performance calculation.

vi. Analysis and Discussion

From the result, the analysis the data were made. The factor that involving in calculation step need to state such as the heat gain that produces by radiation and conduction. This involving factor is dividing by two major which is external heat and internal heat in order to determined cooling load. Besides that, other factor involving is temperature, weather, number of chiller, and orientation of chilled water. Evaluating of performance in chiller plant also occur as this stage. For further analysis, there had undergo an analysis about the flow from plant unit until to the room. At from an analysis, the room total sensible heat also had been determined.

3.3 FKM CHILLER WATER WORKING SYSTEM

There are 2 chiller system serving FKEE and FKM independently. For this project, only focus for FKM chiller water whose consists of 4 nos. of chiller, 4 nos. of cooling towers, 4 nos. of chilled water pumps and 4 nos. of condenser water pumps. The chillers and pumps located at ground floor chiller plant room while cooling tower located on roof top of chiller plant room. The chiller water pumps circulated chilled water from chiller side to every Air handling unit (AHU) and fan coil unit. However, condenser water pumps circulated condenser water from chillers to cooling towers in order to reject the heat generated to by using cooling tower fans. The chiller water pumps is circulated to all the AHUs and FCUs in the building via one set of preinsulated black steel class “B” chiller water pipe. Before the water is circulated to the AHUs and FCUs the chiller water is passing through flow meter and temperature sensor where BTU consumption of the building measured.

The heat rejection of AHUs and FCUs is passed through chiller water to chillers. The chiller subsequently transferred the heat from chiller water side to condenser water side. The warm return chilled water from AHUs, enters the chillers is chilled by transferring heat to the cold refrigerant liquid. After absorption heat from warm return chilled water, the refrigerant liquid transform to vapor condition. The refrigerant vapor is then passed through compressor in which further compression is occurred at this stage. The refrigerant vapor will become very warm and is flowed through condenser chamber. Here, the heat from refrigerant is transferred to cold supply condenser water. After absorbing heat from refrigerant vapor, the hot condenser water is return back to cooling tower via condenser water pipe. The hot condenser water is discharge into distribution basin with patented intricate design in the cooling tower.

Meanwhile, the cooling tower fan drew air from atmosphere into the cooling tower. This air is drawn cross flow to the hot condenser water and absorbed the heat from it. This process is called evaporation. After absorbing heat from the hot condenser water, this hot air is discharge to the atmosphere via the cooling tower fan. Once the hot air is cooled by air, it dropped to cold water basin and is then recirculated back to chillers, thus forming a condenser water circulation. The cold supply chilled water is pumped from chiller by chiller water pumps and distributed to all AHUs before supply to the rooms. The chilled water after passing through cooling coil is then flowed back to chillers again, forming a chilled water circulation.

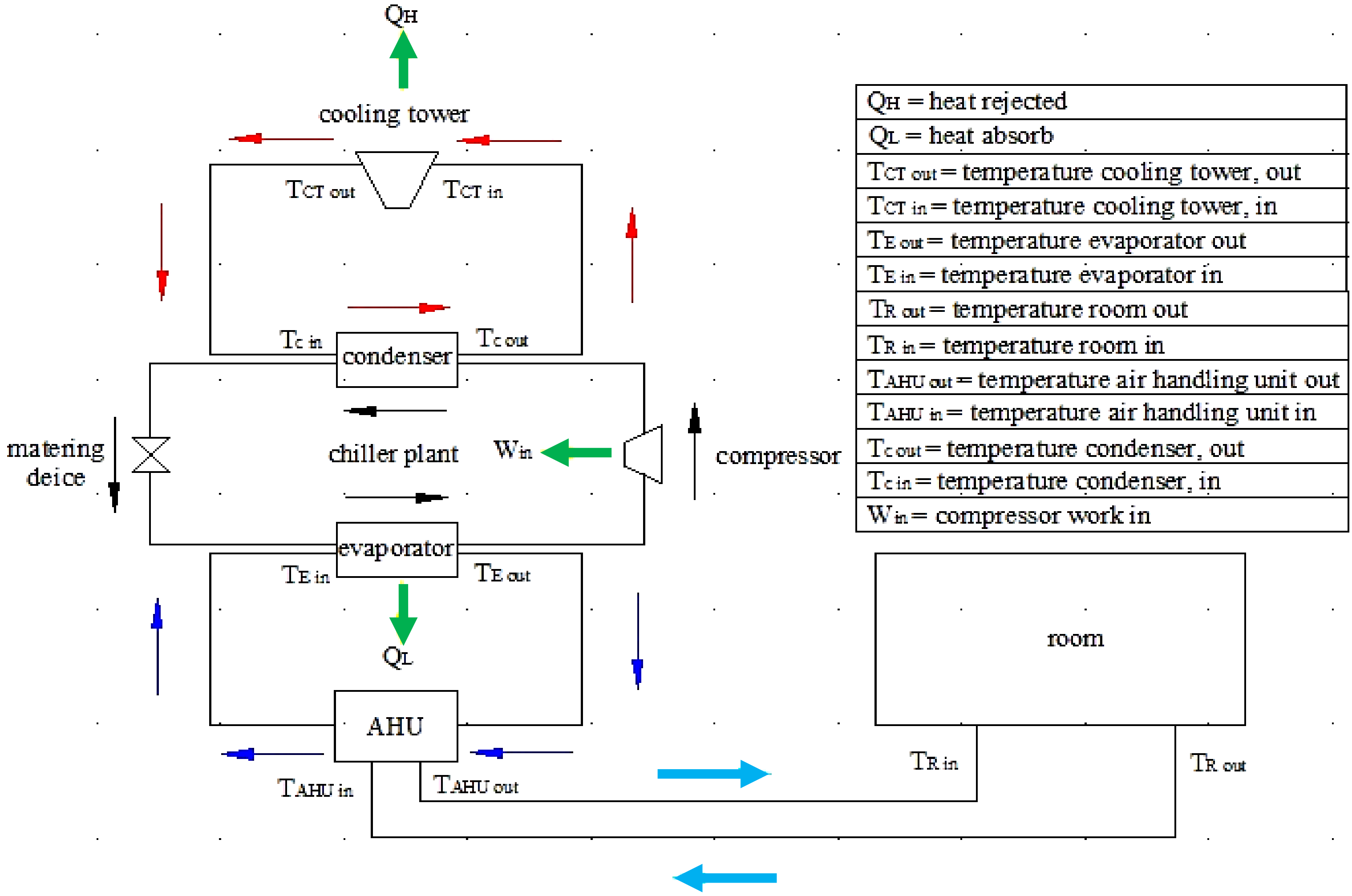

Figure 3.2: System flow of FKM central unit air condition/chiller water

3.4 HEAT GAIN CALCULATION

In heat gain calculation, there are eight number of parameter to be determined. These parameters are discussed as below:

i. Conduction of Heat Gains Through the Exterior Roof, Walls, and Glass

$$Q = U \times A \times CLTD_C \quad (3.1)$$

Source: ASHRAE Fundamentals (1997)

Where;

Q = cooling load for roof, wall, or glass, kW

U = overall heat transfer coefficient for wall, or glass, $W/m^2.^oC$

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

CLTDc = corrected cooling load temperature difference, ^oC

ii. Solar Radiation Through Glass

$$Q = A \times SC \times SCL \quad (3.2)$$

Source: ASHRAE Fundamentals (1997)

Where;

Q = solar radiation cooling load for glass, (kW)

SC = shading coefficient

SCL = solar cooling load, $W/m^2.^oC$

A = area of the glass, (m^2)

iii. Heat Transfer Coefficient

$$U = \frac{1}{\Sigma R} \quad (3.3)$$

Source: ASHRAE Fundamentals (1997)

Where;

U = heat transfer coefficient, $W/m^2.^oC$

ΣR = overall (total) thermal resistance, $m^2.^oC/W$

n = type of thermal resistance

iv. Corrected Cooling Load Temperature Different, CLTDc

$$CLTDc = CLTD + (25.5 - Tr) + (Ta - 29.4) \qquad (3.4)$$

Source: ASHRAE Fundamentals (1997)

Where;

CLTDc	= corrected value of CLTD,^{o} C
CLTD	= cooling load temperature different, ^{o} C
Tr	= room temperature, ^{o} C
Ta	= average outside temperature on a design day, ^{o} C

Available CLTD condition:

a) Indoor temperature is 25.6 ^{o}C
b) Outdoor average temperature on the design day is 29.4 ^{o}C
c) Date is July 21st
d) Location is 40^{o}N latitude.

$$Ta = Tm - (DR/2) \qquad (3.5)$$

Where;

Tm	= outside design dry bulb temperature,^{o} C
DR	= daily temperature range,^{o} C

v. Heat Gain from Lighting

$$Q = W \times BF \times CLF \qquad (3.6)$$

Source: ASHRAE Fundamentals (1997)

Where;

Q	= cooling load from lighting
W	= lighting capacity, (watts)
BF	= ballast factor
CLF	= cooling load factor for lighting

vi. Heat Gain from People

$$Q_S = q_S \times n \times CLF \quad (3.7)$$

$$Q_L = q_L \times n \quad (3.8)$$

Source: ASHRAE Fundamentals (1997)

Where;

Q_S, Q_L = sensible and latent heat gains (loads)

q_S , q_L = sensible and latent heat gains per person

n = number of people

CLF = cooling load factor for people

vii. Heat Gain from Appliances

$$Q = q \times n \times CLF \quad (3.9)$$

Source: ASHRAE Fundamentals (1997)

Where;

q = heat gain per equipment

n = number of equipment

CLF = cooling load factor for appliances

viii. Heat Gain from Ventilation

$$Q_S = 1210 \times \dot{Q} \times \Delta T \quad (3.10)$$

$$Q_L = 3010 \times \dot{Q} \times (Wo' - Wi') \quad (3.11)$$

Source: ASHRAE Fundamentals (1997)

Where;

Q_S, Q_L = sensible and latent cooling loads from ventilation air, kW

$\dot{Q}$ = air ventilation rate m^3/s

ΔT = temperature change between outdoor and inside air,° C

Wo' – Wi' = outdoor and inside humidity ratio, gr w/kg. d.a

Besides the eight parameters that need to be determining, building specification also play important role and significantly contributes into those calculation.

Table 3.1 shows the specification of building wall, door and glass. The specification was obtained from the architectural drawing of FKM building. Appendix B shows the detail drawing of whole building of Administration block. The detail of drawing includes the dimensions, type of material use and direction of building. The specification of material is taken from ASHRAE handbook 1997 in order to determining the cooling load for Computer Lab and Excellent Centre.

Table 3.1: FKM building specification

Structure	Material	
	Actual	**Refer to ASHRAE handbook**
Wall	110mm thick brick wall with 20mm thick cement plaster on both side with groove line externally.	With Indoor moving air and outdoor moving air and 100mm face brick with 100mm low density concrete block. Also Inside surface resistance with 20mm plaster and 25mm insulation
Door	Timber solid door	Timber solid door
Window/glass	Natural anodized aluminium frame top hung glass window	Single glass aluminum with thermal break frame

3.5 PERFORMANCE TEST

The purpose of performance test in FKM central unit is to verify the performance of a refrigeration system, air conditioning and chiller water system by using field measurements. The test will measure net cooling capacity (tons of refrigeration) and energy requirements, at the actual operating conditions. The energy consumed in air conditioning and refrigeration systems is sensitive to load changes, seasonal variations, operation and maintenance, ambient conditions etc.

3.5.1 Inspection/Log Data

Table 3.2 shows the log data reading of FKM chiller plant system. The parameter of the data will be taken and fill in into this data log. From the data collection, the result can be calculated based on performance equation. The result consists the several outputs such as cooling load capacity, coefficient of performance and the capacity require for the FKM chiller plant.

Table 3.2: Log data reading

Date				
Time				
Parameter		Description	Data 1	Data 2
Compressor		Suction temperature (°C)		
		Discharge temperature (°C)		
Cooler	Refrigerant	Suction pressure (kpa), P_{rs}		
	Liquid	Inlet temperature (°C), $T_{ch\ in}$		
		Inlet pressure(kpa), $P_{ch\ in}$		
		Outlet temperature(°C), $T_{ch\ out}$		
		Outlet pressure(kpa), $P_{ch\ out}$		
		Flow rate (kg/s)		
Condenser	Refrigerant	Discharge pressure(kpa), P_{rd}		
		Corresponding temperature(°C)		
		High pressure liquid temperature(°C)		
	Water	Inlet temperature (°C)		
		Inlet pressure(kpa)		
		Outlet temperature (°C)		
		Outlet pressure (kpa)		

3.5.2 Functional Performance Testing

Functional performance tests shall determine if the chilled water system is providing the required cooling services in accordance with the final design intent. The functional performances test can be use to determine the installed capacity of the cooling plant, and heat transfer components. Following is a list of test examples:

a) Procedures shall include a performance checklist and performance test data sheets for each system based on actual system configuration. Special emphasis shall be placed on testing procedures that shall conclusively determine actual system performance and compliance with the design intent.

b) Determine capability of chilled water system to deliver chilled water at the design supply temperature, and required rate of flow.
c) Determine as-installed operating efficiency (kW/ton) of chillers.
d) Determine the ability of the HVAC unit to deliver the cooling and/or heating services to the distribution system, at the design supply air temperature, required static pressure, and proper outside air ventilation rate.

3.5.3 Performance Terms and Definitions

There are four important terms describing performance of central unit air conditioning system. Below are the terms and its specific definition:

(a) Tons of refrigeration (TR): One ton of refrigeration is the amount of cooling obtained by one ton of ice melting in one day: 3024 kCal/h, 12,000 Btu/h or 3.516 thermal kW.
(b) Net Refrigerating Capacity. A quantity defined as the mass flow rate of the evaporator water multiplied by the difference in enthalpy of water entering and leaving the cooler, expressed in kCal/h, tons of Refrigeration.
(c) kW/ton rating: Commonly referred to as efficiency, but actually power input to compressor motor divided by tons of cooling produced, or kilowatts per ton (kW/ton). Lower kW/ton indicates higher efficiency.
(d) Coefficient of Performance (COP): Chiller efficiency measured in Btu output (cooling) divided by Btu input (electric power).

3.5.4 Performance Calculations

Several parameter of performance have been discussed in this work such as net refrigeration capacity, heat rejected, compressor work and coefficient of performance. The net refrigeration capacity is a measurement of the net heat removed from the water as it passes through the evaporator by determination of the water flow rate and temperature difference between entering and leaving water. The net refrigeration capacity is obtained by the following equation:

$$\text{Net refrigeration Capacity (TR)} = \dot{m} \times Cp \times (Tin - Tout) \tag{3.12}$$

Where,

- $\dot{m}$ - Mass flow rate of chilled water, kg/s
- Cp - Specific heat, kJ/kg.K
- Tin - Refrigerant temperature at evaporator/condenser inlet K
- Tout - Refrigerant temperature at evaporator/condenser outlet K

$$\text{Coefficient of performance, COP} = \frac{\text{kW refrigeration effect}}{\text{kW input}} = \frac{Q_L}{W_{in}} \tag{3.13}$$

* COP and EER is same thing to calculate efficiency but difference in unit. They have own value standard rating for central air conditioning system. EER for central air conditioning is 13 while its COP value is around 3.5 and above.

$$\text{Power per Ton, kW/Ton} = \frac{\text{kW input}}{\text{Tons refrigeration effect}} \tag{3.14}$$

Refrigerant Output, Q_r (W)

$$Q_r = \dot{m}_r \times (h_1 - h_4) = \dot{m}C_p\Delta T = \dot{m}\,\Delta h \tag{3.15}$$

Where,

Q_r	=	Refrigeration capacity, W
$\dot{m}$	=	Water mass flow rate, kg/s
$\dot{m}_r$	=	Refrigeration mass flow rate, kg/s
h	=	Enthalpy, kJ/kg
C_p	=	Specific heat for refrigerant, kJ/kg.K
ΔT	=	Temperature different between inlet compressor and outlet of throttling valve, °C
Δh	=	Enthalpy different between inlet compressor and outlet of throttling valve, kJ/kg

The standard relationship between COP, EER and net refrigeration capacity is stated in Table 3.3.

Table 3.3: Others efficiency equations

COP = 0.293 EER	EER = 3.413 COP
kW/Ton = 12 / EER	EER = 12 / (kW/Ton)
kW/Ton = 3.516 / COP	COP = 3.516 / (kW/Ton)

Source: American Refrigeration Institute (ARI)

Actual Compressor work, W_a (kJ/kg)

$$W_a = (h_2 - h_1) \qquad (3.16)$$

Actual Coefficient of performance, ε_a

$$COP_a = (h_1 - h_{3/4})/W_a \qquad (3.17)$$

Theoretical Compressor Work, W_t (kJ/kg)

$$W_t = (h'_2 - h_1) \qquad (3.18)$$

Where,

h'_2 for isentropic compression

Theoretical Coefficient of performance, ε_t

$$COP_t = (h_1 - h_{3/4})/W_t \qquad (3.19)$$

3.7 PRESSURE ENTHALPY CHART

Generally, P-h chart is divided into general areas by the saturated liquid line at the left hand side and the saturated vapor line at other side. The P-h diagrams purposely to find the temperature, pressure, density, enthalpy and entropy for Refrigerant used in refrigeration system. The area to the left of saturated liquid line is called the subcooled region, the area to the right of the saturated vapor line is called superheated region and the area between the saturated liquid and saturated vapor lines is called liquid vapor mixture, or wet region. Due to shape of this region, it is also sometimes called the vapor dome. Appendix C shows a standard p-h diagram. This diagram is a main reference for this project especially to determine enthalpy of working fluid at specific location.

3.8 ROOM TOTAL COOLING LOAD

Room total cooling load (RTCL) is defined as the rate at which heat must be extracted from room to offset these heat gains. The RTCL is divided into two parts which is room sensible cooling load (RSCL) and room latent cooling load (RLCL).

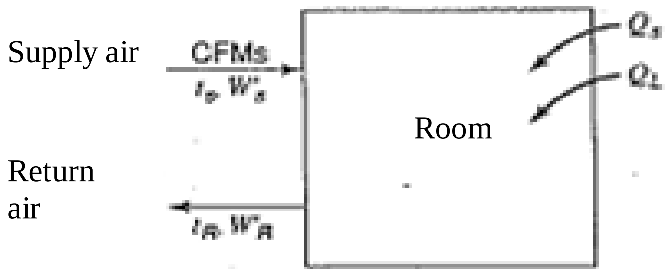

Figure 3.3: Supplying conditioned air to absorb room heat gains

Source: Pita E.G. (1998)

Basically, the heat extraction or cooling effect is provided by supplying air to the room at a temperature and humidity low enough to absorb heat gains. These relationships are shown in Figure 3.4 and are expressed by sensible and latent heat equation as shown as below.

$$RSCL = 1210 \times Q \times \Delta T \tag{3.20}$$

$$RLCL = 3010 \times Q \times \Delta W \tag{3.21}$$

$$RTCL = RSCL + RLCL \tag{3.22}$$

$$Q = \dot{m} \times C_p \times \Delta T \tag{3.23}$$

Where,

Q = Volume flow rate, l/s

ΔT = Air temperature difference, °C

ΔW = Humidity ratio of room and supply air, kg w/kg d.a

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter shows calculations step to determine heat gain in specific room of FKM building in Pekan and calculation to determine the performance of chiller system. The purpose of heat gain calculation is to determine the amount of cooling load required to remove heat from the particular room to comfort the occupants. For the chiller system, the calculation is to determine the best cooling load transfer to the building for each of chiller operation mode. In this chapter also, an analysis has been done on the system to determine the suitable temperature and load for cooling the particular room.

4.2 HEAT GAIN CALCULATION

Amount of heat produce to the space of room or building is divided into two main types such as external load and internal load. For external load, heat is generated through the building wall, roof and glass by conduction and radiation. In order to determine internal heat gain, factor from appliances, lights and peoples need to be considering before calculation process is done. Heat gain also produces by ventilation in the room. The heat gain is calculated to get the value of cooling load that required removing heat that available in the building or room in order to produce comfort condition to occupants. The method used to calculate heat gain in this project is cooling load temperature difference/cooling load factor (CLTD/ CLF) method.

4.3 PEAK LOAD CALCULATION

From the calculation of CLTD and CLF method, the peak load of the room is occurring at 3p.m on the design day. There are two type of rooms here been considered in this study for determining the total heat gain produce in the room. These rooms are namely Computer Lab and Excellent Centre. The room is located at FKM administration block and with difference in its size, capacity of lights, peoples and appliances. Table 4.1 and 4.2 shows the possible peak time occur in specific date which is 21 July with five different times had been consider.

Table 4.1: Peak time possibilities for Computer Lab

	Testing time				
Process	**9.00 a.m**	**11.00 a.m**	**1.00 p.m**	**3.00 p.m**	**5.00 p.m**
External heat gain (kW)	2.612	2.961	3.046	3.478	3.664
Internal heat gain (kW)	19.819	19.819	14.619	19.819	15.659
Total (kW)	22.431	22.78	17.665	23.297	19.322

Table 4.2: Peak time possibilities for Excellent Centre

	Testing time				
Process	**9.00 a.m**	**11.00 a.m**	**1.00 p.m**	**3.00 p.m**	**5.00 p.m**
External heat gain (kW)	4.468	5.206	5.247	5.990	6.331
Internal heat gain (kW)	33.962	33.962	19.792	33.962	25.772
Total (kW)	38.430	39.168	25.039	39.952	32.103

4.3.1 Example of Cooling Load Calculation using CLTD and CLF Method

In order to determining the cooling load for each room, CLTD and CLF method had been used. There are lots of factors that contributing in determining the cooling load of room such as the type of material use, numbers of people, light and appliance and also the radiation and conduction heat transfer mode through the room. In this chapter, the peak load of Computer Lab had been taken as example of cooling load calculation.

1) Heat Gains through Exterior Structure

Conduction process through exterior structures is a process where heat is transferred from outside to inside of the building. The exterior structures that involve in this process are wall, glass and door. Overall of heat transfer coefficient, U needs to be determined before making the detail calculation. The thermal resistance, R through the exterior structure is a sum of overall heat transfer coefficient. The calculation also involves the effective surface area. Equation 3.1 in previous chapter is used to calculate the heat gain caused by exterior structure.

2) Corrected Cooling Load Temperature Different, CLTDc

The cooling load temperature different, CLTD can be taken directly taken from table in Appendix A3 for wall and door and Appendix A7 for glass but the value from the table is not accurate.

For this project, the condition as follow;

1. Indoor temperature is 22.2 ^{o}C or 72 F
2. Outdoor average temperature on the design day is 33 ^{o}C or 91.4 F
3. Date is July 21st
4. Location is 4^{o}N latitude.

Therefore, the CLTD value must be corrected first. The Formula 3.4 used to determine the corrected cooling load temperature different, CLTDc is shown in previous chapter.

3) Overall Heat Transfer Coefficient, U

The value of overall heat transfer coefficient, U for certain types of structures is difficult to be obtained, therefore the best way is by determining the resistance, R for every layer of the structure. The Equation 3.3 to determine the U-value from R-value is shown previous chapter.

The wall characteristics of Computer Lab are described as follow;

a) Wall Structure by Conduction

- Indoor moving air and outdoor moving air
- 100mm face brick
- 100mm low density concrete block
- Inside surface resistance
- 20mm plaster
- 25mm insulation

Referring to ASHRAE 1997, the above characteristics are similar to wall type 10 as shown in Appendix A3. The total wall resistance for wall type 10 is described in Table 4.3.

Table 4.3: Wall total resistance

Code No.	**Element layer**	**R(m^2. ^oC/W)**
A2	100mm face brick	0.076
B5	25mm insulation	0.587
C2	100mm low density concrete block	0.266
E0	Inside surface resistance	0.121
E1	20mm plaster	0.026
	Outside surface	0.059
	Inside surface	0.121
	Total	1.256

By using Equation 3.1 of heat coefficient factor, the overall heat transfer coefficient is calculated to be 0.796 W/m^2. ^oC and effective surface area is taken as 48m^2. From Appendix A3, the cooling load temperature difference (CLTD) is taken as follow;

- CLTD were taken at 3.00p.m at two different direction
  - North west direction (NW) = 7
  - South east direction (SE) = 18

The corrected cooling load temperature differences (CLTDc) is calculated using Equation 3.4 which is;

- $CLTD_c = CLTD + (25.5 – Tr) + (Ta – 29.4)$
$$= 7 + (25.5 – 22.2) + (26.5 – 29.4) = 7.4\ ^{o}C \text{ for NW}$$
$$= 18 + (25.5 – 22.2) + (26.5 – 29.4) = 18.4\ ^{o}C \text{ for NW}$$

Finally, the heat gain through the wall by conduction can be calculated using Equation 3.1, as follow;

- $Q = U \times A \times CLTD_C$
$$= 0.796 \times 48 \times 7.4 = 22.8W \text{ for NW}$$
$$= 0.796 \times 48 \times 18.4 = 703.19W \text{ for SE}$$

i. Window Glass by Conduction

Window glass of the building and room stated manual master drawing as natural anodized aluminum frame window with single glass. Thus, overall heat transfer coefficient, U for glass is **6.07** $W/m^2.\ ^{o}C$. referring to Appendix A4. The following data are significant in order to determine rate of heat transfer through the glass. The total glass areas of all exposure are 7.2 m^2. By using Equation 3.1 and 3.4 from previous chapter, the calculation has been done below;

- CLTD at 3.00 pm. CLTD = $8^{o}C$
- $CLTD_c = 8 + (25.5 – 23) + (27.75 – 29.4) = 8.4\ ^{o}C$
- $Q = 6.07 \times 7.2 \times 8.4 = 367.11W$

ii. Door by Conduction

The type of door is timber door. The overall heat transfer, U for timber door is **2.73** $W/m^2.\ ^{o}C$. The following data are significant in order to determine the heat gain through the door. During the peak time at 3p.m, the directions of sunlight of door are on North West (NW) and South East (SE). An exposure area for both condition are $5m^2$ and $10m^2$. In order to determine the total heat gain produce by the door, Equation 3.1 from previous chapter has been use. The sample calculation had shown below;

- CLTD were taken at 3.00p.m at two direction
    - North west direction (NW) = 10
    - South east direction (SE) = 19 both CLTD is8 ^{o}C

    = 8 + (25.5 –22.2) + (26.5 – 29.4) = 8.4 ºC for both direction
- Q = 2.73 × 5 × 8.4 = 114.66W for NW
- Q = 2.73 × 10 × 8.4 = 229.32W for SE

iii. Window Glass by Solar Radiation

Rate of heat transfer by radiation through glass must be considered in order to calculate total heat gain in the room. The glass is consider as a without shading type with its shading coefficient (SC) is 0.85. The value of shading coefficient has been taken from Appendix A5. The glass area are divided into two direction of sunlight; North West direction (NW) with 2.4m^2 of area, A and South East direction (SE) with 4.8m^2 of area, A. The Equation 3.2 from previous chapter was use to compute the heat gain through solar radiation.

- Solar cooling load, SCL = 202 W/m² for NW and 161 W/m² for SE
- Q = SC × A × SCL

    = 0.85 × 2.4 × 202 = 412.08W for NW direction

    = 0.85 × 4.8 × 161 = 656.88W for SE direction

4) Heat Gain caused by Internal Structure

There are many things that release heat in Computer Lab such as computers, lights and peoples. All these things were classified as internal heat gain. There are specific quantities of heat produce with different value based on its characteristics. The calculation of internal heat gain in Computer Lab during the peak load condition is shown as below.

i. Heat Gain caused by Lights

Both rooms are using same type of light which is called Fluorescent 900 mm, T12 lamp with 30W of its load. The fluorescent lights have its own value of ballast factor, B.F is 1.25. Heat gain from light has covered all about $209.3m^2$ of room's area. By using the Equation 3.6 in previous chapter, the calculation had been done as shown below;

- Cooling load factor, CLF = 1 assume the light will straightly switch on.
- $Q = W \times B.F \times A \times CLF$

  $= 30 \times 1.25 \times 209.3 \times 1 = 7848.75W$

ii. Heat Gain caused by Peoples

Heat gain by people is divided into two types which is sensible heat and latent heat. During the shutdown of all electricity, the cooling load factor was increase do to heat produce by an interior structure and exterior structure. In this case, a CLF of 1.0 should be used. As this factor, CLF = 1.0 were taken as maximum value for designing the room. From Appendix A13, Solar heat gain (SHG) produces by each people is 75W for sensible heat and 55W for latent heat. The number of the people in this room is about 42 peoples in peak condition. From Equation 3.7 and 3.8, the calculation of heat gain by the people has been done as shown as below;

- $Q_{sensible} = n \times SHG \times CLF$

  $= 42 \times 75 \times 1 = 3150W$
- $Q_{latent} = n \times SHG$

  $= 42 \times 55 = 2310W$
- Therefore, the total heat gain produce by people in peak time is 5460W.

iii. Heat Gain caused by Appliances

The room has 42 desktop computers and each computer are consumes about 155W of power. The power is consider as combination between monitor and central processing unit (CPU). The value is taken from Appendix A15. Cooling load factor (CLF) is equal to 1 was taken because the power is produce when an air conditioning is switch off heat was absorbed from the appliances is taken as maximum. Thus, Equation 3.9 from chapter 3 to compute a result as shown as below;

- $Q = q \times n \times CLF$
  $= 155 \times 42 \times 1 = 6510W$

iv. Heat by Ventilation

Ventilation is the process of changing or replacing air in any space to control temperature or remove moisture, odors, smoke, heat, dust and airborne bacteria. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. To determine the heat gain from ventilation process, the Psychrometrics chart is used to find the outdoor and inside humidity ratio. The Psychrometrics chart is shown in Appendix A19. Volume flow rate is $0.01m^3/s$ per person is taken from Appendix 17 in office type space. The following equation is used to calculate heat gain by ventilation;

- $Q_S = 1210 \times \dot{Q} \times \Delta T$
  $= 1210 \times 0.01 \times (33 - 22.2) = 130.68W$
- $Q_L = 3010 \times \dot{Q} \times (Wo' - Wi')$
  $= 3010 \times 0.01 \times (32.5 - 13.2) = 580.93$
- Total heat gain from the ventilation flow is 711.61W.

The largest time of heat gain occur in Computer Lab is around 3 P.M. with the total heat gain at this time is 23.296kW. This is happen because at that time, the direction of window glass and wall was faced the sun. Furthermore, the capacity of people in the room is in maximum value. Thus, the heat rejected from the human body is more at this time.

4.4 ANALYSIS OF COOLING LOAD CALCULATION

As been discussed in previous section, the total cooling load is calculated to be 23.296kW in Computer Lab. From the calculation the CLTD and CLF method was use to estimate the cooling load for the system. In order to analyze the system, the data had been plotted and divide into specific type of condition to determine the largest heat that contributes to the room. Furthermore, the system had varied of heat in every hour due to the orientation and direction of sun.

4.4.1 Heat Gain through Exterior

From the total heat gain calculation, analysis can be carried out. For this project, the first analysis is the comparison heat gain caused by external structure which includes two type of room condition. Its divide into two main category which is heat transfer through conduction and radiation on several material such as wall, glass and door. Figure 4.1 shows graph of heat gain during peak time of the day. From the graph, the highest heat gain of the both rooms is due to solar radiation through the glass. The highest heat gain through radiation occurs because the glass had received a large amount of heat from the sun. In the figure, value of heat through the window is high in Excellent Centre compared with Computer Lab room. Heat gain caused by single glass aluminum with thermal break frame is one of factor why the solar is contributed large amount of heat. Besides that, the window type are fixed causes shading coefficient through the window is high.

Figure 4.1 also shows bar chart of conduction process happen in two locations of rooms at 3.00 pm. The chart describe that the large conduction occur through the wall. The others medium occur in conduction are through glass and door. It makes sense because the area wall is the largest compared to two other structures. While the door structure gives the lowest heat gains because the door’s area is the smallest. Glass receives more heat compared to others material because U-factor of glass structure is greater than others. If area of glass more than area of wall, the room or building will receives a lot of heat and its will caused uncomfortable condition in that location.

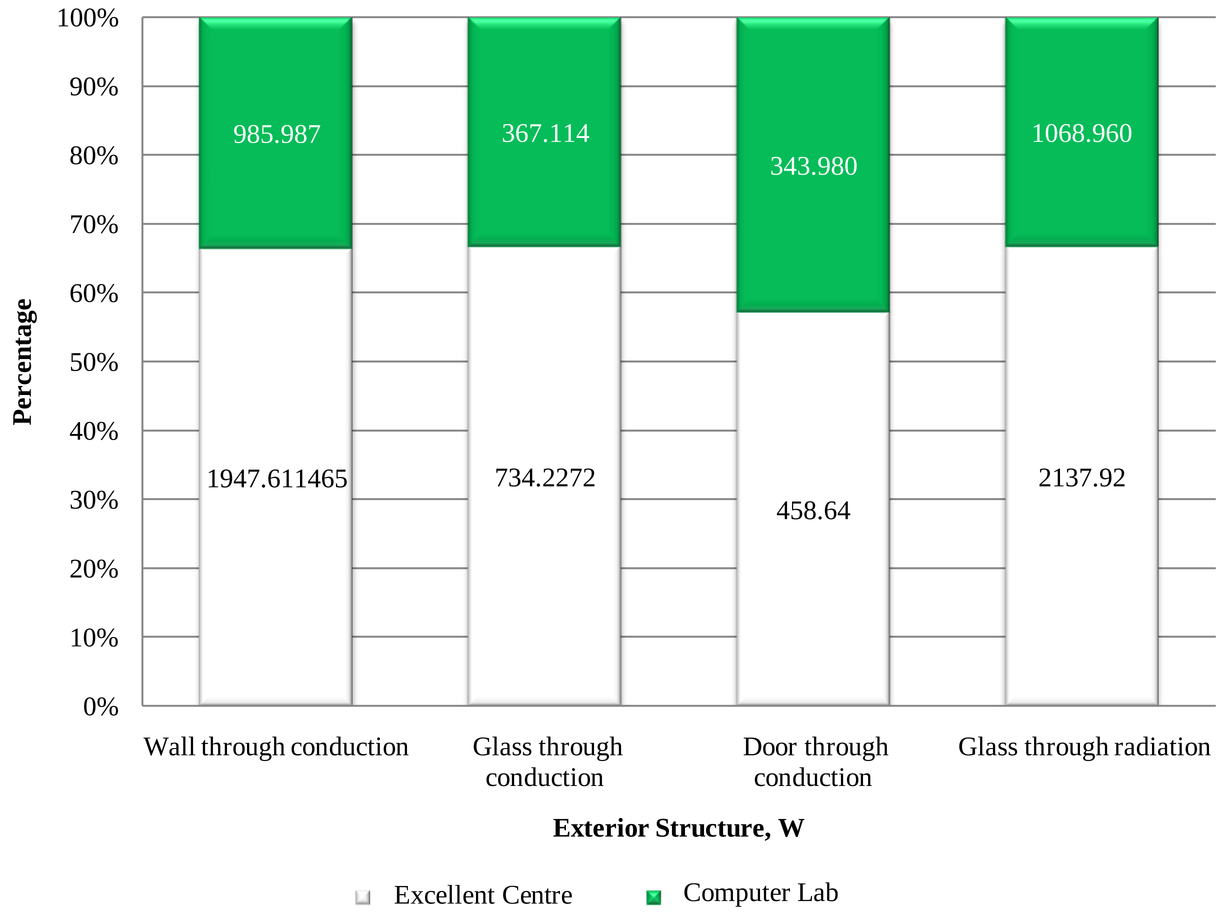

Figure 4.1: Heat gain contribution through exterior structure for Computer Lab and Excellent Centre

From the figure as well, a comparison between two specific rooms had done. From analysis, the heat from Excellent Centre is much greater than heat in Computer Lab. Excellent Centre was generating more heat through the wall and glass structures. The larger area of room will obtain more heat through its structure. Besides that, the orientation of the room also gives an effect to the heat generated. From the result, only the door through conduction was produce heat more in Computer Lab because the area of room is smaller than the others. Another factor of affecting an internal cooling load calculation is number of glass and door. The large number of glass and door will produce much heat for the system.

4.4.2 Heat Gain through Interior

The largest amount of heat generated in this project is in interior structure. For interior structure there are three main parts that contributed to the heat generated such as peoples, appliances and lights. Figure 4.2 shows two difference of heat gain between Computer Lab and Excellent Centre. The heat gain usually involves the addition or removal of heat from air and other substances.

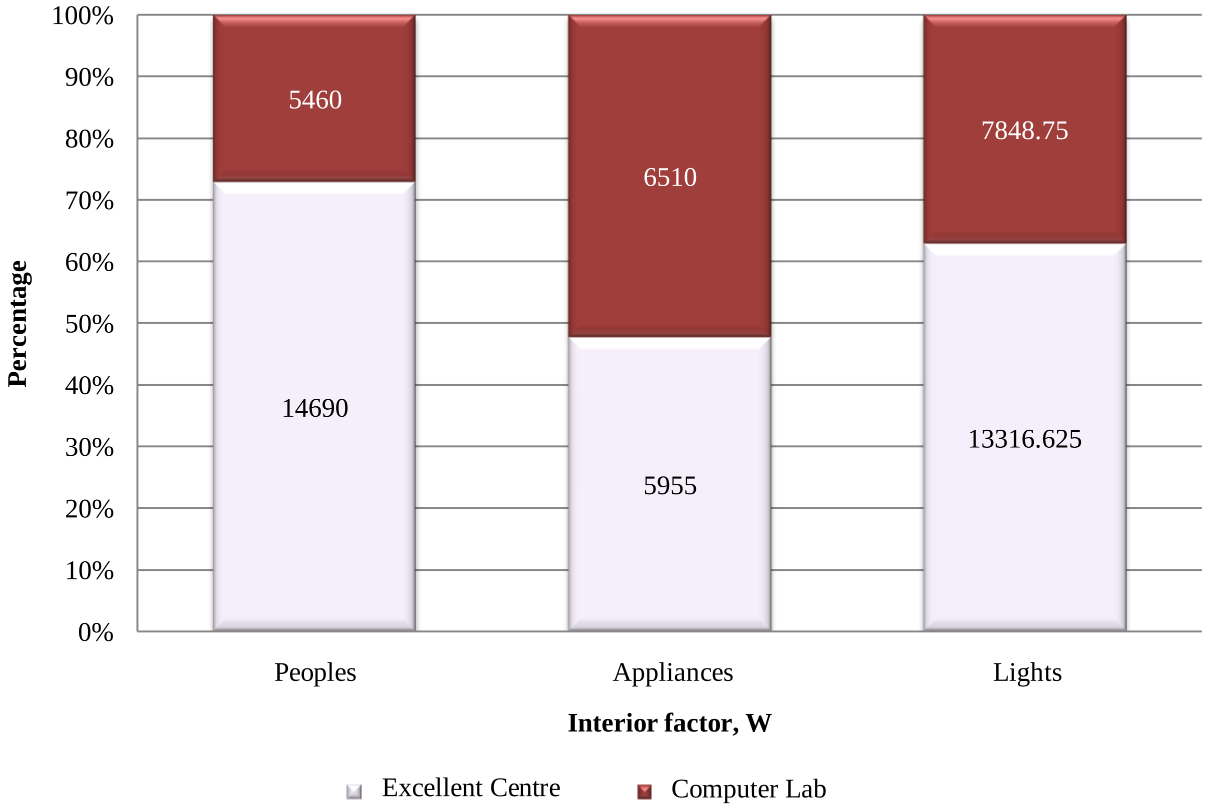

Figure 4.2: Heat gain contribution through interior structure for Computer Lab and Excellent Centre

Generally, heat gain from the peoples can be portion into two parts, sensible heat and latent heat produce from perspiration. When heat added to or removed from substance results in temperature change but not changes in state, the process called a sensible heat. While when heat added or removed from a substance results change in state, then the enthalpy change in the substance is called latent heat. The heat gain from people is difference depend on their physical activity and rooms capacity. From the research, the people had been stated at moderately active room. More people will produce more heat gain. The heat from people produce based on the size of system which means, the smallest room with compact of people will increase the heat. This can be proved by the number of people in Excellent Centre is high than Computer Lab but its percentage is low than Computer Lab due to the sizing of location.

The appliances is one of factor that contributing in cooling load estimation. These appliances sometimes can be found directly from manufacturer or the nameplate data with allowance for intermittent use. For this project there are several number of appliances involving computer, photostat machine, printer, and refrigerator. The item have own values of heat. An appliance is second higher contributor for the Computer Lab because of the heat come from the electronics devices. Appliances are also associated with each room area where when a lot of items located in a small room will result high of heat gain. This comparison between these two rooms can be made based on the quantity appliances of the room and specific heat generate by the appliances. Despite the appliances in and Excellent Centre have various type but the number of appliances in Computer Lab is high enough to produce the large heat to the system.

The room temperatures also depend to cooling load from lighting. The rated capacity of the light can be expressed in Watt. There are many type of light in the market with various design and capacity input. In lighting heat gain, there also involve ballast factor as a losses of heat. In this project the ballast factor are assumed to be 1.25 (Pita E.G. 1998) for fluorescent lighting type. The number of light and area of room must be considered to estimate the heat load. From the chart, the light is classified as a largest contributor for Computer Lab. Comparing to the both room, the heat gain from lighting is greater in and Excellent Centre due to the capacity and area of the rooms.

4.4.3 Overall Heat Gain

The overall heat gain in the particular room is defined as combination of external heat gain and internal heat gain. The calculations of the highest heat gain occur at 3.00 pm for both rooms. From the previous analysis, the major contributor for cooling load produce is by heat gain from internal structure. This is happen due to heat release from interior medium such as lights, peoples and appliances. The load from all of interior structure can affected the high or low heat produce for the systems. Figure 4.3 shows heat gain by external structure with different of time starting from 9a.m to 5p.m.. During the period of time, the patent of heat gain can be observed and analyzed. As the results the highest heat gain can be determined. For the external heat gain, the highest heat produce is at 5p.m. It is because the orientation of the building and also direction of the sun. When sun flow through the glass its release more heat compare to others structure. This statement was followed the theory that the shading coefficient, solar cooling load (SCL) and U-factor are agent to the high heat release.

In Figure 4.4, the graph had plotted based for internal heat gain produce with different of time from 9a.m until 5p.m.. In this graph, the plotted data were not consistent because there are different medium inside the room at different time. Both of room have constant heat gain at 9a.m, 11a.m and 3p.m. Factor of affecting this case because at this time the class were full with peoples. If one people are produce 75W each, there are a lot of heat produce by person if the number of peoples increase for both rooms. During the lunch time, both rooms obtain low heat gain.

The next analysis is comparison of overall heat gain from 9.00a.m to 5.00 pm on Monday to Thursday. Graph shows by Figure 4.5 is the total cooling load for both rooms. From the results, the maximum heat produce at 3p.m. At this time the total cooling load at Pusat Kecemerlangan is greater compared to Makmal Komputer by the reason of its size. For lighting capacity, the cooling load factor are assumed to be 1 because the heat maintain generate during the shut down of electricity. Load from lighting is depend on the sizing of room where more bigger room will have high capacity of load from light. Aside that, the high value of Pusat Kecemerlangan occur by the increasing number of peoples. As a conclusion the result of maximum cooling load is taken for designing the room and to installing the air condition capacity in order to get the comfortable room for the consumers.

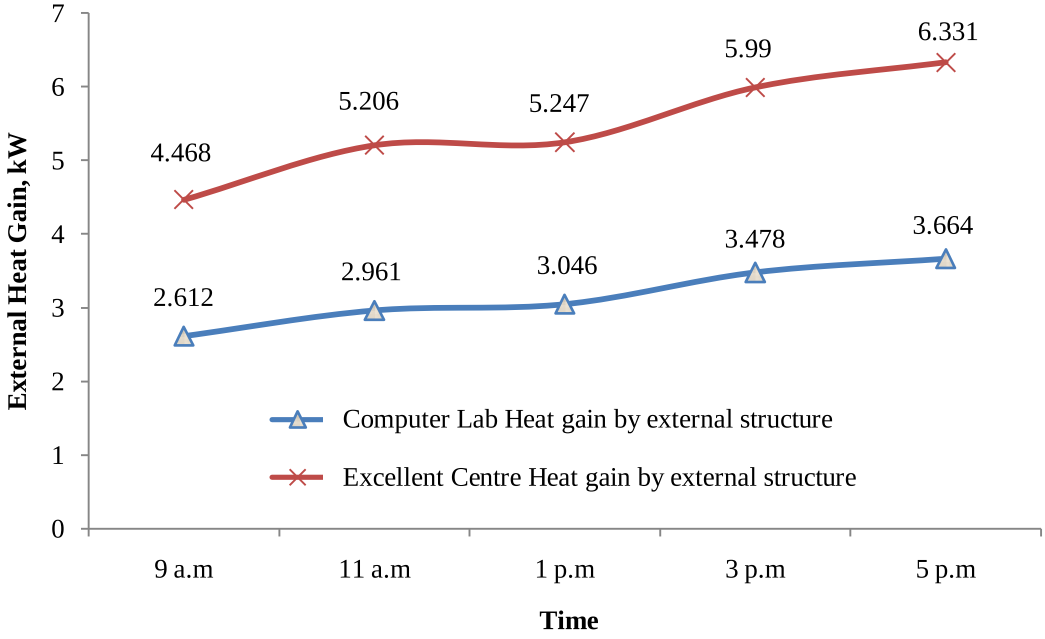

Figure 4.3: External heat gain versus time with different location

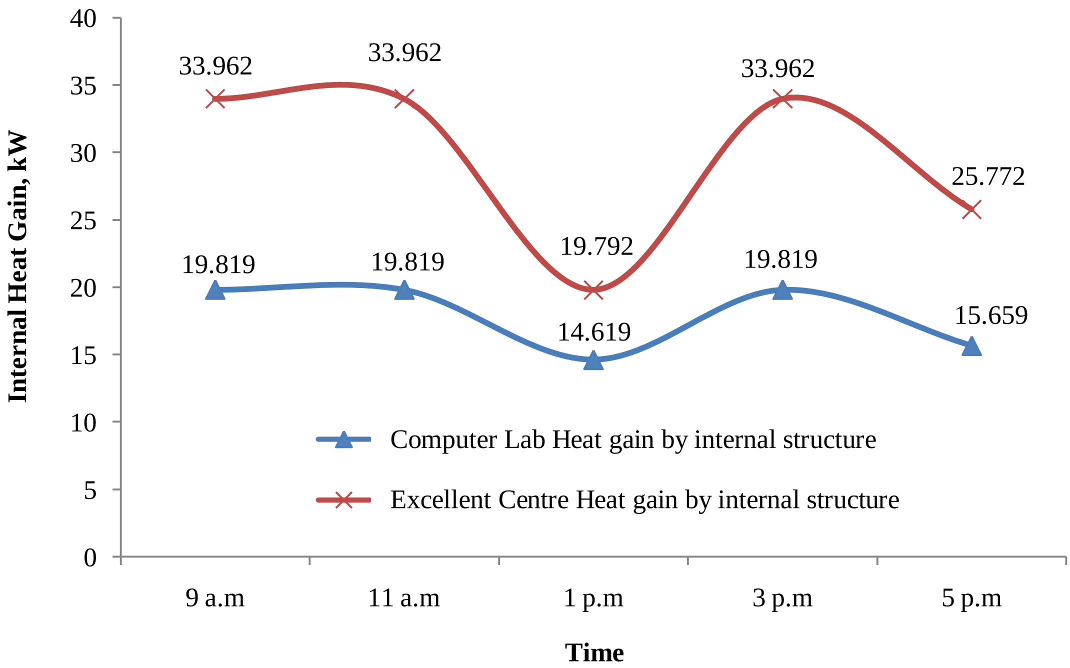

Figure 4.4: Internal heat gain versus time with different location

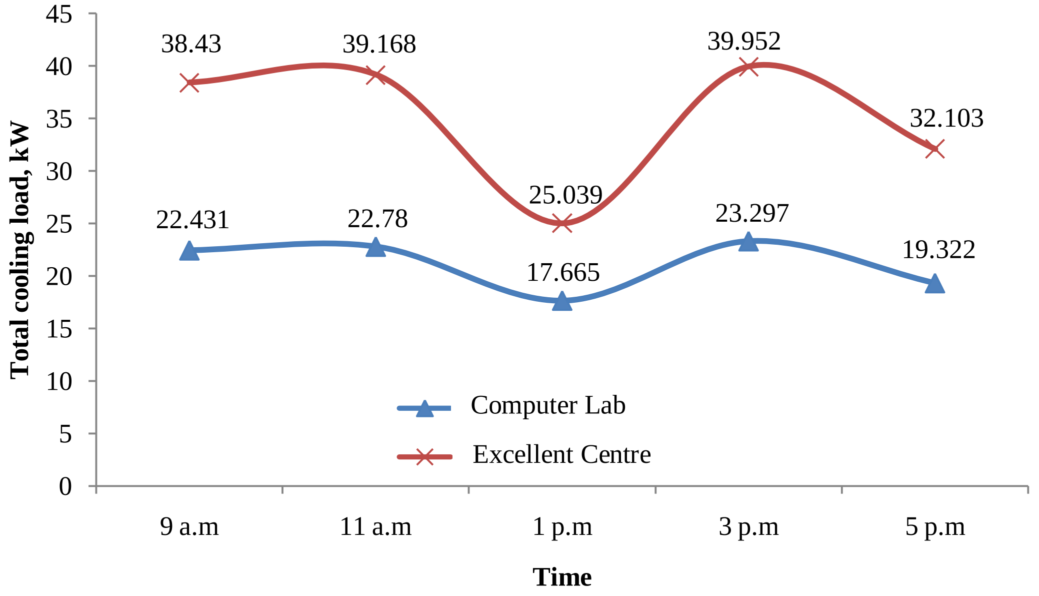

Figure 4.5: Total cooling load versus time with different location

4.5 PERFORMANCE CALCULATION

Testing of the performance was held on chiller plant unit with measuring an actual condition of the plant. The pressure and temperature of the system were recorded at each point to calculate the performance in actual condition and the data was collected in every 1 hour during system running. The data were be recorded before make some calculation in order to determine factor of performance. Figure 4.6 shows the schematic diagram of the chiller plant.

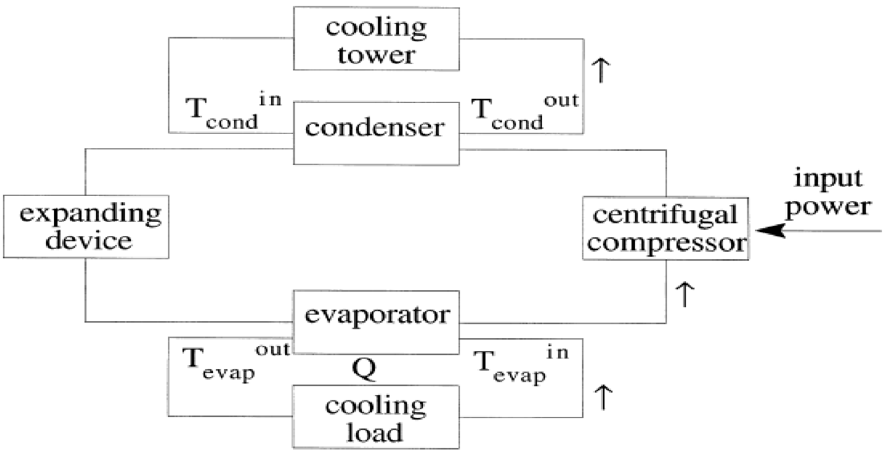

Figure 4.6: Schematic diagram of FKM chiller plant system

Source: Hundy G.F, Trott A.R, Welch T.C. (2008)

4.5.1 Data Collection from Chiller Plant

Data collection was measured from actual condition of chiller plant starting from 10.00a.m to 4.00p.m.. FKM centrifugal chiller was operate based on the vapor compression refrigerant cycle. During the testing, mass flow rate of water at evaporator are change based on ambient temperature and number of chiller. For run the system, 2 chillers must be operating simultaneously in order to supply chilled water to all AHU in the faculty. Mass flow rate water at evaporator is major point that can reflect to the temperature and pressure for the system. Table 4.4 shows data of chiller unit from 10.00a.m until 4.00p.m. The operation of chillers was taken with different day but the parameter of time is same as well as the ambient temperature almost same for each chiller operations.

Table 4.4: Data collection from actual FKM chiller plant

Parameter	Chiller 1&2	Chiller 1	Chiller 2
Water mass flow rate at evaporator, (kg/s)	38.5	30.1	30.5
Pressure, P1 (kPa)	298.98	349.03	337.4
Pressure, P2 (kPa)	900.55	855.26	851.4
Temperature, T1 (^{0}C)	20.98	24.1	23.65
Temperature, T2 (^{0}C)	46.55	47.23	46.83
Temperature, T3 (^{0}C)	34.85	37.72	37.53
Temperature, T4 (^{0}C)	5.68	12.53	11.48

4.5.2 Data Analysis

The data was analyzed based on temperature and pressure at each point. Mollier chart or *p-h* diagram was used to compute the parameter in order to determine enthalpy, compressor work, cooling capacity, refrigerant mass flow rate, heat rejection through condenser and coefficient of performance in the system.

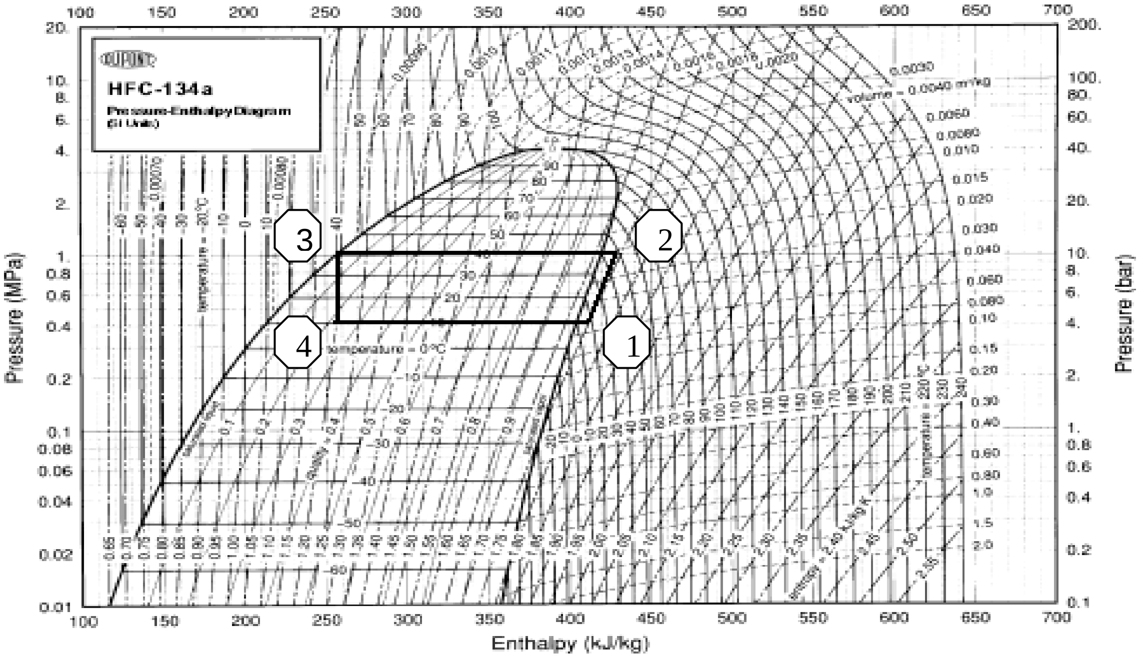

Figure 4.7: Mollier chart for refrigerant cycle on chiller 1 combining with chiller 2

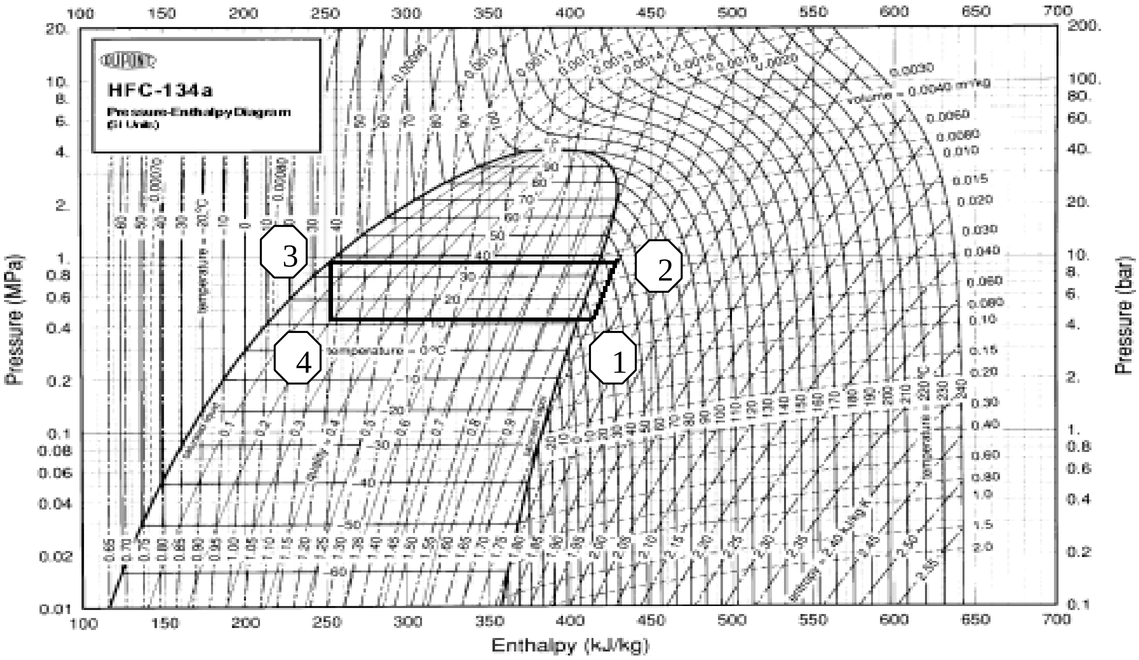

Figure 4.8: Mollier chart for refrigerant cycle on chiller 1 and chiller 2

Source: DuPont (2005)

In this analysis, the theory of ideal vapor compression cycle was followed in order to determine unknown parameters. The Mollier chart is another way to compute the enthalpy, entropy and other related parameter apart from the table refrigerant-134a. Based on the theory, the enthalpy at point three was in saturation liquid region and enthalpy at point four is equal to enthalpy at point three. At suction part, point one is located at saturation vapor line and flow through the superheated region at point 2. This process become superheated due to centrifugal compressor compress the Freon and change to high pressure and temperature side.

However, in the analysis the movement of fluid is difference within the compressor to the condenser stage. At this point, compressor undergoes a compression process. In Figure 4.7, shows the actual condition for combining chiller 1 and chiller 2. During actual condition, suction stage by compressor was compress at superheated region with average temperature is 20.98ºC with its pressure around 298.98kPa. While for chiller 1 and chiller 2 operating condition is high pressure and high temperature comparing to mixing chiller. The chiller run through compressor to condenser before the chilled water was rejecting the heat through cooling tower. After cooled water was inserting into the condenser, the refrigerant drop its temperature but maintain its pressure. The purpose of the cooling tower fan is not only to cool the water but used to subcooled the water to low temperature and pressure. Superheated refrigerant in low pressure pipe line before entering the compressor occur to ensure the refrigerant enter the expansion device with fully liquid phase in order to increase the cooling effect and to ensure the compressor fully in vapor phase to prevent any excessive damage to the compressor. The process at point one and point two is called isentropic process where the entropy at point one was same with entropy at point two with no heat is added.

As a result the condenser receives the same value of entropy and in change stage from gas to superheated liquid region. The temperature and pressure at point two are change to superheated region with 46.55ºC and 900.55kPa. When the discharge line flow through chiller, chilled water was flow in the same condenser to reject the heat. In this stage, a cooling tower is used as medium to exhausting hot water to surrounding. In this stage, the condenser will produce the heat rejection load from the system. Before entering metering device, Freon throttle from high pressure and temperature to low pressure and temperature. At this point, around 6ºC temperature of Freon was produce. At the same time, the Freon was transfer to evaporate and making chilled water before cooled water transferred to the building. This cycle is done when the water returns to chiller plant and Freon start pass through evaporator

The method to calculate the needed result was done by using p-h diagram for refrigerant-134a as shown in previous page. The main purpose is to calculate the required load from the chiller plant to the whole FKM building at actual condition. At the same time, determining the unknown parameter such as heat rejection, working compressor load, flow rate of refrigerant-134a and coefficient of performance also done. From the manual calculation, all the unknown parameter had been calculated based on fundamental of vapor compression the refrigeration cycle equation and using energy balance equation. From the result, performance is increasing during cooling capacity increase. By using the data collection from Table 4.4, an actual calculation has been done. The result from estimating the data were shown in Table 4.5.

Table 4.5: Data analysis for chiller plant unit

Parameters	**Chiller 1 & 2**	**Chiller 1**	**Chiller 2**
Ambient temperature, (^{0}C)	30.75	32.77	30.73
Enthalphy 1, h1 (kJ/kg)	412.5	409.43	412.5
Enthalphy 2, h2 (kJ/kg)	435	435.29	438.33
Enthalphy 3, h3 (kJ/kg)	256.33	251.57	252.86
Enthalphy 4, h4 (kJ/kg)	256.33	251.57	252.86
Heat rejection, Qcond (kW)	1435.2	939.66	910.54
Cooling capacity, Qevap (kW)	1246.77	805.8	779.48
Compressor work, Wc (kW)	188.43	133.87	131.06
Refrigerant mass flow rate, m (kg/s)	7.98	5.01	4.91
Coefficient of performance, COP	6.74	6.09	6
Power per ton, kW/Ton	0.52	0.58	0.59
Ton Refrigerant Effect, Ton	361.21	231.87	223.65

4.5.3 Data Plotting

The graph has been plotting to show the effect with different number of chiller operation. As shown in Figure 4.9, the cooling capacities produce highest of load during 2 chiller operations. In 2 chiller operation, the chillers generate more capacity to supply chilled water to whole FKM building. In this stage the capacity was received the low pressure with low temperature of refrigerant and flow through the evaporator before this medium chilled the water. The chilled water will be supply to the whole building by using connecting piping. More low temperature receives at evaporator will getting more chilled water supply to FKM building before converting into cooled air of temperature. The Figure 4.9 also has shown the reaction of compressor work with the number of chiller operation. The compressor work are highest when 2 chillers running simultaneously. As example, during compressor running the motor generating with high speed to maintain a cooled air can be supply. More high speed compressor running will produce much more work of compressor power.

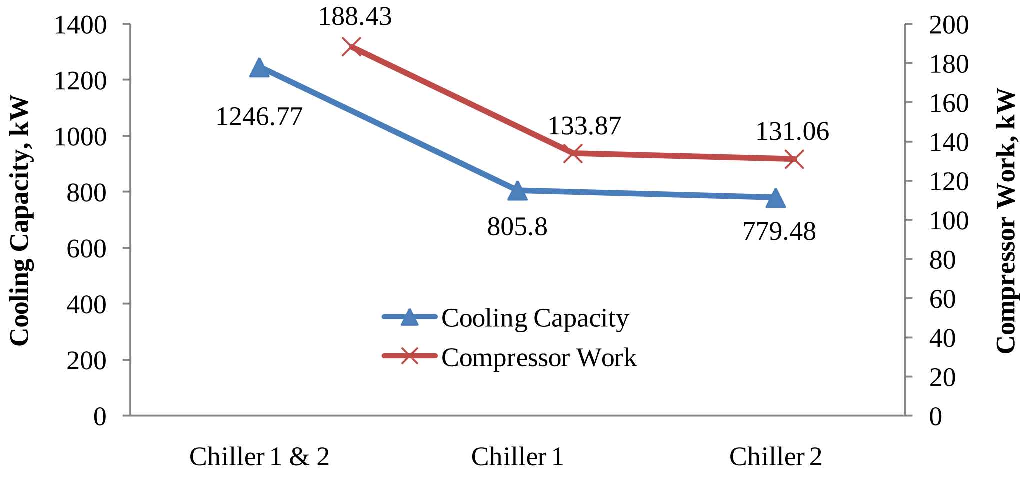

Figure 4.9: Result of cooling capacity and compressor work with number of chiller operation in FKM chiller plant

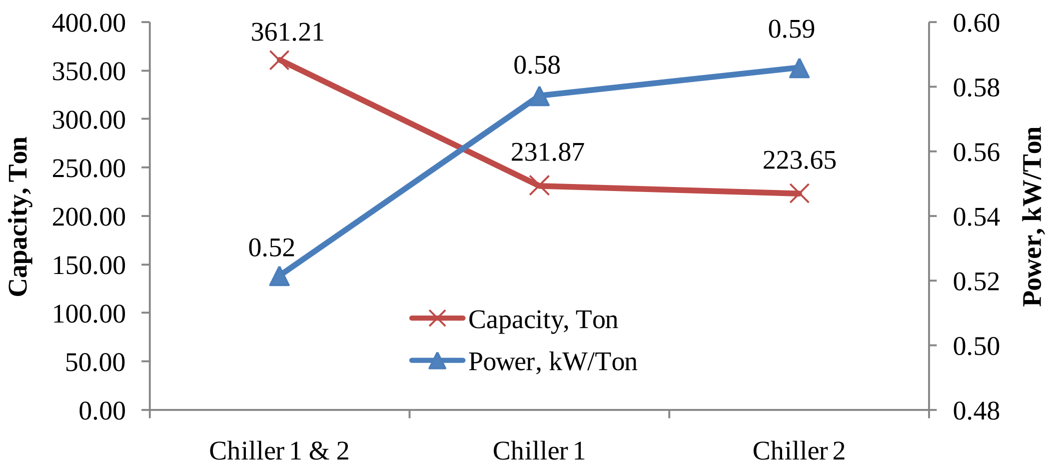

Figure 4.10: Result of capacity and power with number of chiller operation in FKM chiller plant

In Figure 4.10, the capacity and power from chiller can affect the number of chiller operation. FKM building is receives a highest value of capacity and also receive lowest power, kW/Ton on 2 chiller operation. When operating with single chiller, the power produce can't exceed the necessary comfort to the consumers. When the building load decreases, the chiller responds by partially closing its inlet vanes to restrict refrigerant flow. At American Refrigeration Institute (ARI) standard rating conditions centrifugal chiller's performance at full design capacity ranges from 0.53 kW per ton for capacities exceeding 300 tons and between 0.6 to 0.7 kW per ton for capacities up to 300 tons. Same to this project condition, the capacities of FKM chiller can exceed more than 300 ton or between 0.52 W/Ton. Efficiencies have been improving even further over the years as a result of improved impeller designs, better unit configurations, enhanced heat transfer surfaces, and the increased utility emphasis on reducing energy requirements.

Chiller efficiency is typically defined in terms of kW/Ton and coefficient of performance (COP). The highest COP also effect the power obtains for the plant. From the ARI standard, COP of centrifugal chiller in FKM building should be around 6 and above. In the testing, with 2 chillers operation is receiving the highest value of COP. From the result, when the load is high, efficiency of the system also increases. **Figure 4.11**shows the reaction of COP with operating number of chiller.

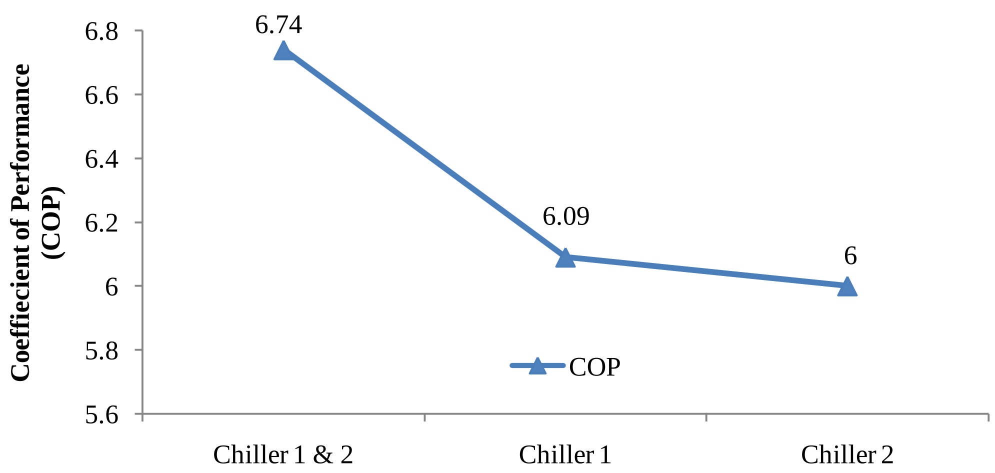

Figure 4.11: Result of coefficient of performance with number of chiller operation in FKM chiller plant

4.5.4 Chiller Analysis

Figure 4.12 shows changes over time on chiller during compressor work. Based on the graph, there are the largest quantity on load are used in mixing chiller. In testing session, about 6 hour period of time has been taken as a guide for estimating the performance of chiller with different number of chiller operations. By using 2 chillers the condition shows unstable line graph by mean at the second period hour the compressor work are increasing its load but for the next three hour there are decreasing its load. A factor happen for this situation is the capacity of users in the particular rooms is much more than the estimation value.

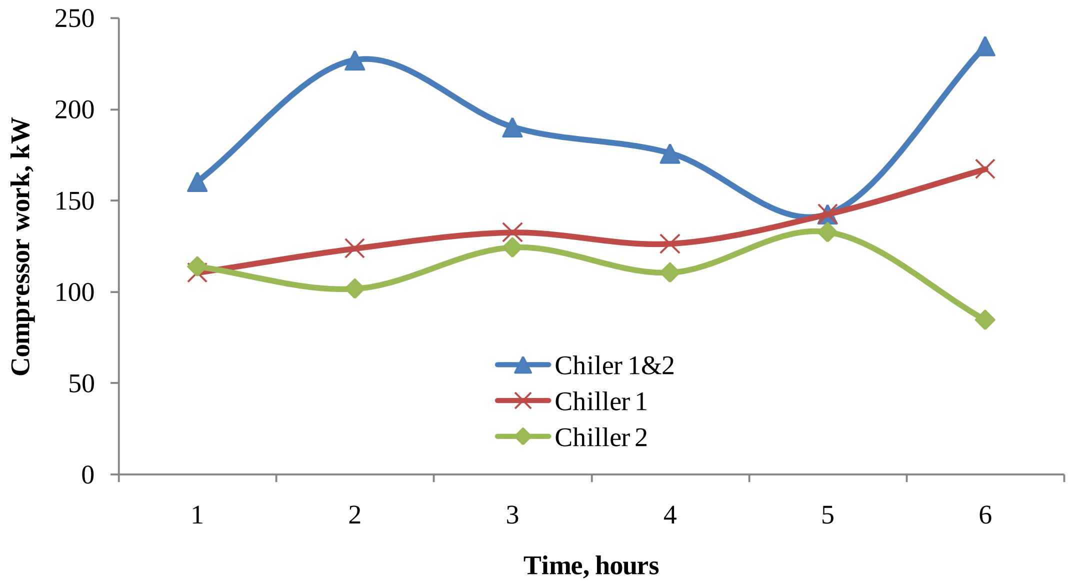

Figure 4.12: Effect of compressor work in 6 hours period of time

Vary to testing on chiller 1 and chiller 2 with single operation is occur, the condition at first period is similar in both case before chiller 1 is run proportional to the time. It’s happen because the time taken are different during the testing day with different of ambient temperature. At chiller 2, at last period hour the load was decrease by the quantity of user are increase. To increase the compressor work, the motor of compressor should be increase on its speed. Meanwhile, the increasing speed also can increase the cost and the life of the component.

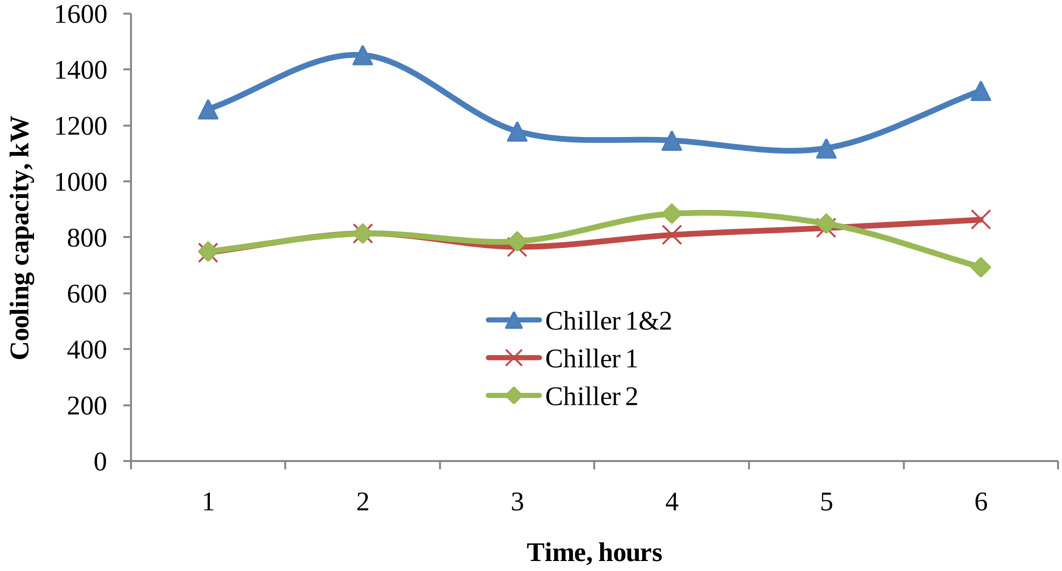

Figure 4.13: Effect of cooling capacity in 6 hours period of time

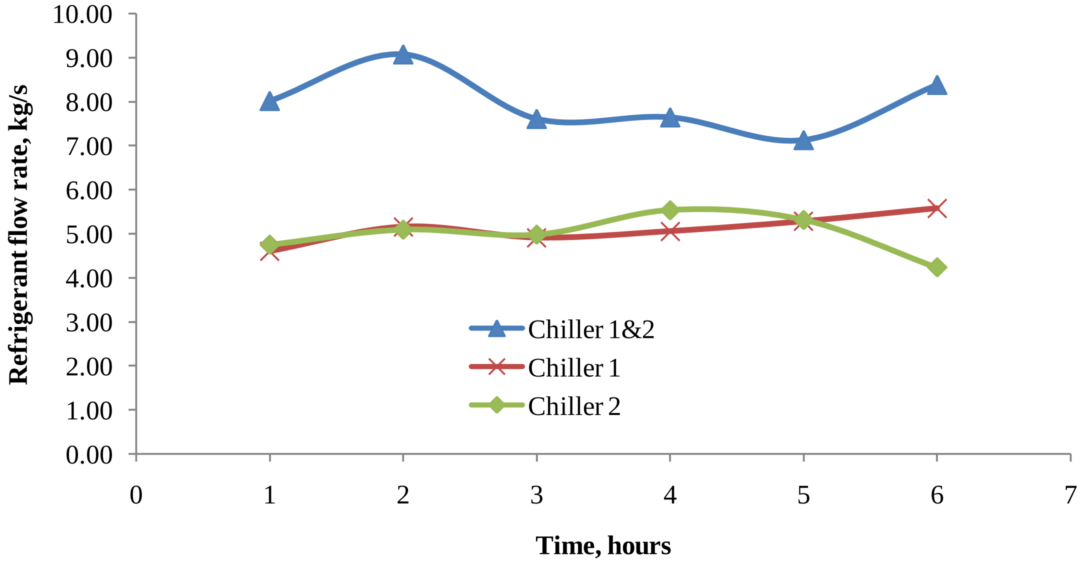

Figure 4.14: Effect refrigerant mass flow rate in 6 hours period of time

From Figure 4.13 and 4.14, the graph shows an effect of cooling capacity and refrigerant from chiller plant. The graph are similar to each other by the reason the cooling capacity have a linear relationship with refrigerant mass flow rate. When refrigerant mass flow rate increase, it also increasing the value of cooling load. This can be proof on Appendix F, the sample calculation of chiller plant performance.

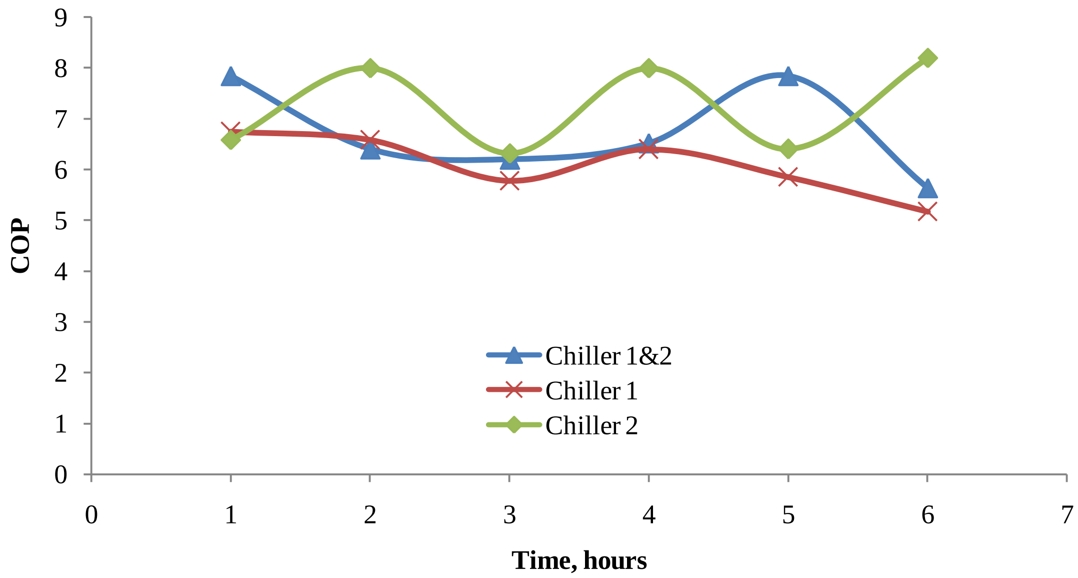

Figure 4.15: Effect of coefficient of performance (COP) in 6 hours period of time

The system was undergoing the changes of the system during the working system in whole building. From the Figure 4.15, there are many factor involve the performance of chiller during the testing such as the load of people, load from appliance and also the temperature of outside air. As a reason, the factor will affect the system. In this condition, the capacity from the chiller is transfer to the whole building by piping system. It will connect to require space by using chilled water as a cooling medium. An air handling unit also takes a role for generating the cooling capacity before changing to cooled aor. At air handling unit, the cooled air was blow by the fan for make sure room receive the capacity needed. The result on Appendix F also stated, when the chiller is absorb with high amount of cooling capacity, its will increase the number of COP. Otherwise, when refrigerant mass flow rate is increase, the COP will. From above result, the highest value of cooling load is supply by combination of chiller 1 and chiller 2. Generally, the highest value of coefficient of performance, the system is better.

4.6 CASE STUDY OF AIR CONDITIONING SUPPLY

This project only considers two rooms in FKM Administration building for estimate cooling capacity. Figure 4.16 shows the direction of movement of cooled air in the particular room in order to remove sensible and latent heat.

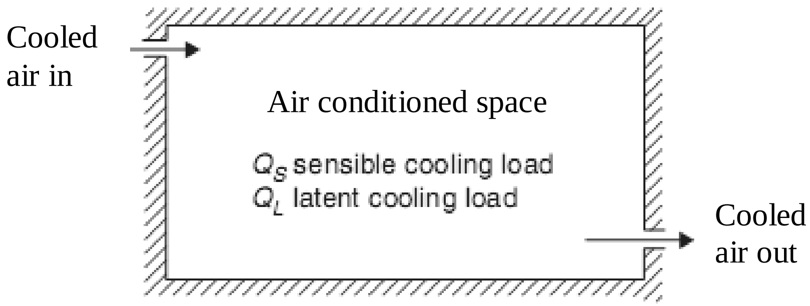

Figure 4.16: Direction movement of cooled air

Source: Hundy G.F, Trott A.R, Welch T.C. (2008)

4.6.1 Room Load Capacity Analysis

There are three data with different day in evaluating and determining the room load capacity. The data taken including supply and return air temperature from air handling unit, humidity ratio and air flow rate through the rooms. By using the Equation 3.23 from previous chapter, the calculation of room load capacity has been done. The input data and the result of calculation example calculation are shown in Table 4.6 for the both rooms. Using collection data below, a result had been calculated. Total heat gain for the particular rooms is taken from Section 4.2.

Table 4.6: Required capacity of particular room on different day

	Date	4 August 2010		12 August 2010		18 August 2010	
	Chiller	**Chiller 1&2**		**Chiller 1**		**Chiller 2**	
	Parameters/Location	**AHU G1**	**AHU G2**	**AHU G1**	**AHU G2**	**AHU G1**	**AHU G2**
AHU	(CW) Tsupply, °C	9.5	9.4	13.2	13.5	12.2	12.3
	(CW) Treturn , °C	16.6	15.4	21.9	21.4	19.9	18.5
	(CW) Psupply, kPa	393	379.21	244	250	289.58	275.79
	(CW) Preturn, kPa	344.74	310.26	232.2	222.1	262	241.32
Room	Tsupply, °C	17	18.6	21.8	21	22.2	21.3
	Treturn, °C	23	23.6	25	24.4	25.4	25.4
	Psupply, kPa	386.1	1916	377	1799	383	1808
	Flow rate, kg/s	4.2	7	3	6.1	3.4	6.3
	Humidity, %	64.5	72.5	81.2	80.4	79.3	77.2
Room Load Capacity	Load Capacity	25.301	42.168	18.072	36.746	20.482	37.951
Room	Heat Gain	23.297	39.952	23.297	39.952	23.297	39.952
Chiller	Cooling Capacity, kW	1246.77		805.8		779.48	

The result of load capacity and heat gain from Table 4.6 can be summarize by compared the capacity of load capacity for both rooms. The comparison result is shown by the Figure 4.17, 4.18 and 4.19.

4.6.2 Result Analysis

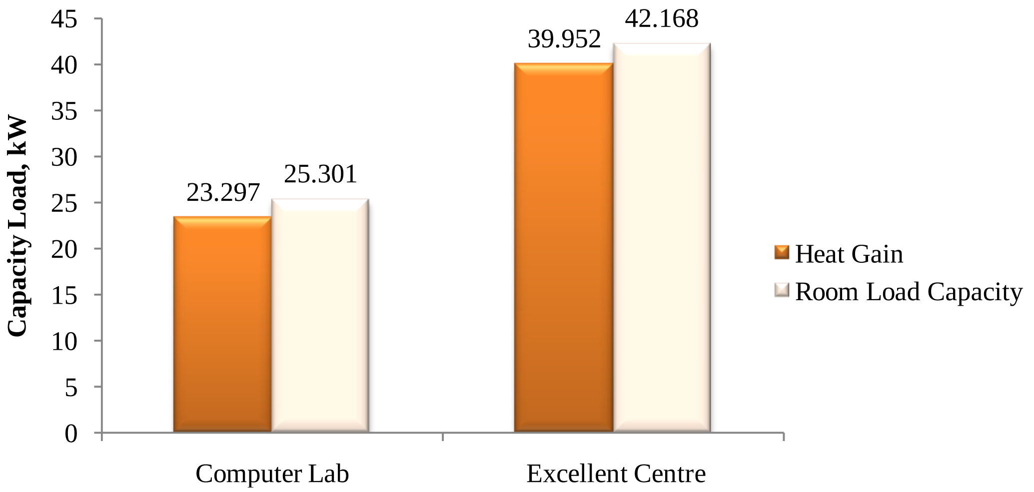

Figure 4.17: Comparison heat gain and room load capacity by 2 chiller operations on 4 August 2010

Analysis of rooms load capacity and heat gain has been done with differences chiller operation. From the results, there is only one capacity had reached above the comfortable cooling load room. With 2 chillers operations, the cooling capacity transfer is over than 1MW to particular space of FKM building. In this condition, the room had occupied enough cooled temperature in order to getting the comfortable air in the location. As a result, both rooms are receiving enough cooled capacity from the plants. During the testing, Computer Lab was received about 25.301kW of load capacity from room while Excellent Centre had received 42.618kW.

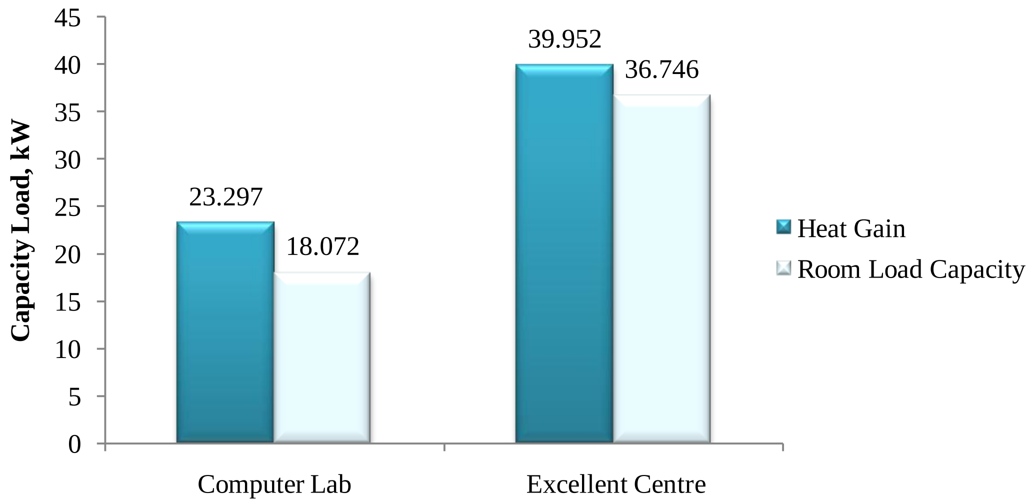

Figure 4.18: Comparison heat gain and room load capacity by chiller 1 operation on 12 August 2010

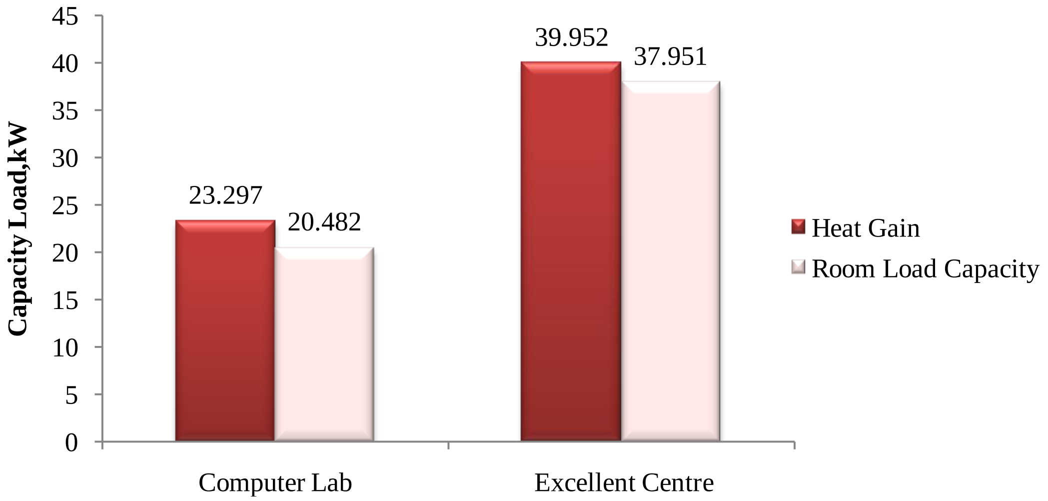

Figure 4.19: Comparison heat gain and room load capacity by chiller 2 operation on 18 August 2010

In another case, in Figure 4.18 and 4.19 shows both condition were run with single chiller. As a result, there is not enough load capacity to remove heat from the rooms. The rooms will receive uncomfortable condition during this state. With the supply heat gain only around 18.072kW to 20.482kW for Computer Lab and 36.746kW to 37.951kW for Excellent Centre, an air conditioning are not supply enough temperature to the room in order to cooled its. There are various factors in occurrence of this situation among the chiller not run with full load. Others factor can occur are the water in the chiller are not enough in the centrifugal chiller, refrigerant fluid is in low pressure and there is something component that ruined the system. This can be conclude, the operation should working with 2 chillers in order to send enough cooled air to the consumers.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The project are created to cover three part of study which is determining the cooling load of particular room based on CLTD/CLF method, evaluating chiller plant performance and calculation of room total load capacity for determining the load of the room in actual condition. The objective in this study which is analyzing the performance of air conditioning/chilled water system is done successfully by three important part; 1) Heat gain in particular room, 2) Performance of chiller plant and 3) Analysis of room load capacity. In first part, heat gain is calculated to determine the total load capacity required to remove the heat in the particular room. From the analysis, the highest peak load occurs at 3p.m conducted on July 21st 2010. Two rooms were selected to determining the heat gain which includes both rooms located in FKM Administration block. Total heat gain for Computer Lab is calculated to be 23.297kW whereas total heat gain for Excellent Centre is 39.952kW. Heat gain is amount of heat needed to be removed by air handling unit (AHU). There are several factor influences of computing the heat gain like ambient temperature, structure of building, direction of sunlight, cooling load temperature difference and cooling load factor.

For the second part, an evaluating of FKM chiller plant is done. According to the analysis as discussed in chapter 4, the result shows an impact of changes between single chiller running and both chiller running in terms of performance. The data had been collect before calculation had been verified. The parameter involve in determining the performance of FKM chiller system are heat rejection of system, compressor work, cooling capacity transfer to the system and also the coefficient performances of the system. The analysis had shows coefficient of performance (COP) at chiller plant with two chiller running is 6.74 while the single chiller running is about 6. The total cooling capacity produced is 1246.77kW with 2 chillers running whereas with single chiller running the total cooling capacity produce is from 780kW to 805kW of its load.

Finally, room analysis has been done to determine the room load capacity that has been transfer at that time. The data from the room and air handling unit are taken. The objective for determining amount of load capacity transfer to the particular room is to ensure that the load producing by the chiller plant is sufficient enough to meet the needs of consumers. The room has received about 25.301kW of Computer Lab while for Excellent Centre around 42.168kW on 2 chillers operation. While the minimum load capacity absorb from Computer Lab is 18.072kW and 36.746kW for Excellent Centre. The several factor contributing during determination of load capacity such as temperature inlet from air handing unit, air flow rate in the system, humidity ratio of the system and the wet bulb temperature of the rooms.

5.2 RECOMMENDATION FOR FUTURE WORK

There are several recommendations for future work in this project. Firstly, simulate the refrigeration flow rate using appropriate software such as Cosmos Flow and others related software. This process is to ensure that every area in the room is equally distributed with conditioned air flow. Besides that, Transfer function method (TFM) and Total Equivalent Temperature Difference (TETD/TA) (ASHRAE 1997) are another method for computing the cooling load. Both methods should be done to compare the result based on difference method as mentioned above. Each method has their advantages and disadvantages. An experimental should be done to get more reliable result and knowledge in order to understanding the flow of system and to analyze the result of chiller plant units. All the related software also should be use to get an accurate result comparing to manual calculation. The experiment also should be conducted for certain time of period as 1 month duration. The reason is to get the performance result with different amount of ambient temperature.

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APPENDIX A1

SAMPLE OF WALL TYPE

Table 6.1: Wall group type characteristics

Wall Group	(Layer Sequence Left to Right = Inside to Outside)
1	Layers E0 A3 B1 B13 A3 A0 Steel siding with 100 mm insulation
2	Layers E0 E1 B14 A1 A0 Frame wall with 13 mm insulation
3	Layers E0 C3 B5 A6 A0 100 mm h.w. concrete block with 25 mm insulation
4	Layers E0 E1 B6 C12 A0 50 mm insulation with 50 mm h.w. concrete
5	Layers E0 A6 B21 C7 A0 35 mm insulation with 200 mm l.w. concrete block
6	Layers E0 E1 B2 C5 A1 A0 25 mm insulation with 100 mm h.w. concrete
7	Layers E0 A6 C5 B3 A3 A0 100 mm h.w. concrete with 50 mm insulation
8	Layers E0 A2 C12 B5 A6 A0 Face brick and 50 mm h.w. concrete with 25 mm insulation
9	Layers E0 A6 B15 B10 A0 150 mm insulation with 50 mm wood
10	Layers E0 E1 C2 B5 A2 A0 100 mm l.w. concrete block with 25 mm ins. and face brick
11	Layers E0 E1 C8 B6 A1 A0 200 mm h.w. concrete block with 50 mm insulation
12	Layers E0 E1 B1 C10 A1 A0 200 mm h.w. concrete
13	Layers E0 A2 C5 B19 A6 A0 Face brick and 100 mm h.w. concrete with 16 mm ins.
14	Layers E0 A2 A2 B6 A6 A0 Face brick and face brick with 50 mm insulation
15	Layers E0 A6 C17 B1 A7 A0 200 mm l.w. conc. block (filled) and face brick
16	Layers E0 A6 C18 B1 A7 A0 200 mm h.w. concrete block (filled) and face brick
17	Layers E0 A2 C2 B15 A0 Face brick and 100 mm l.w. conc. block with 150 mm ins.
18	Layers E0 A6 B25 C9 A0 85 mm insulation with 200 mm common brick
19	Layers E0 C9 B6 A6 A0 200 mm common brick with 50 mm insulation
20	Layers E0 C11 B19 A6 A0 300 mm h.w. concrete with 15 mm insulation
21	Layers E0 C11 B6 A1 A0 300 mm h.w. concrete with 50 mm insulation
22	Layers E0 C14 B15 A2 A0 100 mm l.w. concrete with 150 mm ins. and face brick
23	Layers E0 E1 B15 C7 A2 A0 150 mm insulation with 200 mm l.w. concrete block
24	Layers E0 A6 C20 B1 A7 A0 300 mm h.w. concrete block (filled) and face brick
25	Layers E0 A2 C15 B12 A6 A0 Face brick and 150 mm l.w. conc. with 75 mm ins.

Source: ASHRAE (1997)

APPENDIX A2

SAMPLE OF THERMAL PROPERTIES

Table 6.2: Thermal properties code of wall type

Code Number	Description	Thickness and Thermal Properties					
		L	k	ρ	c_p	R	Mass
A0	Outside surface resistance	0	0.000	0	0.00	0.059	0.00
A1	25 mm Stucco	25	0.692	1858	0.84	0.037	47.34
A2	100 mm Face brick	100	1.333	2002	0.92	0.076	203.50
A3	Steel siding	2	44.998	7689	0.42	0.000	11.71
A4	12 mm Slag	13	0.190	1121	1.67	0.067	10.74
A5	Outside surface resistance	0	0.000	0	0.00	0.059	0.00
A6	Finish	13	0.415	1249	1.09	0.031	16.10
A7	100 mm Face brick	100	1.333	2002	0.92	0.076	203.50
B1	Air space resistance	0	0.000	0	0.00	0.160	0.00
B2	25 mm Insulation	25	0.043	32	0.84	0.587	0.98
B3	50 mm Insulation	51	0.043	32	0.84	1.173	1.46
B4	75 mm Insulation	76	0.043	32	0.84	1.760	2.44
B5	25 mm Insulation	25	0.043	91	0.84	0.587	2.44
B6	50 mm Insulation	51	0.043	91	0.84	1.173	4.88
B7	25 mm Wood	25	0.121	593	2.51	0.207	15.13
B8	65 mm Wood	63	0.121	593	2.51	0.524	37.58
B9	100 mm Wood	100	0.121	593	2.51	0.837	60.02
B10	50 mm Wood	51	0.121	593	2.51	0.420	30.26
B11	75 mm Wood	76	0.121	593	2.51	0.628	45.38
B12	75 mm Insulation	76	0.043	91	0.84	1.760	6.83
B13	100 mm Insulation	100	0.043	91	0.84	2.347	9.27
B14	125 mm Insulation	125	0.043	91	0.84	2.933	11.71
B15	150 mm Insulation	150	0.043	91	0.84	3.520	14.15
B16	4 mm Insulation	4	0.043	91	0.84	0.088	0.49
B17	8 mm Insulation	8	0.043	91	0.84	0.176	0.49
B18	12 mm Insulation	12	0.043	91	0.84	0.264	0.98
B19	15 mm Insulation	15	0.043	91	0.84	0.352	1.46
B20	20 mm Insulation	20	0.043	91	0.84	0.440	1.95
B21	35 mm Insulation	35	0.043	91	0.84	0.792	2.93
B22	42 mm Insulation	42	0.043	91	0.84	0.968	3.90
B23	60 mm Insulation	62	0.043	91	0.84	1.408	5.86
B24	70 mm Insulation	70	0.043	91	0.84	1.584	6.34
B25	85 mm Insulation	85	0.043	91	0.84	1.936	7.81
B26	92 mm Insulation	92	0.043	91	0.84	2.112	8.30
B27	115 mm Insulation	115	0.043	91	0.84	2.640	10.74
C1	100 mm Clay tile	100	0.571	1121	0.84	0.178	113.70
C2	100 mm low density concrete block	100	0.381	609	0.84	0.266	61.98
C3	100 mm high density concrete block	100	0.813	977	0.84	0.125	99.06
C4	100 mm Common brick	100	0.727	1922	0.84	0.140	195.20
C5	100 mm high density concrete	100	1.731	2243	0.84	0.059	227.90
C6	200 mm Clay tile	200	0.571	1121	0.84	0.352	227.90
C7	200 mm low density concrete block	200	0.571	609	0.84	0.352	123.46
C8	200 mm high density concrete block	200	1.038	977	0.84	0.196	198.62
C9	200 mm Common brick	200	0.727	1922	0.84	0.279	390.40
C10	200 mm high density concrete	200	1.731	2243	0.84	0.117	455.79
C11	300 mm high density concrete	300	1.731	2243	0.84	0.176	683.20
C12	50 mm high density concrete	50	1.731	2243	0.84	0.029	113.70
C13	150 mm high density concrete	150	1.731	2243	0.84	0.088	341.60
C14	100 mm low density concrete	100	0.173	641	0.84	0.587	64.90
C15	150 mm low density concrete	150	0.173	641	0.84	0.880	97.60
C16	200 mm low density concrete	200	0.173	641	0.84	1.173	130.30
C17	200 mm low density concrete block (filled)	200	0.138	288	0.84	1.467	58.56
C18	200 mm high density concrete block (filled)	200	0.588	849	0.84	0.345	172.75
C19	300 mm low density concrete block (filled)	300	0.138	304	0.84	2.200	92.72
C20	300 mm high density concrete block (filled)	300	0.675	897	0.84	0.451	273.28
E0	Inside surface resistance	0	0.000	0	0.00	0.121	0.00
E1	20 mm Plaster or gypsum	20	0.727	1602	0.84	0.026	30.74
E2	12 mm Slag or stone	12	1.436	881	1.67	0.009	11.22
E3	10 mm Felt and membrane	10	0.190	1121	1.67	0.050	10.74
E4	Ceiling air space	0	0.000	0	0.00	0.176	0.00
E5	Acoustic tile	19	0.061	481	0.84	0.314	9.27

L = thickness, mm
k = thermal conductivity, W/(m·K)
ρ = density, kg/m^3
c_p = specific heat, kJ/(kg·K)
R = thermal resistance, (m^2·K)/W
Mass = mass per unit area, kg/m^2

APPENDIX A3

SAMPLE OF CLTD FROM SUNLIT WALLS

Table 6.3: Cooling Load Temperature Difference (CLTD) from sunlit wall type

Wall Number 1

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	1	0	−1	−1	−2	−1	4	6	6	7	9	12	14	15	16	16	16	16	15	9	6	4	3	2
NE	1	0	−1	−1	−2	1	13	23	26	24	19	16	15	16	16	16	15	13	11	8	6	4	3	2
E	1	0	−1	−1	−1	1	16	28	34	36	33	27	20	17	17	17	16	14	11	8	6	4	3	2
SE	1	0	−1	−1	−2	0	8	18	26	31	32	31	27	22	18	17	16	14	11	8	6	4	3	2
S	1	0	−1	−1	−2	−1	0	2	6	12	18	24	28	29	28	24	19	15	11	8	6	4	3	2
SW	1	0	−1	−1	−1	−1	0	2	4	7	9	14	22	29	36	39	38	34	25	13	7	4	3	2
W	1	1	−1	−1	−1	−1	1	2	4	7	9	12	15	23	33	41	44	44	34	18	9	5	3	2
NW	1	0	−1	−1	−1	−1	0	2	4	7	9	12	14	16	21	28	34	36	31	16	8	5	3	2

Wall Number 2

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	3	2	1	0	−1	−1	−1	2	4	5	6	8	10	12	13	14	15	16	16	15	12	9	7	4
NE	3	2	1	0	−1	−1	1	7	14	20	22	21	18	17	16	16	16	16	14	13	10	8	6	4
E	3	2	1	0	−1	−1	1	8	18	26	31	32	29	24	21	19	18	17	15	13	11	8	6	4
SE	3	2	1	0	−1	−1	0	4	11	18	24	28	29	28	25	22	19	17	16	13	11	8	6	4
S	3	2	1	0	−1	−1	−1	−1	1	4	8	13	18	23	26	27	26	22	18	15	12	8	6	4
SW	4	2	1	1	0	−1	−1	0	1	3	5	7	11	17	23	29	34	36	34	29	22	15	9	6
W	4	3	2	1	0	−1	−1	0	1	3	5	7	9	13	18	26	33	38	41	37	28	19	12	8
NW	4	2	1	1	−1	−1	−1	−1	1	3	5	7	9	12	14	18	23	28	32	30	23	16	11	7

Wall Number 3

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	4	3	2	1	1	0	1	3	4	4	6	8	9	11	13	13	14	14	15	13	11	9	7	6
NE	4	3	2	1	0	0	4	9	14	17	18	17	17	16	16	16	16	16	14	12	10	8	7	5
E	4	3	2	1	1	1	4	12	18	23	26	26	24	22	21	19	18	17	16	13	11	9	7	6
SE	4	3	2	1	1	0	2	7	12	18	22	24	26	24	23	21	19	18	16	13	11	9	7	6
S	4	3	2	1	1	0	0	1	2	5	9	13	17	21	23	23	22	20	17	14	12	9	8	6
SW	7	5	3	2	1	1	1	1	2	3	5	8	12	17	22	27	31	32	30	25	20	16	12	9
W	8	6	4	3	2	1	1	1	2	3	5	7	9	13	19	25	31	35	35	30	24	18	14	11
NW	7	4	3	2	1	1	0	1	2	3	5	7	9	11	14	18	22	27	28	24	19	15	12	9

Wall Number 4

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	6	4	3	2	1	0	0	1	2	3	4	6	7	9	11	12	13	14	15	15	14	12	11	8
NE	6	4	3	2	1	0	0	2	7	12	16	18	18	18	17	17	17	16	16	14	13	11	9	7
E	6	4	3	2	1	1	1	3	8	15	21	25	27	26	24	22	21	19	18	16	14	12	9	8
SE	6	4	3	2	1	1	0	1	4	9	15	20	24	26	26	24	23	21	19	17	14	12	10	8
S	6	4	3	2	1	1	0	1	0	1	3	7	11	16	19	23	24	23	22	19	17	13	11	8
SW	10	7	5	3	2	1	0	0	0	1	3	4	7	10	15	20	26	29	32	32	28	23	18	14
W	12	8	6	4	2	1	1	0	1	1	3	4	6	8	12	17	22	28	33	36	33	28	22	17
NW	10	7	5	3	2	1	0	0	0	1	2	4	6	8	11	13	17	21	25	27	27	23	18	14

Wall Number 5

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	7	6	4	3	3	2	1	2	3	3	4	5	7	8	9	11	12	13	13	13	13	12	10	8
NE	7	6	4	3	3	2	2	4	8	11	14	15	16	16	16	16	16	16	15	14	13	12	10	8
E	8	6	5	4	3	2	2	4	9	14	18	22	22	22	21	21	19	19	18	16	14	13	11	9
SE	8	7	5	4	3	2	2	3	6	10	14	18	21	22	22	21	21	19	18	17	15	13	11	9
S	8	7	5	4	3	2	2	1	2	2	4	7	11	14	17	19	20	20	19	18	16	13	12	10
SW	12	10	8	6	4	3	3	2	2	3	3	5	7	9	14	18	22	26	27	27	24	21	18	14
W	14	11	9	7	6	4	3	2	2	3	4	5	6	8	11	16	21	25	29	30	28	24	21	17
NW	12	9	7	6	4	3	2	2	2	2	3	4	6	8	9	12	15	19	22	23	22	19	17	14

Wall Number 6

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	7	6	5	4	3	3	2	3	3	4	4	6	7	8	9	10	11	12	12	13	12	11	9	8
NE	8	7	6	4	3	3	3	6	8	11	13	14	14	14	14	15	15	15	14	14	13	12	10	9
E	9	7	6	5	4	3	4	6	10	14	17	19	20	20	19	19	19	18	17	16	14	13	12	10
SE	9	8	6	5	4	3	3	4	7	10	13	16	18	19	20	19	19	18	18	16	15	13	12	10
S	9	7	6	5	4	3	3	2	2	3	5	7	10	13	16	17	18	18	17	16	15	13	12	10
SW	13	11	9	8	6	5	4	3	3	4	4	6	7	10	13	17	21	23	24	24	22	19	17	15
W	14	12	10	8	7	6	4	4	4	4	4	6	7	8	11	15	19	23	26	27	25	22	19	17
NW	12	10	8	7	6	4	4	3	3	3	4	5	6	8	9	12	14	18	20	21	20	18	16	14

Table 6.3: Continue

Wall Number 7

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	7	7	6	5	4	3	3	4	4	4	5	6	7	8	9	9	10	11	11	11	11	10	9	8
NE	8	7	6	6	5	4	5	7	9	11	12	13	13	13	13	14	14	14	13	13	12	11	10	9
E	9	8	7	7	6	5	6	9	12	14	17	18	18	18	18	18	17	17	16	15	14	13	12	11
SE	9	8	7	7	6	5	5	7	9	12	14	16	17	18	18	18	17	17	16	15	14	13	12	11
S	9	8	7	6	6	4	4	4	4	5	7	8	11	13	14	16	16	16	16	14	13	12	11	10
SW	13	11	10	9	7	7	6	6	6	6	6	7	8	11	14	17	19	21	22	21	19	17	16	14
W	14	12	11	9	8	7	7	6	6	6	7	7	8	9	12	16	19	22	23	23	21	19	17	16
NW	11	10	9	8	7	6	5	5	5	5	6	6	7	8	9	12	14	17	18	18	17	16	14	13

Wall Number 9

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	9	8	7	6	5	4	3	2	2	2	3	4	4	6	7	8	9	11	12	12	13	13	12	11
NE	10	8	7	6	5	4	3	3	3	6	9	11	13	14	14	15	15	16	16	15	14	14	13	11
E	11	9	8	7	6	4	3	3	4	7	11	14	18	20	21	21	21	20	19	18	17	16	14	13
SE	11	9	8	7	6	4	3	3	3	5	7	11	14	17	19	20	21	20	19	19	18	16	14	13
S	12	10	8	7	6	4	3	3	2	2	2	3	6	8	11	14	16	18	19	19	18	17	15	13
SW	17	14	12	10	8	7	5	4	3	3	3	3	4	6	8	11	14	18	22	24	25	24	22	20
W	19	17	14	12	9	8	6	4	4	3	3	4	4	6	7	9	12	17	21	24	27	27	25	23
NW	16	14	12	9	8	6	5	4	3	3	3	3	4	5	6	8	10	12	16	19	21	21	20	18

Wall Number 10

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	9	8	7	6	5	4	3	3	3	3	3	4	4	6	7	8	9	10	11	12	12	12	12	11
NE	10	9	7	6	5	4	3	3	4	7	9	11	12	13	14	14	15	15	15	15	14	13	12	11
E	11	9	8	7	6	4	4	4	6	8	11	14	17	19	19	20	20	19	19	18	17	16	14	13
SE	12	10	8	7	6	4	4	3	4	6	8	11	14	17	18	19	19	19	19	18	17	16	14	13
S	12	10	8	7	6	5	4	3	2	2	3	4	6	8	11	13	16	17	18	18	17	16	14	13
SW	17	15	13	11	9	7	6	4	4	3	3	4	4	6	8	11	14	18	21	23	23	23	21	19
W	19	17	14	12	10	8	7	5	4	4	4	4	4	6	7	9	13	17	21	23	25	25	23	22
NW	16	13	12	10	8	7	6	4	3	3	3	3	4	6	7	8	10	13	16	18	19	20	19	17

Wall Number 11

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	9	8	7	7	6	5	4	4	4	4	4	5	6	6	7	8	8	9	10	11	11	11	10	9
NE	10	9	8	7	7	6	5	5	6	8	9	11	12	12	13	13	13	13	14	14	13	13	12	11
E	12	11	9	9	8	7	6	6	7	9	12	14	16	17	17	17	17	17	17	17	16	15	14	13
SE	12	11	9	9	8	7	6	6	6	8	9	12	13	15	16	17	17	17	17	17	16	15	14	13
S	11	10	9	8	7	6	6	5	4	4	4	6	7	9	11	13	14	15	16	16	15	14	13	12
SW	16	14	13	11	10	9	8	7	6	6	6	6	7	8	9	12	14	17	18	20	20	19	18	17
W	17	16	14	12	11	10	9	8	7	7	6	7	7	7	8	11	13	16	18	21	22	21	20	18
NW	14	13	11	10	9	8	7	6	6	5	5	6	6	7	7	8	10	12	14	16	17	17	16	15

Wall Number 12

Wall Face	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	9	8	7	7	6	6	4	4	4	4	4	5	6	6	7	8	8	9	9	10	11	11	10	9
NE	10	9	8	8	7	6	6	6	7	8	9	11	12	12	12	13	13	13	13	13	13	12	12	11
E	12	11	10	9	8	7	7	7	8	9	12	14	16	16	17	17	17	17	17	16	16	15	14	13
SE	12	11	10	9	8	7	7	6	7	8	9	12	13	14	16	16	17	17	17	16	16	15	14	13
S	11	11	9	8	8	7	6	6	5	5	5	6	7	9	11	12	13	14	14	14	14	14	13	12
SW	15	14	13	12	11	9	8	8	7	7	7	7	7	8	9	11	13	16	18	19	19	19	18	17
W	17	16	14	13	12	11	9	8	8	7	7	7	7	8	9	11	13	15	18	19	21	20	19	18
NW	13	12	11	11	9	8	7	7	6	6	6	6	6	7	7	8	10	12	14	16	16	16	16	14

Source: ASHRAE (1997)

APPENDIX A4

SAMPLE OF WINDOW U-FACTOR

Table 6.4: Three different type of window U-Factor, Btu/hr.ft^2.F and [W/m^2.^{o}C]

	Aluminum without thermal break	**Aluminum with thermal break**	**Wood/vinyl**
Single glazing			
1/8 in. [32mm] glass	1.13 [6.42]	1.07 [6.07]	0.98 [5.55]
Double glazing			
1/4 in. [6.4mm] air space	0.69 [3.94]	0.63 [3.56]	0.56 [3.17]
1/2 in. [12.8mm] air space	0.64 [3.61]	0.57 [3.22]	0.50 [2.84]
1/4 in. [6.4mm] argon space	0.66 [3.75]	0.59 [3.37]	0.52 [2.98]
1/2 in. [12.8mm] argon space	0.61 [3.47]	0.54 [3.08]	0.48 [2.70]
Triple glazing			
1/4 in. [6.4mm] air spaces	0.55 [3.10]	0.48 [2.73]	0.41 [2.33]
1/2 in. [12.8mm] air spaces	0.49 [2.76]	0.42 [2.39]	0.35 [2.01]
1/4 in. [6.4mm] argon spaces	0.51 [2.90]	0.45 [2.54]	0.38 [2.15]
1/2 in. [12.8mm] argon spaces	0.47 [2.66]	0.40 [2.30	0.34 [1.91]

APPENDIX A5

SAMPLE OF SHADING COEFFICIENT (SC)

Table 6.5: Shading Coefficient of single and double glazing

	Aluminum Frame		**Other Frames**	
	Operable	**Fixed**	**Operable**	**Fixed**
Uncoated single glazing				
1/4 in. [6.4mm] clear	0.82	0.85	0.69	0.82
1/4 in. [6.4mm] green	0.59	0.61	0.49	0.59
Reflective single glazing				
1/4 in. [6.4mm] SS on clear	0.26	0.28	0.22	0.25
1/4 in. [6.4mm] SS on green	0.26	0.28	0.22	0.25
Uncoated double glazing				
1/4 in. [6.4mm] clear-clear	0.70	0.74	0.60	0.70
1/4 in. [6.4mm] green-green	0.48	0.49	0.40	0.47
Reflective double glazing				
1/4 in. [6.4mm] SS on clear-clear	0.20	0.18	0.15	0.17
1/4 in. [6.4mm] SS on green-green	0.18	0.18	0.15	0.16

Source: ASHRAE (1997)

APPENDIX A6

SAMPLE OF ZONE TYPE FOR USE WITH CLF TABLES

Table 6.6: Location of zone type for use with cooling load factor (CLF) tables

	Zone Parameters			Zone Type	
Room location	**Middle floor**	**Ceiling type**	**Floor covering**	**People and equipment**	**Lights**
Single story	N/A	N/A	Carpet	C	B
	N/A	N/A	Vinyl	D	C
Top Floor	65mm Concrete	With	Carpet	D	C
	65mm Concrete	With	Vinyl	D	D
	65mm Concrete	Without	b	D	B
	25mm Wood	b	b	D	B
Bottom Floor	65mm Concrete	With	Carpet	D	C
	65mm Concrete	b	Vinyl	D	D
	65mm Concrete	Without	Carpet	D	D
	25mm Wood	b	Carpet	D	C
	25mm Wood	b	Vinyl	D	D
Mid Floor	65mm Concrete	N/A	Carpet	D	C
	65mm Concrete	N/A	Vinyl	D	D
	25mm Wood	N/A	b	C	B

APPENDIX A7

SAMPLE OF CLTD FOR CONDUCTION THROUGH GLASS

Table 6.7: Cooling load temperature differences (CLTD) for conduction through glass

Solar Time, h	CLTD, ºC	Solar Time, h	CLTD, ºC	Solar Time, h	CLTD, ºC
0100	1	0900	1	1700	7
0200	0	1000	2	1800	7
0300	-1	1100	4	1900	6
0400	-1	1200	5	2000	4
0500	-1	1300	7	2100	3
0600	-1	1400	7	2200	2
0700	-1	1500	8	2300	2
0800	0	1600	8	2400	1

Source: ASHRAE (1997)

APPENDIX A8

SAMPLE OF WINDOW SOLAR COOLING LOAD (SCL) FOR SUNLIT GLASS

Table 6.8: Window solar cooling load (SCL) zone type for sunlit glass

Zone Type A

Glass Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Solar Time																							
N	0	0	0	0	3	79	85	88	101	110	120	126	126	123	113	98	98	113	38	19	9	3	3	0
NE	0	0	0	0	6	268	406	422	353	236	173	151	139	126	117	101	82	57	22	9	6	3	0	0
E	0	0	0	0	6	293	495	583	576	485	334	211	167	142	123	104	82	57	22	9	6	3	0	0
SE	0	0	0	0	3	148	299	413	473	473	413	306	198	154	129	107	85	57	22	9	6	3	0	0
S	0	0	0	0	0	28	54	79	129	202	268	306	302	265	198	132	98	63	25	13	6	3	0	0
SW	0	0	0	0	0	28	54	76	95	110	123	202	318	419	476	479	419	293	110	54	25	13	6	3
W	3	0	0	0	0	28	54	76	95	110	120	126	205	359	498	589	605	491	180	85	41	19	9	6
NW	3	0	0	0	0	28	54	76	95	110	120	126	126	158	265	381	450	410	145	69	35	16	9	3
Hor	0	0	0	0	0	76	217	378	532	665	759	810	816	772	684	554	394	221	91	44	22	9	6	3

Zone Type B

Glass Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Solar Time																							
N	6	6	3	3	3	69	72	76	88	101	110	117	120	117	110	101	98	110	50	32	22	16	13	9
NE	6	3	3	3	6	230	343	365	318	230	183	164	151	142	129	113	95	72	41	28	19	16	9	9
E	6	6	3	3	6	252	419	501	510	450	331	233	198	173	151	129	107	79	47	32	22	16	13	9
SE	6	6	3	3	3	126	255	353	413	422	384	302	217	183	154	132	110	82	47	32	25	19	13	9
S	6	6	3	3	3	25	47	66	113	176	233	271	274	249	198	145	117	85	50	35	25	19	13	9
SW	19	16	13	9	6	28	50	69	85	98	113	183	280	369	425	435	397	296	145	98	66	47	35	25
W	25	19	16	13	9	28	50	69	85	98	110	117	186	318	438	523	545	463	208	135	95	66	47	35
NW	19	16	13	9	6	28	50	69	85	98	107	117	117	145	239	340	403	375	161	104	69	50	35	25
Hor	25	19	16	13	9	69	189	328	463	583	674	734	753	731	668	567	432	284	167	117	85	60	44	35

Zone Type C

Glass Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Solar Time																							
N	16	16	13	13	13	76	72	76	85	95	104	107	110	107	101	91	91	107	44	32	25	22	19	19
NE	22	19	19	16	19	236	334	337	277	192	154	148	142	135	126	113	98	79	50	41	35	32	28	25
E	28	25	25	22	25	261	410	466	457	391	280	195	176	164	148	135	117	95	63	54	47	41	38	35
SE	28	25	22	19	19	142	258	337	381	381	337	258	186	161	148	132	113	91	60	50	44	41	35	32
S	22	22	19	16	16	38	57	72	113	170	221	249	249	221	170	126	104	82	50	41	38	32	28	25
SW	44	38	35	32	28	47	66	82	91	104	113	180	271	347	391	394	350	252	117	88	72	63	54	47
W	54	47	41	38	35	54	69	85	98	107	113	117	186	309	416	482	491	403	158	110	88	76	66	60
NW	38	35	32	28	25	44	63	79	91	101	107	113	113	139	230	321	372	337	123	82	66	54	47	41
Hor	76	66	60	54	50	107	214	337	454	551	627	668	677	652	595	504	387	261	167	139	120	107	95	85

Zone Type D

Glass Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Solar Time																							
N	25	22	19	19	19	66	66	66	76	85	91	98	101	98	95	88	91	101	54	44	38	35	32	28
NE	35	32	28	25	28	198	274	284	243	183	154	151	145	139	132	123	110	91	69	60	54	47	44	38
E	47	41	38	35	35	221	337	387	391	347	268	205	189	180	167	151	135	117	91	79	69	63	57	50
SE	44	41	35	32	32	123	214	284	321	328	299	246	189	173	161	148	132	110	85	76	66	60	54	50
S	35	32	28	25	22	38	54	66	101	145	186	211	217	198	164	129	113	95	69	60	54	47	44	38
SW	66	60	54	47	44	57	69	79	88	98	107	161	233	296	334	343	315	246	142	117	104	91	82	72
W	79	72	63	57	54	66	76	88	95	104	107	110	167	265	353	410	425	365	180	145	123	110	98	88
NW	57	50	47	41	38	54	66	76	85	95	101	104	107	129	202	274	318	296	132	104	91	79	69	63
Hor	117	104	95	85	76	120	202	299	391	473	539	583	602	592	554	491	403	302	227	198	176	158	142	129

Notes:
1. Values are in W/m^2.
2. Apply data directly to standard double strength glass with no inside shade.
3. Data applies to 21st day of July.
4. For other types of glass and internal shade, use shading coefficients as multiplier. See text. For externally shaded glass, use north orientation. See text.

APPENDIX A9

SAMPLE OF COOLING LOAD FACTOR (CLF) FOR PEOPLES

Table 6.9: Cooling load factor (CLF) for peoples

Hours in Space	Number of Hours after Entry into Space or Equipment Turned On																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Zone Type A																								
2	0.75	0.88	0.18	0.08	0.04	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.75	0.88	0.93	0.95	0.22	0.10	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.75	0.88	0.93	0.95	0.97	0.97	0.23	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.75	0.88	0.93	0.95	0.97	0.97	0.98	0.98	0.24	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
10	0.75	0.88	0.93	0.95	0.97	0.97	0.98	0.98	0.99	0.99	0.24	0.12	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
12	0.75	0.88	0.93	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.25	0.12	0.07	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01
14	0.76	0.88	0.93	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.25	0.12	0.07	0.05	0.03	0.03	0.02	0.02	0.01	0.01
16	0.76	0.89	0.94	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.25	0.12	0.07	0.05	0.03	0.03	0.02	0.02
18	0.77	0.89	0.94	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25	0.12	0.07	0.05	0.03	0.03
Zone Type B																								
2	0.65	0.74	0.16	0.11	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.65	0.75	0.81	0.85	0.24	0.17	0.13	0.10	0.07	0.06	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
6	0.65	0.75	0.81	0.85	0.89	0.91	0.29	0.20	0.15	0.12	0.09	0.07	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
8	0.65	0.75	0.81	0.85	0.89	0.91	0.93	0.95	0.31	0.22	0.17	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01
10	0.65	0.75	0.81	0.85	0.89	0.91	0.93	0.95	0.96	0.97	0.33	0.24	0.18	0.14	0.11	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01
12	0.66	0.76	0.81	0.86	0.89	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.34	0.24	0.19	0.14	0.11	0.08	0.06	0.05	0.04	0.03	0.02	0.02
14	0.67	0.76	0.82	0.86	0.89	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.35	0.25	0.19	0.15	0.11	0.09	0.07	0.05	0.04	0.03
16	0.69	0.78	0.83	0.87	0.90	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.35	0.25	0.19	0.15	0.11	0.09	0.07	0.05
18	0.71	0.80	0.85	0.88	0.91	0.93	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.35	0.25	0.19	0.15	0.11	0.09
Zone Type C																								
2	0.60	0.68	0.14	0.11	0.09	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
4	0.60	0.68	0.74	0.79	0.23	0.18	0.14	0.12	0.10	0.08	0.06	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
6	0.61	0.69	0.74	0.79	0.83	0.86	0.28	0.22	0.18	0.15	0.12	0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01
8	0.61	0.69	0.75	0.79	0.83	0.86	0.89	0.91	0.32	0.26	0.21	0.17	0.14	0.11	0.09	0.08	0.06	0.05	0.04	0.04	0.03	0.02	0.02	0.02
10	0.62	0.70	0.75	0.80	0.83	0.86	0.89	0.91	0.92	0.94	0.35	0.28	0.23	0.18	0.15	0.12	0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.03
12	0.63	0.71	0.76	0.81	0.84	0.87	0.89	0.91	0.93	0.94	0.95	0.96	0.37	0.29	0.24	0.19	0.16	0.13	0.11	0.09	0.07	0.06	0.05	0.04
14	0.65	0.72	0.77	0.82	0.85	0.88	0.90	0.92	0.93	0.94	0.95	0.96	0.97	0.97	0.38	0.30	0.25	0.20	0.17	0.14	0.11	0.09	0.08	0.06
16	0.68	0.74	0.79	0.83	0.86	0.89	0.91	0.92	0.94	0.95	0.96	0.96	0.97	0.98	0.98	0.98	0.39	0.31	0.25	0.21	0.17	0.14	0.11	0.09
18	0.72	0.78	0.82	0.85	0.88	0.90	0.92	0.93	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.99	0.99	0.39	0.31	0.26	0.21	0.17	0.14
Zone Type D																								
2	0.59	0.67	0.13	0.09	0.08	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
4	0.60	0.67	0.72	0.76	0.20	0.16	0.13	0.11	0.10	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
6	0.61	0.68	0.73	0.77	0.80	0.83	0.26	0.20	0.17	0.15	0.13	0.11	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.02	0.02
8	0.62	0.69	0.74	0.77	0.80	0.83	0.85	0.87	0.30	0.24	0.20	0.17	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.03
10	0.63	0.70	0.75	0.78	0.81	0.84	0.86	0.88	0.89	0.91	0.33	0.27	0.22	0.19	0.17	0.14	0.12	0.11	0.09	0.08	0.07	0.06	0.05	0.05
12	0.65	0.71	0.76	0.79	0.82	0.84	0.87	0.88	0.90	0.91	0.92	0.93	0.35	0.29	0.24	0.21	0.18	0.16	0.13	0.12	0.10	0.09	0.08	0.07
14	0.67	0.73	0.78	0.81	0.83	0.86	0.88	0.89	0.91	0.92	0.93	0.94	0.95	0.95	0.37	0.30	0.25	0.22	0.19	0.16	0.14	0.12	0.11	0.09
16	0.70	0.76	0.80	0.83	0.85	0.87	0.89	0.90	0.92	0.93	0.94	0.95	0.95	0.96	0.96	0.97	0.38	0.31	0.26	0.23	0.20	0.17	0.15	0.13
18	0.74	0.80	0.83	0.85	0.87	0.89	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.97	0.97	0.97	0.98	0.98	0.39	0.32	0.27	0.23	0.20	0.17

Note: See Table 35 for zone type. Data based on a radiative/convective fraction of 0.70/0.30.

Source: ASHRAE (1997)

APPENDIX A10

SAMPLE OF COOLING LOAD FACTOR (CLF) FOR LIGHTS

Table 6.10: Cooling load factor (CLF) for lights

Lights On For	Number of Hours after Lights Turned On																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Zone Type A																								
8	0.85	0.92	0.95	0.96	0.97	0.97	0.97	0.98	0.13	0.06	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.85	0.93	0.95	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.14	0.07	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
12	0.86	0.93	0.96	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.14	0.07	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
14	0.86	0.93	0.96	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.15	0.07	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.02
16	0.87	0.94	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.15	0.08	0.05	0.04	0.03	0.03	0.03	0.02
Zone Type B																								
8	0.75	0.85	0.90	0.93	0.94	0.95	0.95	0.96	0.23	0.12	0.08	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01
10	0.75	0.86	0.91	0.93	0.94	0.95	0.95	0.96	0.96	0.97	0.24	0.13	0.08	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02
12	0.76	0.86	0.91	0.93	0.95	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.24	0.14	0.09	0.07	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03
14	0.76	0.87	0.92	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.25	0.14	0.09	0.07	0.06	0.05	0.05	0.04	0.04	0.03
16	0.77	0.88	0.92	0.95	0.96	0.96	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.25	0.15	0.10	0.07	0.06	0.05	0.05	0.04
Zone Type C																								
8	0.72	0.80	0.84	0.87	0.88	0.89	0.90	0.91	0.23	0.15	0.11	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03
10	0.73	0.81	0.85	0.87	0.89	0.90	0.91	0.92	0.92	0.93	0.25	0.16	0.13	0.11	0.09	0.08	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04
12	0.74	0.82	0.86	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.26	0.18	0.14	0.12	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.05
14	0.75	0.84	0.87	0.89	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.95	0.96	0.96	0.27	0.19	0.15	0.13	0.11	0.10	0.09	0.08	0.08	0.07
16	0.77	0.85	0.89	0.91	0.92	0.93	0.93	0.94	0.95	0.95	0.95	0.96	0.96	0.97	0.97	0.97	0.28	0.20	0.16	0.13	0.12	0.11	0.10	0.09
Zone Type D																								
8	0.66	0.72	0.76	0.79	0.81	0.83	0.85	0.86	0.25	0.20	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04
10	0.68	0.74	0.77	0.80	0.82	0.84	0.86	0.87	0.88	0.90	0.28	0.23	0.19	0.17	0.15	0.14	0.12	0.11	0.10	0.09	0.08	0.07	0.06	0.06
12	0.70	0.75	0.79	0.81	0.83	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.30	0.25	0.21	0.19	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.08
14	0.72	0.77	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.32	0.26	0.23	0.20	0.18	0.16	0.14	0.13	0.12	0.10
16	0.75	0.80	0.83	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.95	0.96	0.96	0.34	0.28	0.24	0.21	0.19	0.17	0.15	0.14

Note: See Table 35 for zone type. Data based on a radiative/convective fraction of 0.59/0.41.

Source: ASHRAE (1997)

APPENDIX A11

SAMPLE OF COOLING LOAD FACTOR (CLF) FOR APPLIANCES

Table 6.11: Cooling load factor (CLF) for appliances

Hours in Operation	Number of Hours after Equipment Turned On																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Zone Type A																								
2	0.64	0.83	0.26	0.11	0.06	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.64	0.83	0.90	0.93	0.31	0.14	0.07	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.64	0.83	0.90	0.93	0.96	0.96	0.33	0.16	0.09	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.64	0.83	0.90	0.93	0.96	0.96	0.97	0.97	0.34	0.16	0.09	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
10	0.64	0.83	0.90	0.93	0.96	0.96	0.97	0.97	0.99	0.99	0.34	0.17	0.10	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00
12	0.64	0.83	0.90	0.94	0.96	0.97	0.97	0.97	0.99	0.99	0.99	0.99	0.36	0.17	0.10	0.06	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01
14	0.66	0.83	0.90	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.36	0.17	0.10	0.07	0.04	0.04	0.03	0.03	0.03	0.01
16	0.66	0.84	0.91	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.36	0.17	0.10	0.07	0.04	0.04	0.04	0.03
18	0.67	0.84	0.91	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.36	0.17	0.10	0.08	0.07	0.04
Zone Type B																								
2	0.50	0.63	0.23	0.16	0.11	0.09	0.07	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.50	0.64	0.73	0.79	0.34	0.24	0.19	0.14	0.10	0.09	0.06	0.04	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
6	0.50	0.64	0.73	0.79	0.84	0.87	0.41	0.29	0.21	0.17	0.13	0.10	0.07	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00
8	0.50	0.64	0.73	0.79	0.84	0.87	0.90	0.93	0.44	0.31	0.24	0.19	0.14	0.11	0.09	0.07	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01
10	0.50	0.64	0.73	0.79	0.84	0.87	0.90	0.93	0.94	0.96	0.47	0.34	0.26	0.20	0.16	0.11	0.09	0.07	0.06	0.04	0.03	0.03	0.03	0.01
12	0.51	0.66	0.73	0.80	0.84	0.89	0.91	0.93	0.94	0.96	0.97	0.97	0.49	0.34	0.27	0.20	0.16	0.11	0.09	0.07	0.06	0.05	0.04	0.03
14	0.53	0.66	0.74	0.80	0.84	0.89	0.91	0.93	0.94	0.96	0.97	0.97	0.99	0.99	0.50	0.36	0.27	0.21	0.16	0.13	0.10	0.08	0.07	0.06
16	0.56	0.69	0.76	0.81	0.86	0.89	0.91	0.93	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.50	0.36	0.27	0.21	0.16	0.14	0.13	0.10
18	0.59	0.71	0.79	0.83	0.87	0.90	0.93	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.50	0.36	0.27	0.23	0.21	0.16
Zone Type C																								
2	0.43	0.54	0.20	0.16	0.13	0.10	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
4	0.43	0.54	0.63	0.70	0.33	0.26	0.20	0.17	0.14	0.11	0.09	0.07	0.06	0.06	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
6	0.44	0.56	0.63	0.70	0.76	0.80	0.40	0.31	0.26	0.21	0.17	0.14	0.11	0.10	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.01	0.01
8	0.44	0.56	0.64	0.70	0.76	0.80	0.84	0.87	0.46	0.37	0.30	0.24	0.20	0.16	0.13	0.11	0.09	0.07	0.06	0.06	0.04	0.03	0.03	0.03
10	0.46	0.57	0.64	0.71	0.76	0.80	0.84	0.87	0.89	0.91	0.50	0.40	0.33	0.26	0.21	0.17	0.14	0.11	0.10	0.09	0.07	0.06	0.06	0.04
12	0.47	0.59	0.66	0.73	0.77	0.81	0.84	0.87	0.90	0.91	0.93	0.94	0.53	0.41	0.34	0.27	0.23	0.19	0.16	0.13	0.10	0.09	0.09	0.07
14	0.50	0.60	0.67	0.74	0.79	0.83	0.86	0.89	0.90	0.91	0.93	0.94	0.96	0.96	0.54	0.43	0.36	0.29	0.24	0.20	0.16	0.14	0.13	0.11
16	0.54	0.63	0.70	0.76	0.80	0.84	0.87	0.89	0.91	0.93	0.94	0.94	0.96	0.97	0.97	0.97	0.56	0.44	0.36	0.30	0.24	0.22	0.20	0.16
18	0.60	0.69	0.74	0.79	0.83	0.86	0.89	0.90	0.91	0.93	0.94	0.96	0.96	0.97	0.97	0.99	0.99	0.99	0.56	0.44	0.37	0.33	0.30	0.24
Zone Type D																								
2	0.41	0.53	0.19	0.13	0.11	0.09	0.07	0.07	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.43	0.53	0.60	0.66	0.29	0.23	0.19	0.16	0.14	0.11	0.10	0.09	0.07	0.07	0.06	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.01	0.01
6	0.44	0.54	0.61	0.67	0.71	0.76	0.37	0.29	0.24	0.21	0.19	0.16	0.13	0.11	0.10	0.09	0.07	0.07	0.06	0.04	0.04	0.04	0.04	0.03
8	0.46	0.56	0.63	0.67	0.71	0.76	0.79	0.81	0.43	0.34	0.29	0.24	0.21	0.19	0.16	0.14	0.11	0.10	0.09	0.07	0.07	0.06	0.06	0.06
10	0.47	0.57	0.64	0.69	0.73	0.77	0.80	0.83	0.84	0.87	0.47	0.39	0.31	0.27	0.24	0.20	0.17	0.16	0.13	0.11	0.10	0.09	0.09	0.07
12	0.50	0.59	0.66	0.70	0.74	0.77	0.81	0.83	0.86	0.87	0.89	0.90	0.50	0.41	0.34	0.30	0.26	0.23	0.19	0.17	0.14	0.13	0.13	0.11
14	0.53	0.61	0.69	0.73	0.76	0.80	0.83	0.84	0.87	0.89	0.90	0.91	0.93	0.93	0.53	0.43	0.36	0.31	0.27	0.23	0.20	0.18	0.17	0.16
16	0.57	0.66	0.71	0.76	0.79	0.81	0.84	0.86	0.89	0.90	0.91	0.93	0.93	0.94	0.94	0.96	0.54	0.44	0.37	0.33	0.29	0.26	0.24	0.21
18	0.63	0.71	0.76	0.79	0.81	0.84	0.87	0.89	0.90	0.91	0.93	0.93	0.94	0.96	0.96	0.96	0.97	0.97	0.56	0.46	0.39	0.35	0.33	0.29

Note: See Table 35 for zone type. Data based on a radiative/convective fraction of 1.0/0.

Source: ASHRAE (1997)

APPENDIX A12

HEATING AND WIND DESIGN CONDITIONS—WORLD LOCATIONS

Table 6.12: Heating and wind design condition by world location

							Heating Dry Bulb		Extreme Wind Speed, m/s			Coldest Month				MWS/MWD to DB				Extr. Annual Daily			
												0.4%		1%		99.6%		0.4%		Mean DB		StdD DB	
	WHO#	Lat.	Long.	Elev. m	StdP, kPa	Dates	99.6%	99%	1%	2.5%	5%	WS	MDB	WS	MDB	MWS	MWD	MWS	MWD	Max.	Min.	Max.	Min.
KOREA, SOUTH																							
Cheju	471820	33.50 N	126.55 E	27	101.00	8293	−1.1	−0.1	12.2	10.7	9.6	12.4	3.0	11.2	4.6	6.2	40	6.3	230	33.8	−3.2	1.2	1.4
Inch'on	471120	37.48 N	126.63 E	70	100.49	8293	−11.2	−9.5	9.9	8.5	7.3	10.1	−4.6	8.8	−5.3	4.7	320	3.1	230	33.5	−12.8	3.8	2.6
Kangnung	471050	37.75 N	128.90 E	27	101.00	8293	−8.7	−6.9	8.1	7.0	6.1	8.7	−1.5	7.6	−1.5	5.2	250	2.8	90	34.8	−10.9	1.7	2.3
Kwangju	471560	35.13 N	126.92 E	72	100.46	8293	−7.1	−5.8	7.7	6.7	5.8	7.5	0.1	6.8	0.4	1.9	20	3.3	250	34.1	−9.2	1.5	1.8
Osan	471220	37.08 N	127.03 E	12	101.18	8293	−13.9	−11.8	7.7	6.4	5.4	7.3	−2.0	6.2	−1.9	1.3	10	2.6	10	34.8	−16.8	1.2	3.0
Seoul	471100	37.55 N	126.80 E	19	101.10	8293	−14.1	−12.1	8.6	7.5	6.5	8.3	−4.5	7.2	−3.7	1.2	10	4.2	160	33.5	−16.8	0.9	3.4
Taegu	471430	35.88 N	128.62 E	61	100.59	8293	−8.2	−6.7	9.1	7.9	7.0	9.8	−0.5	8.6	0.2	3.6	290	3.9	270	35.6	−11.0	1.4	1.7
Taejon	471330	36.30 N	127.40 E	78	100.39	8293	−11.0	−9.3	6.8	5.8	5.0	5.5	2.6	4.7	1.1	0.3	110	2.8	270	34.9	−13.5	1.9	1.5
Ulsan	471520	35.55 N	129.32 E	33	100.93	8293	−6.8	−5.4	7.1	6.2	5.4	8.0	−0.3	7.0	−0.5	3.0	320	3.6	140	35.0	−9.3	1.7	1.9
KUWAIT																							
Kuwait	405820	29.22 N	47.98 E	55	100.67	8293	3.2	5.0	11.5	10.4	9.5	10.5	16.0	9.3	15.3	1.7	300	6.1	340	49.4	0.7	1.3	1.3
KYRGYZSTAN																							
Bishkek (Frunze)	383530	42.85 N	74.53 E	635	93.93	8293	−22.4	−18.8	9.2	7.7	6.5	8.3	0.0	6.8	0.5	1.2	150	3.4	220	38.4	−24.0	1.2	4.2
Tianshan (Mtn Stn)	369820	41.92 N	78.23 E	3614	64.80	8293	−32.6	−30.8	9.7	8.5	7.4	9.0	−15.8	7.7	−17.4	0.3	360	4.7	210	19.8	−35.6	4.3	2.2
LATVIA																							
Liepaja	264060	56.55 N	21.02 E	8	101.23	8293	−17.1	−12.9	12.4	10.6	9.5	12.0	3.8	10.4	3.3	3.3	30	3.8	120	28.1	−16.0	1.6	6.1
Riga	264220	56.97 N	24.07 E	3	101.29	8293	−19.6	−15.5	10.8	9.2	8.2	10.3	2.6	9.2	2.1	2.0	40	4.1	150	29.5	−19.2	2.0	7.3
LIBYA																							
Banghazi	620530	32.08 N	20.27 E	132	99.75	8293	6.7	7.5	13.5	12.2	10.3	13.1	12.8	10.4	13.7	2.3	90	6.6	350	41.1	3.9	1.0	1.6
Tripoli	620100	32.67 N	13.15 E	81	100.36	8293	4.1	5.1	10.3	9.4	8.4	9.6	15.0	8.4	14.6	1.7	240	5.6	60	45.5	1.9	1.7	1.1
LIECHTENSTEIN																							
Vaduz	69900	47.13 N	9.53 E	463	95.89	8293	−11.1	−8.6	10.0	7.6	6.0	9.7	9.9	8.1	9.0	1.2	180	4.5	320	31.7	−13.1	1.1	3.7
LITHUANIA																							
Kaunas	266290	54.88 N	23.88 E	75	100.43	8293	−19.9	−15.9	10.2	9.1	8.1	10.2	−0.3	9.3	0.2	2.5	70	3.7	180	29.9	−18.7	2.0	4.7
Klaipeda	265090	55.70 N	21.15 E	10	101.20	8293	−17.4	−13.3	13.7	11.7	10.0	12.8	4.2	10.9	3.9	3.4	70	3.7	140	28.3	−15.6	1.7	5.7
Vilnius	267300	54.63 N	25.28 E	156	99.46	8293	−20.4	−16.7	11.3	10.1	9.0	11.2	−1.4	10.0	−1.5	2.2	70	4.7	140	30.2	−20.6	1.6	4.3
MACEDONIA																							
Skopje	135860	41.97 N	21.65 E	239	98.49	8293	−12.4	−9.3	9.0	7.7	6.2	8.3	2.2	6.7	1.1	0.4	50	2.0	270	38.0	−15.8	2.5	5.2
MADEIRA ISLANDS																							
Funchal	85210	32.68 N	16.77 W	55	100.67	8293	11.9	12.8	13.5	11.9	10.4	15.0	16.3	12.8	16.5	3.6	310	4.9	30	30.7	10.0	2.9	1.0
MALAYSIA																							
George Town	486010	5.30 N	100.27 E	4	101.28	8293	22.8	22.9	6.5	5.6	5.1	6.0	27.5	5.2	28.4	1.1	350	3.7	270	35.7	21.2	2.2	0.7
Kota Baharu	486150	6.17 N	102.28 E	5	101.26	8293	21.6	22.2	7.7	6.8	6.1	8.1	27.4	7.4	27.2	0.5	190	4.0	90	35.1	20.1	1.6	0.8
Kuala Lumpur	486470	3.12 N	101.55 E	22	101.06	8293	21.6	22.0	7.0	6.1	5.3	5.9	29.5	5.1	29.4	0.5	340	3.4	270	36.6	19.9	1.7	1.9
Kuantan	486570	3.78 N	103.22 E	16	101.13	8293	21.1	21.5	7.1	6.2	5.5	7.3	28.2	6.7	27.9	2.1	350	3.5	230	37.4	14.7	2.9	13.0
Malacca	486650	2.27 N	102.25 E	9	101.22	8293	22.0	22.4	7.0	6.0	5.2	7.6	29.0	6.8	28.8	1.3	10	3.5	20	36.2	18.8	1.9	3.1
Sitiawan	486200	4.22 N	100.70 E	8	101.23	8293	21.8	22.3	6.0	5.2	4.5	5.1	28.9	4.4	29.3	0.6	60	3.3	180	37.3	19.0	3.3	2.7
Kuching	964130	1.48 N	110.33 E	27	101.00	8293	21.8	22.0	5.4	4.7	4.1	5.8	28.0	5.1	27.9	0.9	260	2.2	360	37.3	19.6	2.3	4.1
Miri	964490	4.33 N	113.98 E	18	101.11	8293	22.4	22.8	8.0	6.7	5.7	7.9	28.0	7.0	28.4	1.1	120	3.9	270	37.0	18.9	4.6	5.7
MALI																							
Bamako	612910	12.53 N	7.95 W	381	96.83	8293	15.1	16.8	8.9	7.6	6.7	8.2	25.2	7.3	25.0	3.0	40	4.0	80	43.1	9.8	3.4	3.7
MALTA																							
Luqa	165970	35.85 N	14.48 E	91	100.24	8293	6.8	7.8	11.5	10.2	9.1	12.9	13.2	11.4	13.2	2.6	270	4.1	310	37.3	3.3	2.3	1.7
MARSHALL ISLANDS																							
Kwajalein Atoll	913660	8.73 N	167.73 E	8	101.23	8293	24.4	24.8	11.1	10.3	9.6	12.4	27.3	11.4	27.5	5.5	70	4.9	70	34.9	15.3	3.9	13.1
MAURITANIA																							
Nouadhibou	614150	20.93 N	17.03 W	3	101.29	8293	12.9	13.9	14.4	13.4	12.5	13.4	17.2	12.3	17.4	6.3	360	6.3	20	38.3	8.9	1.6	3.5
Nouakchott	614420	18.10 N	15.95 W	3	101.29	8293	12.8	13.9	10.4	9.5	8.5	11.8	23.7	10.5	23.9	3.8	60	6.3	80	44.8	6.7	0.7	3.7
MEXICO																							
Acapulco	768056	16.77 N	99.75 W	5	101.26	8293	20.0	20.9	10.2	8.3	7.6	7.7	28.9	6.3	29.1	1.0	320	7.4	200	36.2	15.8	1.5	4.8
Merida	766440	20.98 N	89.65 W	10	101.20	8293	13.9	15.8	15.1	10.1	8.5	10.0	25.0	8.4	25.0	2.0	90	6.6	140	39.7	8.1	1.2	1.2
Mexico City	766790	19.43 N	99.08 W	2234	77.21	8293	4.0	5.4	22.6	9.8	8.0	22.8	10.9	9.8	19.1	2.1	90	4.8	360	31.3	0.0	1.2	2.3
Puerto Vallarta (766010)	766014	20.68 N	105.25 W	6	101.25	8293	14.8	15.6	7.9	6.2	5.4	5.5	25.9	5.3	25.8	0.2	10	7.5	330	34.5	12.4	0.9	0.8
Tampico (765491)	765494	22.28 N	97.87 W	24	101.04	8293	9.9	11.8	14.5	10.5	9.4	15.1	15.2	12.6	16.6	3.8	270	4.9	90	36.2	6.2	2.4	3.6
Veracruz	766910	19.20 N	96.13 W	14	101.16	8293	14.0	15.2	20.6	15.2	12.9	20.8	20.9	15.5	20.0	2.0	330	9.6	90	38.4	9.8	2.2	2.5
MICRONESIA																							
Truk Intl/Moen Isl	913340	7.47 N	151.85 E	2	101.30	8293	24.0	24.4	9.2	8.2	7.4	9.4	27.1	8.5	27.6	3.9	100	3.9	40	39.0	13.3	4.4	14.3
MIDWAY ISLAND																							
Midway Island Naf	910660	28.22 N	177.37 W	4	101.28	8293	14.8	15.4	10.9	9.9	9.1	13.1	19.2	11.7	19.5	4.6	360	4.2	110	31.7	7.5	1.0	11.2
MOLDOVA																							
Chisinau (Kishinev)	338150	47.02 N	28.87 E	180	99.18	8293	−14.2	−12.0	6.8	5.9	5.2	7.4	−0.3	6.3	−1.9	2.1	300	2.8	200	32.9	−15.4	2.1	3.2
MONGOLIA																							
Ulaanbataar	442920	47.93 N	106.98 E	1316	86.48	8293	−30.3	−28.6	10.4	9.4	7.6	8.3	−17.8	6.6	−17.4	0.8	320	3.7	270	31.4	−32.6	2.9	2.6
Ulaangom	442120	49.97 N	92.08 E	936	90.57	8293	−40.2	−38.4	7.9	6.0	4.9	3.9	−34.0	3.2	−33.8	0.6	180	2.1	50	31.8	−41.6	2.8	2.2
MOROCCO																							
Al Hoceima	601070	35.18 N	3.85 W	14	101.16	8293	6.9	7.8	10.9	9.5	8.1	10.7	14.5	8.4	14.5	1.3	180	5.2	360	36.4	3.9	5.0	2.3

WMO# = World Meteorological Organization number
Lat = latitude, °
Long. = longitude, °
Elev. = elevation, m
StdP = standard pressure at station elevation, kPa
DB = dry–bulb temperature, °C
WS = wind speed, m/s

APPENDIX A13

REPRESENTATIVE RATES AT HEAT AND MOISTURE BY HUMAN BEINGS IN DIFFERENT STATES OF ACTIVITY

Table 6.13: Rates at heat and moisture by human beings with different activity

Degree of Activity		Total Heat, W		Sensible Heat, W	Latent Heat, W	% Sensible Heat that is Radiant[b]	
		Adult Male	Adjusted, M/F[a]			Low V	High V
Seated at theater	Theater, matinee	115	95	65	30		
Seated at theater, night	Theater, night	115	105	70	35	60	27
Seated, very light work	Offices, hotels, apartments	130	115	70	45		
Moderately active office work	Offices, hotels, apartments	140	130	75	55		
Standing, light work; walking	Department store; retail store	160	130	75	55	58	38
Walking, standing	Drug store, bank	160	145	75	70		
Sedentary work	Restaurant[c]	145	160	80	80		
Light bench work	Factory	235	220	80	140		
Moderate dancing	Dance hall	265	250	90	160	49	35
Walking 4.8 km/h; light machine work	Factory	295	295	110	185		
Bowling[d]	Bowling alley	440	425	170	255		
Heavy work	Factory	440	425	170	255	54	19
Heavy machine work; lifting	Factory	470	470	185	285		
Athletics	Gymnasium	585	525	210	315		

APPENDIX A14

RECOMMENDED RATES OF HEAT GAIN FROM COOKING APPLIANCES

Table 6.14: Rates of heat gain for commercial cooking appliances

		Energy Rate, W		Recommended Rate of Heat Gain,[a] W			
				Without Hood			With Hood
Appliance	Size	Rated	Standby	Sensible	Latent	Total	Sensible
Microwave oven (heavy duty, commercial)	20 L	2630	—	2630	—	2630	0
Microwave oven (residential type)	30 L	600 to 1400	—	600 to 1400	—	600 to 1400	0
Mixer (large), per litre of capacity	77 L	29	—	29	—	29	0
Mixer (small), per litre of capacity	11 to 72 L	15	—	15	—	15	0
Press cooker (hamburger)	300 patties/h	2200	—	1450	750	2200	700
Refrigerator (large), per cubic metre of interior space	0.71 to 2.1 m^3	780	—	310	—	310	0
Refrigerator (small) per cubic metre of interior space	0.17 to 0.71 m^3	1730	—	690	—	690	0
Rotisserie	300 hamburgers/h	3200	—	2110	1090	3200	1020
Serving cart (hot), per cubic metre of well	50 to 90 L	21200	—	7060	3530	10590	3390
Serving drawer (large)	252 to 336 dinner rolls	1100	—	140	10	150	45
Serving drawer (small)	84 to 168 dinner rolls	800	—	100	10	110	33
Skillet (tilting), per litre of capacity	45 to 125 L	180	—	90	50	140	66
Slicer, per square metre of slicing carriage	0.06 to 0.09 m^2	2150	—	2150	—	2150	680
Soup cooker, per litre of well	7 to 11 L	130	—	45	24	69	21
Steam cooker, per cubic metre of compartment	30 to 60 L	214000	—	17000	10900	27900	8120
Steam kettle (large), per litre of capacity	76 to 300 L	95	—	7	5	12	4
Steam kettle (small), per litre of capacity	23 to 45 L	260	—	21	14	35	10
Syrup warmer, per litre of capacity	11 L	87	—	29	16	45	14

Sources: Alereza and Breen (1984) & Fisher (1998)

APPENDIX A15

RECOMMENDED HEAT GAIN FROM TYPICAL COMPUTER EQUIPMENT

Table 6.15: Heat gain outcome from computer equipment

	Continuous, W	Energy Saver Mode, W
Computers		
Average value	55	20
Conservative value	65	25
Highly conservative value	75	30
Monitors		
Small monitor (330 to 380mm)	55	0
Medium monitor (400 to 460mm)	70	0
Large monitor (480 to 510mm)	80	0

Source: ASHRAE Fundamental (2001)

APPENDIX A16

RECOMMENDED HEAT GAIN FROM LASER PRINTERS AND COPIERS

Table 6.16: Heat gain outcome from printers and copiers

	Continuous, W	1 page per minute, W	Idle, W
Laser Pinters			
Small desktop	130	75	10
Desktop	215	100	35
Small office	320	160	70
Large office	550	275	125
Copier			
Desktop copier	400	85	20
Office copier	1100	400	300

Source: ASHRAE Fundamental (2001)

APPENDIX A17

VENTILATION

Table 6.17: Ventilation from the building

Type of space	Outdoor air (per person)	Outdoor air (per ft^2 [m^2])
Auditorium	15 cfm [0.008 m^3/s]	
Classroom	15 cfm [0.008 m^3/s]	
Locker rooms		0.5 cfm [0.0025 m^3/s]
Office space	20 cfm [0.010 m^3/s]	
Public restrooms	50 cfm [0.025 m^3/s]	
Smoking lounge	60 cfm [0.003 m^3/s]	

Source: ASHRAE Fundamental (2001)

APPENDIX A18

TYPICAL NONINCANDESCENT LIGHT FIXTURES

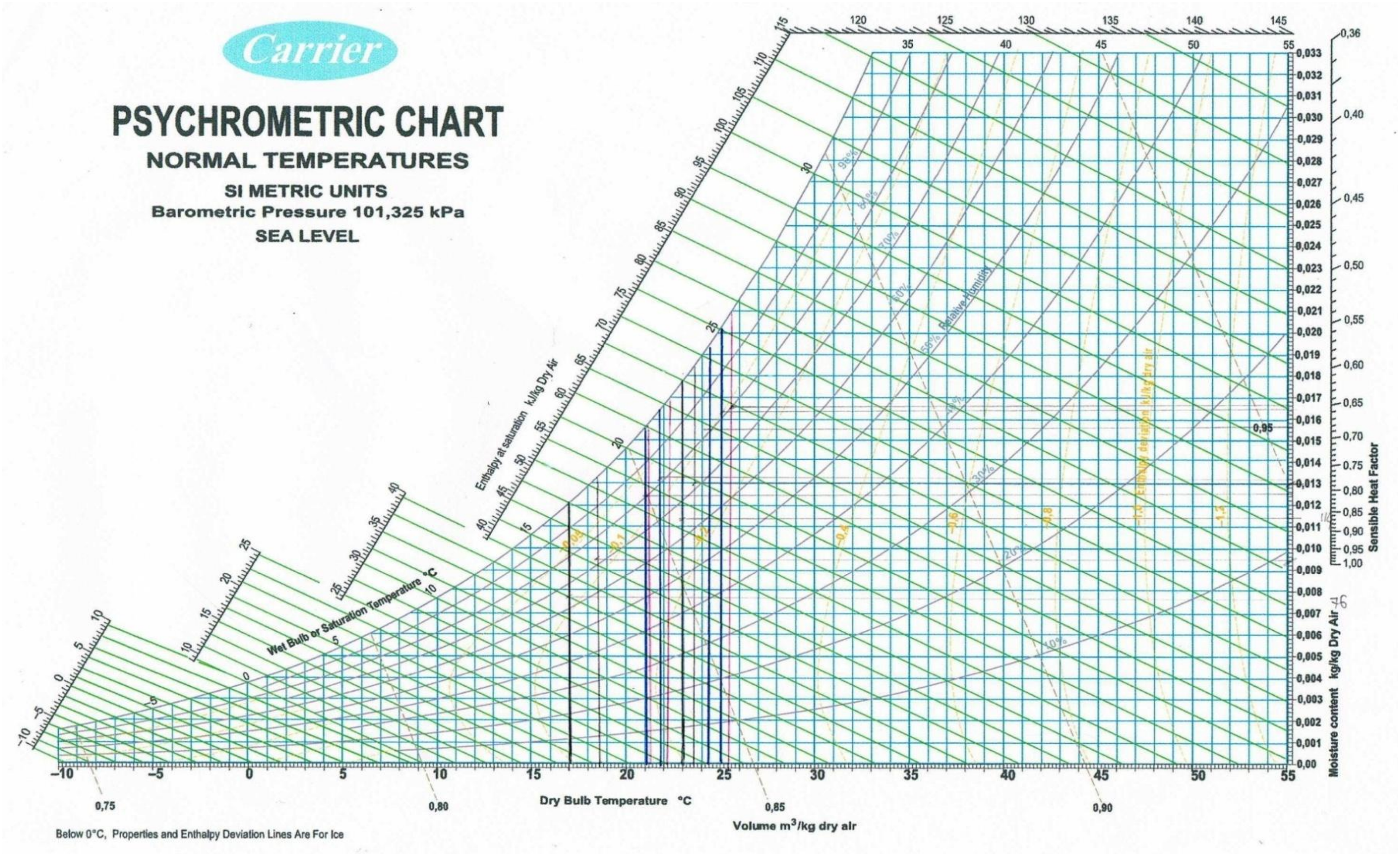
Table 6.18: Type of nonincandescent lights

Description	Ballast	Watts/Lamp	Lamps/Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor	Description	Ballast	Watts/Lamp	Lamps/Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor
Fluorescent Fixtures													
(1) 450 mm, T8 lamp	Mag-Std	15	1	15	19	1.27	(4) 1200 mm, T8 lamp	Electronic	32	4	128	120	0.94
(1) 450 mm, T12 lamp	Mag-Std	15	1	15	19	1.27	(1) 1500 mm, T12 lamp	Mag-Std	50	1	50	63	1.26
(2) 450 mm, T8 lamp	Mag-Std	15	2	30	36	1.20	(2) 1500 mm, T12 lamp	Mag-Std	50	2	100	128	1.28
(2) 450 mm, T12 lamp	Mag-Std	15	2	30	36	1.20	(1) 1500 mm, T12 HO lamp	Mag-Std	75	1	75	92	1.23
(1) 600 mm, T8 lamp	Mag-Std	17	1	17	24	1.41	(2) 1500 mm, T12 HO lamp	Mag-Std	75	2	150	168	1.12
(1) 600 mm, T12 lamp	Mag-Std	20	1	20	28	1.40	(1) 1500 mm, T12 ES VHO lamp	Mag-Std	135	1	135	165	1.22
(2) 600 mm, T12 lamp	Mag-Std	20	2	40	56	1.40	(2) 1500 mm, T12 ES VHO lamp	Mag-Std	135	2	270	310	1.15
(1) 600 mm, T12 HO lamp	Mag-Std	35	1	35	62	1.77	(1) 1500 mm, T12 HO lamp	Mag-ES	75	1	75	88	1.17
(2) 600 mm, T12 HO lamp	Mag-Std	35	2	70	90	1.29	(2) 1500 mm, T12 HO lamp	Mag-ES	75	2	150	176	1.17
(1) 600 mm, T8 lamp	Electronic	17	1	17	16	0.94	(1) 1500 mm, T12 lamp	Electronic	50	1	50	44	0.88
(2) 600 mm, T8 lamp	Electronic	17	2	34	31	0.91	(2) 1500 mm, T12 lamp	Electronic	50	2	100	88	0.88
(1) 900 mm, T12 lamp	Mag-Std	30	1	30	46	1.53	(1) 1500 mm, T12 HO lamp	Electronic	75	1	75	69	0.92
(2) 900 mm, T12 lamp	Mag-Std	30	2	60	81	1.35	(2) 1500 mm, T12 HO lamp	Electronic	75	2	150	138	0.92
(1) 900 mm, T12 ES lamp	Mag-Std	25	1	25	42	1.68	(1) 1500 mm, T8 lamp	Electronic	40	1	40	36	0.90
(2) 900 mm, T12 ES lamp	Mag-Std	25	2	50	73	1.46	(2) 1500 mm, T8 lamp	Electronic	40	2	80	72	0.90
(1) 900 mm, T12 HO lamp	Mag-Std	50	1	50	70	1.40	(3) 1500 mm, T8 lamp	Electronic	40	3	120	106	0.88
(2) 900 mm, T12 HO lamp	Mag-Std	50	2	100	114	1.14	(4) 1500 mm, T8 lamp	Electronic	40	4	160	134	0.84
(2) 900 mm, T12 lamp	Mag-ES	30	2	60	74	1.23	(1) 1800 mm, T12 lamp	Mag-Std	55	1	55	76	1.38
(2) 900 mm, T12 ES lamp	Mag-ES	25	2	50	66	1.32	(2) 1800 mm, T12 lamp	Mag-Std	55	2	110	122	1.11
(1) 900 mm, T12 lamp	Electronic	30	1	30	31	1.03	(3) 1800 mm, T12 lamp	Mag-Std	55	3	165	202	1.22
(1) 900 mm, T12 ES lamp	Electronic	25	1	25	26	1.04	(4) 1800 mm, T12 lamp	Mag-Std	55	4	220	244	1.11
(1) 900 mm, T8 lamp	Electronic	25	1	25	24	0.96	(1) 1800 mm, T12 HO lamp	Mag-Std	85	1	85	120	1.41
(2) 900 mm, T12 lamp	Electronic	30	2	60	58	0.97	(2) 1800 mm, T12 HO lamp	Mag-Std	85	2	170	220	1.29
(2) 900 mm, T12 ES lamp	Electronic	25	2	50	50	1.00	(1) 1800 mm, T12 VHO lamp	Mag-Std	160	1	160	180	1.13
(2) 900 mm, T8 lamp	Electronic	25	2	50	46	0.92	(2) 1800 mm, T12 VHO lamp	Mag-Std	160	2	320	330	1.03
(2) 900 mm, T8 HO lamp	Electronic	25	2	50	50	1.00	(2) 1800 mm, T12 lamp	Mag-ES	55	2	110	122	1.11
(2) 900 mm, T8 VHO lamp	Electronic	25	2	50	70	1.40	(4) 1800 mm, T12 lamp	Mag-ES	55	4	220	244	1.11
(1) 1200 mm, T12 lamp	Mag-Std	40	1	40	55	1.38	(2) 1800 mm, T12 HO lamp	Mag-ES	85	2	170	194	1.14
(2) 1200 mm, T12 lamp	Mag-Std	40	2	80	92	1.15	(4) 1800 mm, T12 HO lamp	Mag-ES	85	4	340	388	1.14
(3) 1200 mm, T12 lamp	Mag-Std	40	3	120	140	1.17	(1) 1800 mm, T12 lamp	Electronic	55	1	55	68	1.24
(4) 1200 mm, T12 lamp	Mag-Std	40	4	160	184	1.15	(2) 1800 mm, T12 lamp	Electronic	55	2	110	108	0.98
(1) 1200 mm, T12 ES lamp	Mag-Std	34	1	34	48	1.41	(3) 1800 mm, T12 lamp	Electronic	55	3	165	176	1.07
(2) 1200 mm, T12 ES lamp	Mag-Std	34	2	68	82	1.21	(4) 1800 mm, T12 lamp	Electronic	55	4	220	216	0.98
(3) 1200 mm, T12 ES lamp	Mag-Std	34	3	102	100	0.98	(1) 2400 mm, T12 ES lamp	Mag-Std	60	1	60	75	1.25
(4) 1200 mm, T12 ES lamp	Mag-Std	34	4	136	164	1.21	(2) 2400 mm, T12 ES lamp	Mag-Std	60	2	120	128	1.07
(1) 1200 mm, T12 ES lamp	Mag-ES	34	1	34	43	1.26	(3) 2400 mm, T12 ES lamp	Mag-Std	60	3	180	203	1.13
(2) 1200 mm, T12 ES lamp	Mag-ES	34	2	68	72	1.06	(4) 2400 mm, T12 ES lamp	Mag-Std	60	4	240	256	1.07
(3) 1200 mm, T12 ES lamp	Mag-ES	34	3	102	115	1.13	(1) 2400 mm, T12 ES HO lamp	Mag-Std	95	1	95	112	1.18
(4) 1200 mm, T12 ES lamp	Mag-ES	34	4	136	144	1.06	(2) 2400 mm, T12 ES HO lamp	Mag-Std	95	2	190	227	1.19
(1) 1200 mm, T8 lamp	Mag-ES	32	1	32	35	1.09	(3) 2400 mm, T12 ES HO lamp	Mag-Std	95	3	285	380	1.33
(2) 1200 mm, T8 lamp	Mag-ES	32	2	64	71	1.11	(4) 2400 mm, T12 ES HO lamp	Mag-Std	95	4	380	454	1.19
(3) 1200 mm, T8 lamp	Mag-ES	32	3	96	110	1.15	(1) 2400 mm, T12 ES VHO lamp	Mag-Std	185	1	185	205	1.11
(4) 1200 mm, T8 lamp	Mag-ES	32	4	128	142	1.11	(2) 2400 mm, T12 ES VHO lamp	Mag-Std	185	2	370	380	1.03
(1) 1200 mm, T12 ES lamp	Electronic	34	1	34	32	0.94	(3) 2400 mm, T12 ES VHO lamp	Mag-Std	185	3	555	585	1.05
(2) 1200 mm, T12 ES lamp	Electronic	34	2	68	60	0.88	(4) 2400 mm, T12 ES VHO lamp	Mag-Std	185	4	740	760	1.03
(3) 1200 mm, T12 ES lamp	Electronic	34	3	102	92	0.90	(2) 2400 mm, T12 ES lamp	Mag-ES	60	2	120	123	1.03
(4) 1200 mm, T12 ES lamp	Electronic	34	4	136	120	0.88	(3) 2400 mm, T12 ES lamp	Mag-ES	60	3	180	210	1.17
(1) 1200 mm, T8 lamp	Electronic	32	1	32	32	1.00	(4) 2400 mm, T12 ES lamp	Mag-ES	60	4	240	246	1.03
(2) 1200 mm, T8 lamp	Electronic	32	2	64	60	0.94	(2) 2400 mm, T12 ES HO lamp	Mag-ES	95	2	190	207	1.09
(3) 1200 mm, T8 lamp	Electronic	32	3	96	93	0.97	(4) 2400 mm, T12 ES HO lamp	Mag-ES	95	4	380	414	1.09

Source: ASHRAE Fundamental (2001)

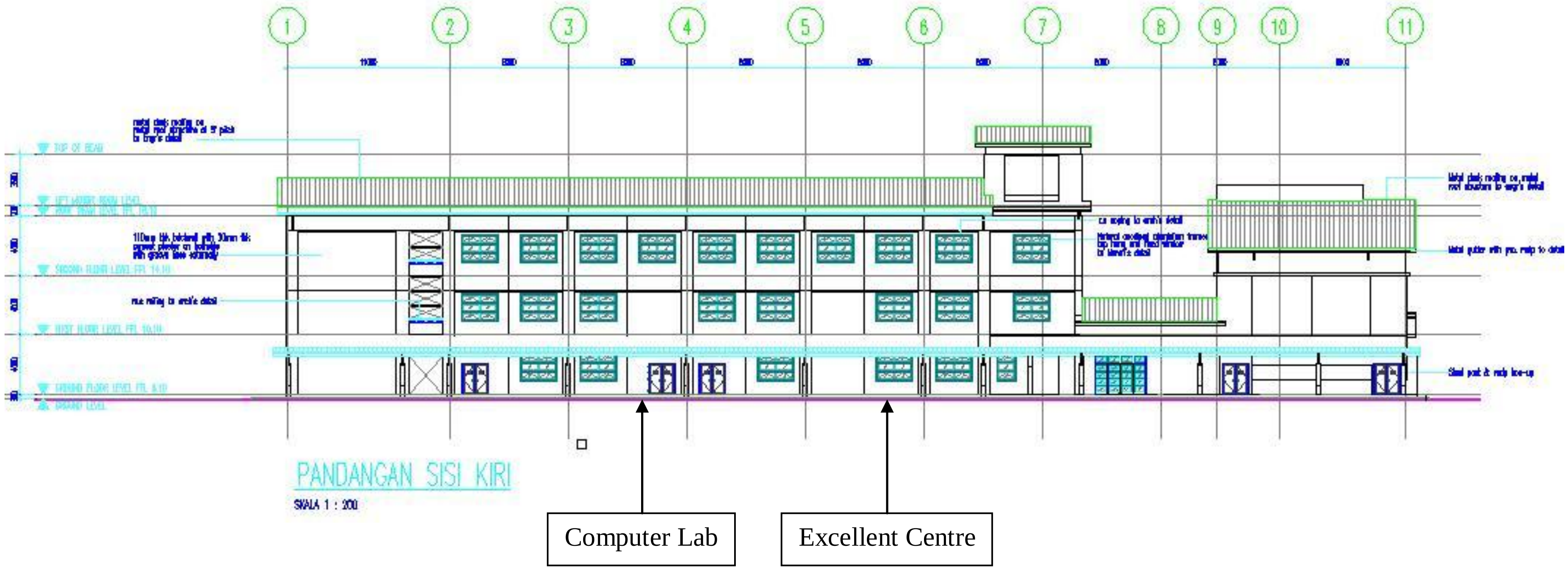
APPENDIX A19

PSYCHROMETRIC CHART



APPENDIX B

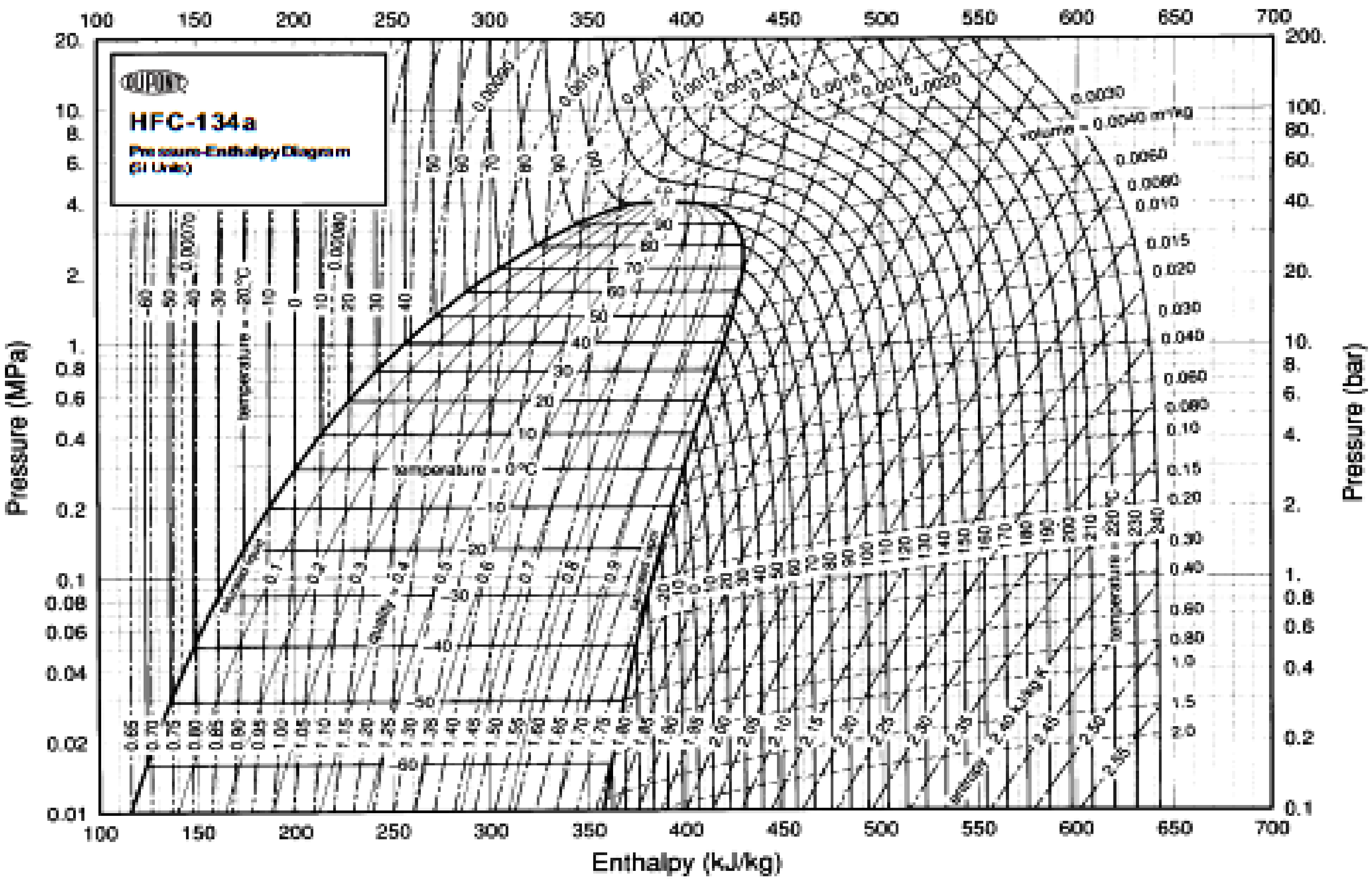
FKM ADMINISTRATION BUILDING PLAN



Source: Architect Plan of Universiti Malaysia Pahang, Pekan Campus

APPENDIX C

MOLLIER CHART OR *P-H* DIAGRAM



APPENDIX D

REQUIRED COOLING LOAD FOR COMPUTER LAB AT 9.00 A.M

AHU-BP-G-1

	makmal computer	bilik stor	bilik juruteknik	total
Computer	41		1	42
people	41		1	42
Lamp (x2)	30	1	1	64
room size	16m X 11.4m	3.8m X 4.2m	2.6m X 4.2m	
(m²)	182.4	16	10.9	209.3

wall	R (m²K/W)	U (W/m²K)
Rin	0.121	
Rout	0.059	
Rbrick	0.076	
R 25mm insulation	0.587	
Rplaster	0.026	
R low density concreate	0.266	
R inside resistance	0.121	
	1.256	0.796

Location:	makmal computer + bilik stor + bilik juruteknik		
Plan size:	16m X 11.4m + 3.8m X 4.2m + 2.6m X 4.2m =		209.3m²
Daily range, DR:		13	
Day:	Time:		9:00
Latitude:	4^0 N		

max outdoor temp, to	37.4
ta=to-DR/2	26.5

Design Conditions

	DB (ºC)	WB (ºC)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².ºC)	A, m²	CLTD (ºC)	CLTDc	Cooling load, W
Wall	NW	0.796	48	3	3.4	129.936
	SE	0.796	48	4	4.4	168.153
Window glass		6.07	7.2	1	1.4	61.186
Door	NW	2.730	5	1	1.4	19.110
	SE	2.730	10	1	1.4	38.220

wall (m)	16	3
		48
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
Window glass	NW	0.85	2.4	85	173.4
	SE	0.85	4.8	321	1309.68

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	42	75	1	3150
LH	42	55		2310
APPLIANCE	n		CLF	
Computer	42	155	1	6510
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	6279	1	7848.75

Total , W **22430.045**

REQUIRED COOLING LOAD FOR COMPUTER LAB AT 11.00 A.M

AHU-BP-G-1

	makmal computer	bilik stor	bilik juruteknik	total
Computer	41		1	42
people	41		1	42
Lamp (x2)	30	1	1	64
room size	16m X 11.4m	3.8m X 4.2m	2.6m X 4.2m	
(m²)	182.4	16	10.9	209.3

wall	R (m²K/W)
Rin	0.121
Rout	0.059
Rbrick	0.076
R 25mm insulation	0.587
Rplaster	0.026
R low density concreate	0.266
R inside resistance	0.121
	1.256

U (W/m²K)
0.796

Location:	makmal computer + bilik stor + bilik juruteknik		
Plan size:	16m X 11.4m + 3.8m X 4.2m + 2.6m X 4.2m =		209.3m²
Daily range, DR:		13	
Day:		Time:	11:00
Latitude:	4^0 N		

max outdoor temp, to 37.4

ta=to-DR/2 26.5

Design Conditions		DB (°C)	WB (°C)	RH (%)
	Outdoor, to	33		
	Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
	NW	0.796	48	3	3.4	129.936
Wall	SE	0.796	48	8	8.4	321.019
Window glass		6.07	7.2	4	4.4	192.298
	NW	2.730	5	4	4.4	60.060
Door	SE	2.730	10	4	4.4	120.120

wall (m)	16	3
		48
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
	NW	0.85	2.4	101	206.04
Window glass	SE	0.85	4.8	299	1219.92

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	42	75	1	3150
LH	42	55		2310
APPLIANCE	n		CLF	
Computer	42	155	1	6510
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	6279	1	7848.75

Total , W **22779.753**

REQUIRED COOLING LOAD FOR COMPUTER LAB AT 1.00 P.M

AHU-BP-G-1

	makmal computer	bilik stor	bilik juruteknik	total
Computer	41		1	42
people	41		1	42
Lamp (x2)	30	1	1	64
room size	16m X 11.4m	3.8m X 4.2m	2.6m X 4.2m	
(m²)	182.4	16	10.9	209.3

wall		R (m²K/W)	U (W/m²K)
Rin		0.121	
Rout		0.059	
Rbrick		0.076	
R 25mm insulation		0.587	
Rplaster		0.026	
R low density concreate		0.266	
R inside resistance		0.121	
		1.256	0.796

Location:	makmal computer + bilik stor + bilik juruteknik		
Plan size:	16m X 11.4m + 3.8m X 4.2m + 2.6m X 4.2m =		209.3m²
Daily range, DR:		13	
Day:	Time:		13:00
Latitude:	4^0 N		

max outdoor temp, to	37.4
ta=to-DR/2	26.5

Design Conditions		DB (°C)	WB (°C)	RH (%)
	Outdoor, to	33		
	Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
	NW	0.796	48	4	4.4	168.153
Wall	SE	0.796	48	14	14.4	550.318
Window glass		6.07	7.2	7	7.4	323.410
	NW	2.730	5	7	7.4	101.010
Door glass	SE	2.73	10	7	7.4	202.020

wall (m)	16	3
		48
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
	NW	0.85	2.4	107	218.28
Window glass	SE	0.85	4.8	189	771.12

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	2	75	1	150
LH	2	55		110
APPLIANCE	n		CLF	
Computer	42	155	1	6510
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	6279	1	7848.75

Total , W **17664.671**

REQUIRED COOLING LOAD FOR COMPUTER LAB AT 3.00 P.M

AHU-BP-G-1

	makmal computer	bilik stor	bilik juruteknik	total
Computer	41		1	42
people	41		1	42
Lamp (x2)	30	1	1	64
room size	16m X 11.4m	3.8m X 4.2m	2.6m X 4.2m	
(m²)	182.4	16	10.9	209.3

wall	R (m²K/W)	U (W/m²K)
Rin	0.121	
Rout	0.059	
Rbrick	0.076	
R 25mm insulation	0.587	
Rplaster	0.026	
R low density concreate	0.266	
R inside resistance	0.121	
	1.256	0.796

Location:	makmal computer + bilik stor + bilik juruteknik		
Plan size:	16m X 11.4m + 3.8m X 4.2m + 2.6m X 4.2m =		209.3m²
Daily range, DR:		13	
Day:	Time:		15:00
Latitude:	4^0 N		

max outdoor temp, to	37.4
ta=to-DR/2	26.5

Design Conditions	DB (°C)	WB (°C)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
	NW	0.796	48	7	7.4	282.803
Wall	SE	0.796	48	18	18.4	703.185
Window glass		6.07	7.2	8	8.4	367.114
	NW	2.730	5	8	8.4	114.660
Door	SE	2.730	10	8	8.4	229.320

wall (m)	16	3
		48
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
	NW	0.85	2.4	202	412.08
Window glass	SE	0.85	4.8	161	656.88

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	42	75	1	3150
LH	42	55		2310
APPLIANCE	n		CLF	
Computer	42	155	1	6510
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	6279	1	7848.75

Total , W **23296.401**

REQUIRED COOLING LOAD FOR COMPUTER LAB AT 5.00 P.M

AHU-BP-G-1

	makmal computer	bilik stor	bilik juruteknik	total
Computer	41		1	42
people	41		1	42
Lamp (x2)	30	1	1	64
room size	16m X 11.4m	3.8m X 4.2m	2.6m X 4.2m	
(m²)	182.4	16	10.9	209.3

wall	R (m²K/W)	U (W/m²K)
Rin	0.121	
Rout	0.059	
Rbrick	0.076	
R 25mm insulation	0.587	
Rplaster	0.026	
R low density concreate	0.266	
R inside resistance	0.121	
	1.256	0.796

Location:	makmal computer + bilik stor + bilik juruteknik		
Plan size:	16m X 11.4m + 3.8m X 4.2m + 2.6m X 4.2m =		209.3m²
Daily range, DR:		13	
Day:	Time:		17:00
Latitude:	4^0 N		

max outdoor temp, to	37.4
ta=to-DR/2	26.5

Design Conditions	DB (°C)	WB (°C)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
Wall	NW	0.796	48	10	10.4	397.452
	SE	0.796	48	19	19.4	741.401
Window glass		6.07	7.2	7	7.4	323.410
Door	NW	2.730	5	7	7.4	101.010
	SE	2.730	10	7	7.4	202.020

wall (m)	16	3
		48
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
Window glass	NW	0.85	2.4	318	648.72
	SE	0.85	4.8	132	538.56

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	10	75	1	750
LH	10	55		550
APPLIANCE	n		CLF	
Computer	42	155	1	6510
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	6279	1	7848.75

Total , W **19322.933**

REQUIRED COOLING LOAD FOR EXCELLENT CENTRE AT 9.00 A.M

AHU-BP-G-2

	Bilik aktiviti pelajar	Klinik	Pusat kecemerlangan	total
Computer	1	2	13	16
Printer		1	2	3
Refrigerator		1		1
Photostat			1	1
People	102	10	1	113
Lamp (x2)	30	14	20	128
Room size	9.7m X 16.2m	10.1m X 8.4m	10.1m X 11.2m	
(m²)	157.14	84.84	113.13	355.11

wall	R (m²K/W)
Rin	0.121
Rout	0.059
Rbrick	0.076
R 25mm insulation	0.587
Rplaster	0.026
R low density concreate	0.266
R inside resistance	0.121
	1.256

U (W/m²K)
0.796

Location:	bilik aktiviti pelajar + klinik + pusat kecemerlangan			
Plan size:	9.7m X 16.2m + 10.1m X 8.4m + 10.1m X 11.2m =		355.11m²	
Daily range, DR:		13		
Day:		Time:	9:00	
Latitude:	4^0 N			

max outdoor temp, to 37.4
ta=to-DR/2 26.5

Design Conditions	DB (°C)	WB (°C)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
Wall	NW	0.796	63	3	3.4	170.541
	SE	0.796	63	4	4.4	220.701
	NE	0.796	57	4	4.4	199.682
Window glass		6.07	14.4	1	1.4	122.371
Door	NW	2.730	5	1	1.4	19.110
	SE	2.730	15	1	1.4	57.330

wall (m)	21	3
		63
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
Window glass	NW	0.85	4.8	85	346.8
	SE	0.85	9.6	321	2619.36

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	113	75	1	8475
LH	113	55		6215
APPLIANCE	n		CLF	
Computer	16	155	1	2480
Printer	3	215	1	645
Refrigerator	1	1730	1	1730
Photostat	1	1100	1	1100
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	10653.3	1	13316.625

Total , W **38429.130**

REQUIRED COOLING LOAD FOR EXCELLENT CENTRE AT 11.00 A.M

AHU-BP-G-2

	Bilik aktiviti pelajar	Klinik	Pusat kecemerlangan	total
Computer	1	2	13	16
Printer		1	2	3
Refrigerator		1		1
Photostat			1	1
People	102	10	1	113
Lamp (x2)	30	14	20	128
Room size	9.7m X 16.2m	10.1m X 8.4m	10.1m X 11.2m	
(m²)	157.14	84.84	113.13	355.11

wall	R (m²K/W)	U (W/m²K)
Rin	0.121	
Rout	0.059	
Rbrick	0.076	
R 25mm insulation	0.587	
Rplaster	0.026	
R low density concreate	0.266	
R inside resistance	0.121	
	1.256	0.796

Location:	bilik aktiviti pelajar + klinik + pusat kecemerlangan		
Plan size:	9.7m X 16.2m + 10.1m X 8.4m + 10.1m X 11.2m =		355.11m²
Daily range, DR:		13	
Day:	Time:		11:00
Latitude:	4^0 N		

max outdoor temp, to 37.4
ta=to-DR/2 26.5

Design Conditions	DB (°C)	WB (°C)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
Wall	NW	0.796	63	3	3.4	170.541
	SE	0.796	63	8	8.4	421.338
	NE	0.796	57	9	9.4	426.592
Window glass		6.07	14.4	4	4.4	384.595
Door	NW	2.730	5	4	4.4	60.060
	SE	2.730	15	4	4.4	180.180

wall (m)	21	3
		63
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
Window glass	NW	0.85	4.8	101	412.08
	SE	0.85	9.6	299	2439.84

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	113	75	1	8475
LH	113	55		6215
APPLIANCE	n		CLF	
Computer	16	155	1	2480
Printer	3	215	1	645
Refrigerator	1	1730	1	1730
Photostat	1	1100	1	1100
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	10653.3	1	13316.625

Total , W **39168.462**

REQUIRED COOLING LOAD FOR EXCELLENT CENTRE AT 1.00 P.M

AHU-BP-G-2

	Bilik aktiviti pelajar	Klinik	Pusat kecemerlangan	total
Computer	1	2	13	16
Printer		1	2	3
Refrigerator		1		1
Photostat			1	1
People	102	10	1	113
Lamp (x2)	30	14	20	128
Room size	9.7m X 16.2m	10.1m X 8.4m	10.1m X 11.2m	
(m²)	157.14	84.84	113.13	355.11

wall	R (m²K/W)	U (W/m²K)
Rin	0.121	
Rout	0.059	
Rbrick	0.076	
R 25mm insulation	0.587	
Rplaster	0.026	
R low density concreate	0.266	
R inside resistance	0.121	
	1.256	0.796

Location:	bilik aktiviti pelajar + klinik + pusat kecemerlangan		
Plan size:	9.7m X 16.2m + 10.1m X 8.4m + 10.1m X 11.2m		355.11m²
Daily range, DR:		13	
Day:		Time:	13:00
Latitude:	4^0 N		

max outdoor temp, to	37.4
ta=to-DR/2	26.5

Design Conditions	DB (°C)	WB (°C)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
Wall	NW	0.796	63	4	4.4	220.701
	SE	0.796	63	14	14.4	722.293
	NE	0.796	57	12	12.4	562.739
Window glass		6.07	14.4	7	7.4	646.819
Door	NW	2.730	5	7	7.4	101.010
	SE	2.730	15	7	7.4	303.030

wall (m)	21	3
		63
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
Window glass	NW	0.85	4.8	107	436.56
	SE	0.85	9.6	189	1542.24

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	4	75	1	300
LH	4	55		220
APPLIANCE	n		CLF	
Computer	16	155	1	2480
Printer	3	215	1	645
Refrigerator	1	1730	1	1730
Photostat	1	1100	1	1100
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	10653.3	1	13316.625

Total , W **25038.627**

REQUIRED COOLING LOAD FOR EXCELLENT CENTRE AT 3.00 P.M

AHU-BP-G-2

	Bilik aktiviti pelajar	Klinik	Pusat kecemerlangan	total
Computer	1	2	13	16
Printer		1	2	3
Refrigerator		1		1
Photostat			1	1
People	102	10	1	113
Lamp (x2)	30	14	20	128
Room size	9.7m X 16.2m	10.1m X 8.4m	10.1m X 11.2m	
(m^2)	157.14	84.84	113.13	355.11

wall	R (m^2K/W)
Rin	0.121
Rout	0.059
Rbrick	0.076
R 25mm insulation	0.587
Rplaster	0.026
R low density concreate	0.266
R inside resistance	0.121
	1.256

U (W/m^2K)
0.796

Location:	bilik aktiviti pelajar + klinik + pusat kecemerlangan		
Plan size:	9.7m X 16.2m + 10.1m X 8.4m + 10.1m X 11.2m =		355.11m²
Daily range, DR:		13	
Day:	Time:		15:00
Latitude:	4^0 N		

max outdoor temp, to 37.4

ta=to-DR/2 26.5

Design Conditions	DB (°C)	WB (°C)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
Wall	NW	0.796	63	7	7.4	371.178
	SE	0.796	63	18	18.4	922.930
	NE	0.796	57	14	14.4	653.503
Window glass		6.07	14.4	8	8.4	734.227
Door	NW	2.730	5	8	8.4	114.660
	SE	2.730	15	8	8.4	343.980

wall (m)	21	3
		63
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
Window glass	NW	0.85	4.8	202	824.16
	SE	0.85	9.6	161	1313.76

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	113	75	1	8475
LH	113	55		6215
APPLIANCE	n		CLF	
Computer	16	155	1	2480
Printer	3	215	1	645
Refrigerator	1	1730	1	1730
Photostat	1	1100	1	1100
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	10653.3	1	13316.625

Total , W **39951.634**

REQUIRED COOLING LOAD FOR EXCELLENT CENTRE AT 5.00 P.M

AHU-BP-G-2

	Bilik aktiviti pelajar	Klinik	Pusat kecemerlangan	total
Computer	1	2	13	16
Printer		1	2	3
Refrigerator		1		1
Photostat			1	1
People	102	10	1	113
Lamp (x2)	30	14	20	128
Room size	9.7m X 16.2m	10.1m X 8.4m	10.1m X 11.2m	
(m²)	157.14	84.84	113.13	355.11

wall	R (m²K/W)	U (W/m²K)
Rin	0.121	
Rout	0.059	
Rbrick	0.076	
R 25mm insulation	0.587	
Rplaster	0.026	
R low density concreate	0.266	
R inside resistance	0.121	
	1.256	0.796

Location:	bilik aktiviti pelajar + klinik + pusat kecemerlangan		
Plan size:	9.7m X 16.2m + 10.1m X 8.4m + 10.1m X 11.2m =		355.11m²
Daily range, DR:		13	
Day:	Time:		17:00
Latitude:	4^0 N		

max outdoor temp, to 37.4
ta=to-DR/2 26.5

Design Conditions	DB (°C)	WB (°C)	RH (%)
Outdoor, to	33		
Indoor, tr	22.2		79.3

EXTERNAL COOLING LOAD

Conduction	Direction	U (w/m².°C)	A, m²	CLTD (°C)	CLTDc	Cooling load, W
Wall	NW	0.796	63	10	10.4	521.656
	SE	0.796	63	19	19.4	973.089
	NE	0.796	57	15	15.4	698.885
Window glass		6.07	14.4	7	7.4	646.819
Door	NW	2.730	5	7	7.4	101.010
	SE	2.730	15	7	7.4	303.030

wall (m)	21	3
		63
door	2.5	2
		5
room volume	209.3	3
		627.9

Solar	Direction	SC	A, m²	SCL, W/m²	Cooling load, W
Window glass	NW	0.85	4.8	318	1297.44
	SE	0.85	9.6	132	1077.12

Light	
Fluorescent B.F	1.25
q, W	30

VENTILATION		Q, (m³/s)	Δt	Cooling load, W
SH	1210	0.01	10.8	130.68
		Q, (m³/s)	Δw	
LH	3010	0.01	19.3	580.93

INTERNAL COOLING LOAD

PEOPLE	n	SHG, W	CLF	Cooling load, W
SH	50	75	1	3750
LH	50	55		2750
APPLIANCE	n		CLF	
Computer	16	155	1	2480
Printer	3	215	1	645
Refrigerator	1	1730	1	1730
Photostat	1	1100	1	1100
LIGHT	BF	q, W	CLF	
Fluorescent 900 mm, T12 lamp	1.25	10653.3	1	13316.625

Total , W **32102.285**

APPENDIX E

DATA COLLECTION

Table 6.19: 1st Data Collection from Chiller Plant in SI Unit – Chiller 1 & 2

Date			**4 August 2010**					
Data			**Data 1**	**Data 2**	**Data 3**	**Data 4**	**Data 5**	**Data 6**
		T ambient air (°C)	29	32.4	26.9	31.3	33.2	31.7
Compressor		Suction temperature (°C)	20.5	21	21.2	20.4	21.3	21.5
		Discharge temperature (°C)	45.5	47.3	46.6	47.1	47.8	45.0
Cooler (chilled water)	Refrigerant	Suction pressure (kpa), P_{rs}	300.5	295.8	302.5	295.0	300.5	299.6
		Suction temperature (°C)	5.5	5.9	5.2	5.4	5.8	6.3
	Liquid	Inlet temperature (°C), $T_{ch\ in}$	17.6	18.9	16.3	15.4	16.2	17.8
		Inlet pressure (kpa), $P_{ch\ in}$	112.38	105.49	105.49	110.32	105.49	106.87
		Outlet temperature (°C), $T_{ch\ out}$	9.5	9.8	9.1	8.9	9.0	9.5
		Outlet pressure (kpa), $P_{ch\ out}$	479.19	486.77	486.77	525.38	490.91	506.76
		Flow rate (kg/s)	37	38	39	42	37	38
Condenser (cooling tower)	Refrigerant	Discharge pressure (kpa), P_{rd}	900.5	904.5	895.5	910.2	900.2	892.4
		Discharge temperature (°C)	35.2	35.4	34.1	34.3	34.6	35.5
	Water	Inlet temperature (°C)	35.4	35.8	32.2	32.5	33.5	32.5
		Inlet pressure (kpa)	248.21	255.11	199.95	206.84	220.63	241.32
		Outlet temperature (°C)	32.0	32.4	28.3	29.1	30.2	31.3
		Outlet pressure (kpa)	124.11	137.90	117.21	103.42	103.42	124.11

Table 6.20: 2nd Data Collection from Chiller Plant in SI Unit – Chiller 1

Date			**12 August 2010**					
Data			**Data 1**	**Data 2**	**Data 3**	**Data 4**	**Data 5**	**Data 6**
		T ambient air (°C)	32.9	33.3	33.5	32.5	32.4	32.0
Compressor		Suction temperature (°C)	23.5	24	24	23.4	23.3	23.7
		Discharge temperature (°C)	47.3	47.5	47.1	47.1	47.3	47.1
Cooler (chilled water)	Refrigerant	Suction pressure (kpa), P_{rs}	350.9	352.6	350.0	348.3	347.5	344.9
		Suction temperature (°C)	12.7	12.7	12.5	12.6	12.4	12.3
	Liquid	Inlet temperature (°C), $T_{ch\ in}$	22	22	21.5	21.8	21.6	22.5
		Inlet pressure (kpa), $P_{ch\ in}$	114.5	113.1	113.8	113.8	113.8	114.5
		Outlet temperature (°C), $T_{ch\ out}$	16	15.7	15.5	15.4	15	14.9
		Outlet pressure (kpa), $P_{ch\ out}$	315.8	315.8	315.8	315.8	315.1	313.7
		Flow rate (kg/s)	29.6	30.8	30.4	30.1	30.1	29.4
Condenser (cooling tower)	Refrigerant	Discharge pressure (kpa), P_{rd}	862.9	862.7	851.4	851.6	851.6	854.1
		Discharge temperature (°C)	37.9	37.9	37.5	37.5	37.8	37.7
	Water	Inlet temperature (°C)	35.7	35.6	35.6	35.2	35.5	35.3
		Inlet pressure (kpa)	206.8	227.5	206.8	213.7	206.8	213.7
		Outlet temperature (°C)	31.4	31.3	31.1	30.8	31.2	31.0
		Outlet pressure (kpa)	103.4	117.2	110.3	103.4	103.4	110.3

Table 6.21: 3rd Data Collection from Chiller Plant in SI unit – chiller 2

Date			**18 August 2010**					
Data			**Data 1**	**Data 2**	**Data 3**	**Data 4**	**Data 5**	**Data 6**
		T ambient air (°C)	29.6	29.9	30.4	31.6	31.4	31.5
Compressor		Suction temperature (°C)	23.5	24	24.5	24.1	23.9	24
		Discharge temperature (°C)	47.3	46.6	46.7	46.9	46.7	46.8
Cooler (chilled water)	Refrigerant	Suction pressure (kpa), P_{rs}	337	337	336.1	337	337.8	339.5
		Suction temperature (°C)	11.4	11.5	11.4	11.5	11.5	11.6
	Liquid	Inlet temperature (°C), $T_{ch\ in}$	21	21.5	21.2	22	21.7	20.5
		Inlet pressure (kpa), $P_{ch\ in}$	112.3	112.3	112.4	111.7	113.1	111.7
		Outlet temperature (°C), $T_{ch\ out}$	16	15.1	15	15.2	15	15.1
		Outlet pressure (kpa), $P_{ch\ out}$	311.6	313	314.4	315.8	313.7	314.4
		Flow rate (kg/s)	30.8	30.3	30.2	31	30.2	30.6
Condenser (cooling tower)	Refrigerant	Discharge pressure (kpa), P_{rd}	843.3	846.9	851.8	849.9	852.7	863.8
		Discharge temperature (°C)	37.2	37.4	37.6	37.4	37.6	38
	Water	Inlet temperature (°C)	35.2	35.4	35.6	35.8	35.8	35.9
		Inlet pressure (kpa)	220.6	206.8	206.8	213.7	199.9	199.9
		Outlet temperature (°C)	30.6	30.9	31.1	31.1	31.3	31.4
		Outlet pressure (kpa)	110.3	103.4	96.5	96.5	110.3	96.5

APPENDIX F

SAMPLE CALCULATION FOR CHILLER PERFORMANCE

Table 6.22: Sample calculation of chiller plant performance – Chiller 1&2

		refrigerant (kJ/kg)				water (°C)				Eva		Cond		Comp		Eva	Cond	Cond	Comp	
m dot water at evaporator (kg/s)	Cp(kJ/kg.K)	h1	h2	h3	h4	T1	T2	T3	T4	(T1-T4) (°C)	(h1-h4) (kJ/kg)	(T2-T3) (°C)	(h2-h3) (kJ/kg)	(h2-h1) (kJ/kg)	**m dot R (kg/s)**	**Q Evap (kW)**	**m dot water at cond**	**Q cond (kW)**	**W comp (kW)**	**COP**
37	4.2	415	435	258	258	17.6	35.4	32	9.5	8.1	157	3.4	177	20	8.02	1258.74	99.38	1419.09	160.35	**7.85**
38	4.2	413	438	253	253	18.9	35.8	32.4	9.8	9.1	160	3.4	185	25	9.08	1452.36	117.60	1679.29	226.93	**6.40**
39	4.2	410	435	255	255	16.3	32.2	28.3	9.1	7.2	155	3.9	180	25	7.61	1179.36	83.61	1369.58	190.22	**6.20**
42	4.2	410	433	260	260	15.4	32.5	29.1	8.9	6.5	150	3.4	173	23	7.64	1146.6	92.61	1322.41	175.81	**6.52**
37	4.2	415	435	258	258	16.2	33.5	30.2	9	7.2	157	3.3	177	20	7.13	1118.88	91.01	1261.41	142.53	**7.85**
38	4.2	412	440	254	254	17.8	32.5	31.3	9.5	8.3	158	1.2	186	28	8.38	1324.68	309.41	1559.43	234.75	**5.64**

Table 6.23: Sample calculation of chiller plant performance– Chiller 1

		refrigerant (kJ/kg)				water (°C)				Eva		Cond		Comp		Eva	Cond	Cond	Comp	
m dot water at evaporator (kg/s)	Cp(kJ/kg.K)	h1	h2	h3	h4	T1	T2	T3	T4	(T1-T4) (°C)	(h1-h4) (kJ/kg)	(T2-T3) (°C)	(h2-h3) (kJ/kg)	(h2-h1) (kJ/kg)	**m dot R (kg/s)**	**Q Evap (kW)**	**m dot water at cond**	**Q cond (kW)**	**W comp (kW)**	**COP**
29.6	4.2	412	436	250	250	22	35.7	31.4	16	6	162	4.3	186	24	4.60	745.92	47.42	856.43	110.51	**6.75**
30.8	4.2	411	435	253	253	22	35.6	31.3	15.7	6.3	158	4.3	182	24	5.16	814.97	51.98	938.76	123.79	**6.58**
30.4	4.2	409	436	253	253	21.5	35.6	31.1	15.5	6	156	4.5	183	27	4.91	766.08	47.55	898.67	132.59	**5.78**
30.1	4.2	410	435	250	250	21.8	35.2	30.8	15.4	6.4	160	4.4	185	25	5.06	809.09	50.62	935.51	126.42	**6.40**
30.1	4.2	410	437	252	252	21.6	35.5	31.2	15	6.6	158	4.3	185	27	5.28	834.37	54.09	976.95	142.58	**5.85**
29.4	4.2	405	435	250	250	22.5	35.3	31	15.5	7	155	4.3	185	30	5.58	864.36	57.12	1031.66	167.30	**5.17**

Table 6.24: Sample calculation of chiller plant performance - Chiller 2

		refrigerant (kJ/kg)				water (C)				Eva		Cond		Comp		Eva	Cond	Cond	Comp	
m dot water at evaporator (kg/s)	Cp(kJ/kg. K)	h1	h2	h3	h4	T1	T2	T3	T4	(T1-T4) (^{0}C)	(h1-h4) (kJ/kg)	(T2-T3) (^{0}C)	(h2-h3) (kJ/kg)	(h2-h1) (kJ/kg)	**m dot R (kg/s)**	**Q Evap (kW)**	**m dot water at cond**	**Q cond (kW)**	**W comp (kW)**	**COP**
30.8	4.2	411	435	253	253	21	35.2	30.6	16	5	158	4.6	182	24	4.09	646.80	38.56	745.05	98.25	**6.58**
30.3	4.2	410	440	250	250	21.5	35.4	30.9	15.1	6.4	160	4.5	190	30	5.09	814.46	51.17	967.18	152.71	**5.33**
30.2	4.2	411	435	252	252	21.2	35.6	31.1	15	6.2	159	4.5	183	24	4.95	786.41	47.89	905.11	118.70	**6.63**
31	4.2	413	440	255	255	22	35.8	31.1	15.2	6.8	158	4.7	185	27	5.60	885.36	52.52	1036.66	151.30	**5.85**
30.2	4.2	415	440	255	255	21.7	35.8	31.3	15	6.7	160	4.5	185	25	5.31	849.83	51.99	982.61	132.79	**6.40**
30.6	4.2	410	440	253	253	20.5	35.9	31.4	15.1	5.4	157	4.5	187	30	4.42	694.01	43.74	826.62	132.61	**5.23**

APPENDIX G

GANTT CHART

Table 6.25: Gantt chart for FYP 1

	Planning process
	Actual process

ACTIVITES SCHDULE	WEEKS														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Project title were given and set meeting time with supervisor															
Find the important input such as project objective, background project, problem statement and scope of project.															
Do some research about title given (literature review). Find the possible journal, article or books.															
Study the theory and application of air condition system/chiller water system.															
State the method of project research including how to evaluate the performance of air condition.															
Report preparation (chapter 1 – chapter 3)															
Submit draft thesis and required data to supervisor for final checking															
FYP 1 Presentation															

Table 6.26: Gantt chart for FYP 2

	Planning process
	Actual process

ACTIVITES SCHDULE	WEEKS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Preparation to collect the data and state the related equation based on the needed outcome. Collect the data.															
Determine the cooling load for room of FKM administration building in order to calculate the performance required															
Calculate the parameter such as cooling load, flow rate, COP and Power consumption before analyze.															
Analysis the data according to the calculate values.															
Make some discussion about final result by plotting the data and verify the output															
Fill the logbook by week and submit to supervisor for checking.															
Report preparation (chapter 1 – chapter 5)															
Submit draft thesis and required data to supervisor for final checking															
FYP 2 Presentation															