CENTRALIZED AIR CONDITION SYSTEM'S COEFFICIENT OF PERFORMANCE AND RELATIONS WITH ENERGY USAGE AT LAMAN HIKMAH LIBRARY UTEM

THINESWARY ARUMUGAM

This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "Centralized Air Condition System's Coefficient of Performance and relations with Energy Usage at Laman Hikmah Library UTeM" is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Hons).

Signature	:.	....
Name of Supervisor	:	ASSOC. PROF. DR. MUSTHAFAH BIN MOHD TAHIR
Date	:	....

DEDICATION

To my beloved mother and father

ABSTRACT

The sole purpose of this thesis is to conduct an analysis regarding the centralized air conditioning system's coefficient of performance (COP) in relation with energy usage at Laman Hikmah UTeM. Laman Hikmah is one of the leading building in energy consumption at UTeM. The use and energy production has a huge impact on the climate and climate change will affect our capacity for generating energy and our demands for energy. Air conditioning system in Laman Hikmah is dramatically increasing day by day. Thus, it is particularly important to understand the detailed energy consumption structure in that building, focusing especially on air conditioning usage. Library UTeM was established as a new building at the main Campus, Durian Tunggal on 8 July 2009. It started its operation on 29 September 2009. The Library Gross Floor Area (GFA) is 14,503.64 m^2, Net Floor Area (NFA) is 7977.00 m^2 (55% from GFA) and the Air Conditioning Area (ACA) is 13,053.28 m^2 (90% from GFA) could provide a seating capacity of 500 users at any one time. This library have 66 staffs. The building main energy supply are in the form of electricity from TNB (100%) with C1 tariff. The annual electricity consumption for August 2014 until July 2015 was 1,374,110 kWh. Two chillers operate during the audit process with the COP is 4.4 respectively. Other heat rejection device is cooling tower (CT). Based on overall energy consumption baseline (July 2014-June 2015), it was discover that Laman Hikmah consumed total of 8% of energy from UTeM. Then chiller of Laman Hikmah itself consume about 50% energy compare to other energy sources of the library. In an order to find out the coefficient of performance of chiller, some data was measured and analyzed such as Chiller Water Supply (CHWS) temperature, Chiller Water Return (CHWR) temperature, flowrate, and power consumption of the chiller. The overall energy consumption data of Laman Hikmah was gathered via available Internet of Things (IoT) energy management tools and compared with the manually gathered and also with the projected baseline data. A statistical regression analysis is then used to analyze the relation between the COP and energy consumption. Finally, the analyzed data is visualized in a graphical form to be further discussed. As a result, it was noticed that there is a relationship between COP and energy consumption. Then the collected data was compared using ASHRAE table and noticed that the system's performance is in a good state. Analysis result also shows that, as the Coefficient of Performance increases, the energy consumption decreases and well as the cost of electricity. This also have been proven in this thesis whereby, the highest power consumption by the chiller is 117.62kW with the lowest COP of 3.67, and the lowest power consumption by the chiller is 92.88kW with the highest COP of 5.55. It is essential to carryout energy audit and calculate the COP in an order to find out the chiller's performance.

ABSTRAK

Tujuan utama tesis ini adalah untuk melakukan analisis mengenai pekali prestasi sistem penghawa dingin terpusat (COP) yang berkaitan dengan penggunaan tenaga di Laman Hikmah UTeM. Laman Hikmah adalah salah satu bangunan terkemuka dalam penggunaan tenaga di UTeM. Penggunaan dan pengeluaran tenaga memberi kesan besar terhadap iklim dan perubahan iklim akan mempengaruhi keupayaan kita untuk menjana tenaga dan permintaan kita untuk tenaga. Sistem penyaman udara di Laman Hikmah semakin meningkat dari hari ke hari. Oleh itu, sangat penting untuk memahami struktur penggunaan tenaga terperinci di bangunan itu, dengan fokus terutamanya pada penggunaan penyaman udara. Perpustakaan UTeM didirikan sebagai bangunan baru di Kampus utama, Durian Tunggal pada 8 Julai 2009. Ia mula beroperasi pada 29 September 2009. Kawasan Lantai Kasar Perpustakaan (GFA) adalah 14,503,64 m^2, Luas Lantai Bersih (NFA) adalah 7977,00 m^2 (55% dari GFA) dan Kawasan Penyaman Udara (ACA) adalah 13.053.28 m^2 (90% dari GFA) dapat memberikan kapasitas tempat duduk 500 pengguna pada satu-satu masa. Perpustakaan ini mempunyai 66 kakitangan. Bekalan tenaga utama bangunan adalah dalam bentuk elektrik dari TNB (100%) dengan tarif C1. Penggunaan elektrik tahunan untuk Ogos 2014 hingga Julai 2015 adalah 1,374,110 kWh. Dua pendingin beroperasi semasa proses audit dengan COP masing-masing 4.4. Peranti penolakan haba lain adalah cooling tower (CT). Berdasarkan garis dasar penggunaan tenaga secara keseluruhan (Julai 2014-Jun 2015), didapati bahawa Hikmah menggunakan 8% tenaga dari UTeM. Kemudian pendingin Laman Hikmah sendiri menggunakan sekitar 50% tenaga berbanding dengan sumber tenaga lain di perpustakaan. Untuk mengetahui pekali prestasi chiller, beberapa data diukur dan dianalisis seperti suhu Chiller Water Supply (CHWS), Chiller Water Return (CHWR), flowrate, dan penggunaan daya chiller. Keseluruhan data penggunaan tenaga Laman Hikmah dikumpulkan melalui alat pengurusan tenaga Internet of Things (IoT) yang tersedia dan dibandingkan dengan data yang dikumpulkan secara manual dan juga dengan data asas yang diproyeksikan. Analisis regresi statistik kemudian digunakan untuk menganalisis hubungan antara COP dan penggunaan tenaga. Akhirnya, data yang dianalisis dipvisualisasikan dalam bentuk grafik untuk dibincangkan lebih lanjut. Akibatnya, diperhatikan bahawa ada hubungan antara COP dan penggunaan tenaga. Kemudian data yang dikumpulkan dibandingkan dengan menggunakan jadual ASHRAE dan melihat bahawa prestasi sistem berada dalam keadaan baik. Hasil analisis juga menunjukkan bahawa, apabila Pekali Prestasi meningkat, penggunaan tenaga menurun dan juga kos elektrik. Ini juga telah dibuktikan dalam tesis ini di mana, penggunaan kuasa tertinggi oleh chiller adalah 117.62kW dengan COP terendah 3.67, dan penggunaan kuasa terendah oleh chiller adalah 92.88kW dengan COP tertinggi 5.55. Adalah mustahak untuk menjalankan audit tenaga dan mengira COP untuk mengetahui prestasi chiller.

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LIST OF ABBEREVATIONS

HVAC	Heating Ventilation Air Conditioning
NFA	Net Floor Area
COP	Coefficient of Performance
VCR	Vapor Compression Refrigerant
WLHP	Wick-mounted Heat Loop
AHU	Air Handling Unit
AC	Air Conditioner
CT	Cooling Tower
CHWP	Chiller Water Pump
CHDP	Condenser Water Pump
CHWS	Chill Water Supply
CHWR	Chill Water Return
IoT	Internet of Things
EER	Energy Efficiency Ratio
VFD	Variable Frequency Drives

LIST OF SYMBOL

η_{th}	=	Thermal efficiency
W	=	Work done
Q	=	Flowrate
T	=	Temperature
T_{out}	=	Temperature return
T_{in}	=	Temperature supplied
Q_H	=	Heat input at high temperature
Q_{hot}	=	Heat gain
Q_{cold}	=	Heat released
ΔP	=	Changes in Pressure

CHAPTER 1

INTRODUCTION

1.1 Background

The average global temperature has risen at the fastest rate in recorded history over the past 50 years. Yet experts see the trend is accelerating. Hansen (2015) states that Global warming occurs when carbon dioxide, CO_2 and other air pollutants and greenhouse gases collect in the atmosphere, absorb sunlight, solar radiation that have bounced off the earth's surface. This radiation will usually disperse into space, but these pollutants, which can last in the atmosphere for years to decades, trap the air and make the earth hotter. 'Global warming' is a term referring to the environmental impact of human activities, in particular the burning of fossil fuels (coal, oil and gas) and large-scale deforestation, causing large quantities of' greenhouse gas' pollution into the environment, the most important of which is carbon dioxide. Global warming's effects were felt across the globe. In recent years, extreme heat waves have caused tens of thousands of deaths worldwide. Every year, researchers learn more about the effects of global warming and many believe that if current trends continue, ecological, economic and health implications will likely occur. The increasing heat-trapping gases emitted by human activities into the atmosphere produce an energy imbalance between incoming solar radiation and outgoing long wave radiation that leads to global heating (Von Schuckmann et al. 2016). If energy never managed well, then it's really hard to overcome global warming issues.

Energy is one of the most imperative aspects of technological advancement in the state. Sustainable development includes efficient energy use and savings. The energy saving process is called energy management. Saving energy is essential for saving planet. Fossil fuels and conventional energy sources are the primary sources of energy. Thus energy management is a global concern. It's necessary to reduce the planet's damage. Shafie et al. (2011) found that the economic growth is measure by gross domestic product (GDP) and in Malaysia GDP is correlates almost exactly with the energy consumptions of the country. In the last 28 years, primary energy consumption has increased by an average of 6.8% and electricity consumption by 9.2% annually in Malaysia.

According to Malaysia energy statistic handbook 2018, the primary production of fuel on year 1996 is total 76,171 ktoe and increased by 102,801 ktoe in 2016. In this era with limited resources, conservation and energy efficiency continue to be major challenges. The application of energy conservation techniques in air conditioning systems must be matched with the convenience and safety of the occupants. There were few specific guidelines on energy savings in air conditioning systems, but these recommendations do not satisfy all specifications and model varieties. Air Conditioning use is expected to be the second largest source of growth in global electricity demand and the main driver of buildings by 2050. The supply of energy to these Air Conditioning involves significant costs and environmental consequences. Diversity of Air Conditioning usage behavior among residents is the main cause of the variation in heating energy consumption (Goetzler, 2016).

1.2 Problem Statement

The global climate is changing, posing ever more serious risks to biodiversity, human health, and the economy. All around the world already experiencing climate change impacts, including rising sea levels, more extreme weather, floods, droughts and storms. Globally, energy consumption is by far the largest source greenhouse gas emissions by human activities. Approximately two-thirds of global greenhouse gas emissions are related to the burning of fossil fuels for heating, electricity, transportation and industrial use. The use and energy production has a huge impact on the climate and climate change will affect our capacity for generating energy and our demands for energy.

Laman Hikmah Library UTeM as shown in Figure 1.1., is one of the leading building in energy consumption at UTeM, its total NFA is 7,977.00m^2 and have 66 staffs and 500 users capacity. Laman Hikmah Library UTeM is a curated collection of information sources and chosen by students for reference and borrowing purposes of books. Air conditioning system in Laman Hikmah is dramatically increasing day by day. Thus, it is particularly important to understand the detailed energy consumption structure in that building, focusing especially on air conditioning usage. So this thesis attempts to figure out the centralized and split unit air condition system's coefficient of performance and relations with energy usage at Laman Hikmah Library UTeM.

Figure 1.1 : Laman Hikmah Library UTeM

1.3 Objective

The objectives of this thesis are as follows:

1. To obtain the measurement of the Centralized Air-conditioning system's energy consumption at the building Laman Hikmah Library UTeM.
2. To establish the relationship between the power consumption and coefficient of performance of Air conditioning at Laman Hikmah Library UTeM.

1.4 Scope

The scopes of this thesis are:

1. The comparison of energy consumption at Laman Hikmah with other UTeM buildings by using IoT baseline data.
2. Analyzing the COP of chiller system and obtain the relationship with energy consumption in Laman Hikmah Library UTeM
3. Provide necessary measures to improve the system's performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

General air conditioning can be supported by a range of devices varying from low-horsepower self-contained systems to several thousand tons of very large built-up central systems. The primary goal of user is to obtain and use an air conditioning system that delivers the most suitable performance in terms of capital, operating, substitution and operating costs on a life-long basis (Bhatia, A., 2011).

The Vapour-compression cooling system uses a flowing fluid refrigerant as the operating medium that collects then separates the heat from the cooling region and then returns it into the atmosphere. Vapour Compression Refrigerant (VCR) process performance is determined as a coefficient of performance (COP). If COP is greater, the device absorbs more energy and is therefore more effective for a particular work input (Nethaji, N., 2017).

Air conditioning device incorporated wick-mounted loop heat pipes (WLHP). The WLHP is on the air conditioning unit's evaporator side. The WLHP's operating medium is R134a coolant gas, an alternative coolant (Hussam, 2013). The WLHP is a system that enables very significant heat transfer across huge distances across small surface spaces, with minimal differences in temperature and no external pumping energy. Usually the WLHP consists of heavy thermal conductivity products such as copper, aluminium and brass based on the usability of the operating medium and the implementation range of temperatures. For quicker heat removal, the condenser portion is bigger in size compared to the evaporator

(Hatem, 2012). Likewise, the diameter of the vapour loop is greater than the diameter of the water loop for smoother flow of lighter vapour than the denser working fluid. Due to thermo siphon effect, the vapour that flows through the vapour loop enters the WLHP condenser portion, where the heat is rejected and the liquid is saturated at the same pressure and temperature and flows down through the liquid loop to the evaporator column (Tharves, 2017).

2.2 Laman Hikmah UTeM

Universiti Teknikal Malaysia Melaka (UTeM) was founded as a consequence of the rebranding of Kolej Universiti Teknikal Kebangsaan Malaysia (KUTKM) Section 8 of the University and College University Act 1971 (Act 30), published as P.U. (A) 45/2007, 1 February 2007. The UTeM Library has been in service at the Temporary Campus in Taman Tasik Utama, Ayer Keroh, Melaka, serving 348 groundbreaking students since 10 June 2001 (Hafiz, 2018).

Laman Hikmah Library was moved to the Industrial Campus on September 5, 2005 from the Temporary Campus, which started operating on September 12, 2005. Laman Hikmah Library will fill about 400 occupants with an area of 2,229 square meters. In addition, the Main Laman Hikmah Library, 432 square meters, has for 120 sitting capacity users to meet students needs from both the Faculty of Electrical Engineering (FKE) and the Faculty of Electronics and Computer Engineering (FKEKK).

The Laman Hikmah Library has a seating capacity of 500 users at any time on the Main Campus (10,063.68 square meters). Laman Hikmah Library has a maximum collection of over 115,000 titles comprising 13 registered titles addressing the core areas of Electrical

Engineering, Electronics and Computer Engineering, Mechanical Engineering, Industrial Engineering, Engineering, Information and Communication Technology and Knowledge Creation & Technopreneurship. Other scientific fields such as physics, chemistry and mathematics are also available as well as general readings (Razak, 2018).

Tenaga Nasional Berhad (TNB) electricity is the main source of energy for the tower. The input of diesel fuel to the generator array is not known to be a building energy source. Library is committed to providing outstanding information tools and guides, as well as providing quality facilities in accordance with the university's vision and mission, using the latest technology (Tahir, 2018).

The building usually runs about 14 hours a day from Monday to Friday from 8.00 AM to 10.00 PM and operates around 5 hours a day on weekends from 10.00 AM to 3.00 PM. Nevertheless, spaces such as book or file storage room are run 24 hours a day. Since the building was first occupied, there has been no significant retrofit and re-commissioning. Nonetheless, in order to accommodate different requirements of each floor, some interior renovations were made (Sulaima, 2018).

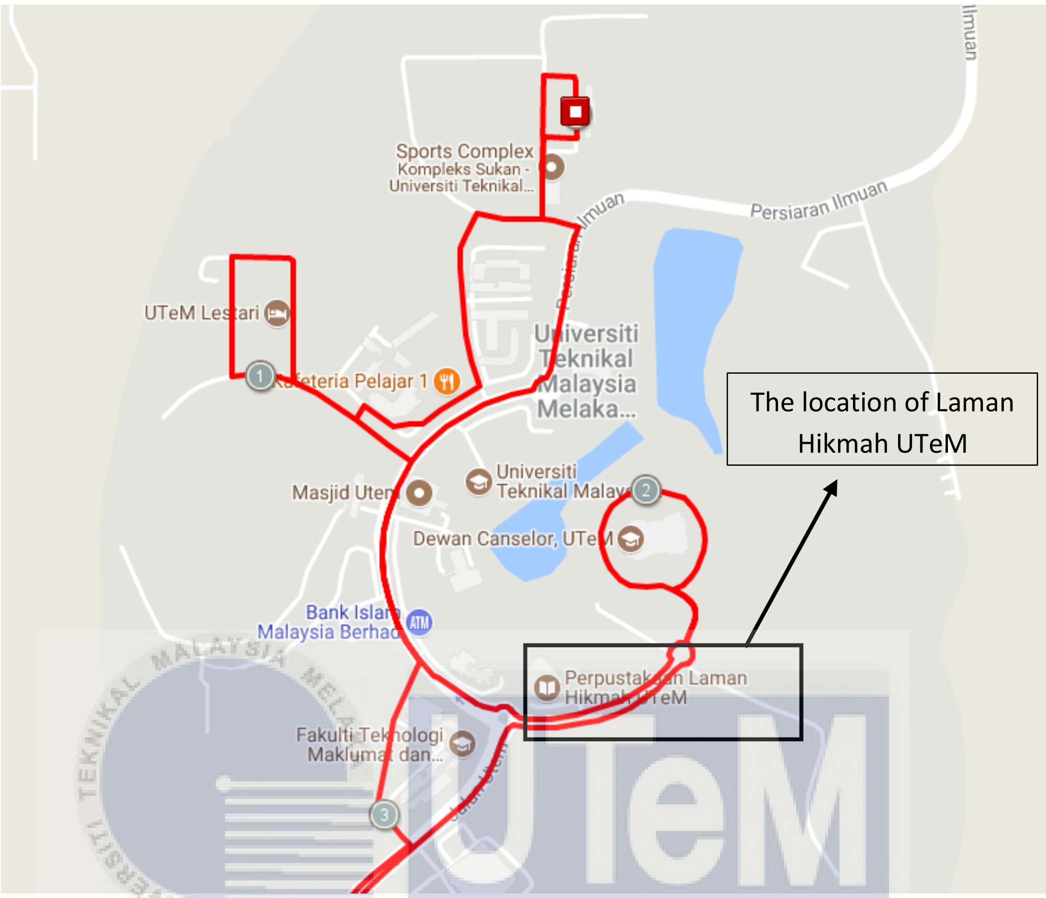

Figure 2.1 : Library UTeM location

2.3 Electrical Energy

Ali, R.,and Taib, S., (2012) claim that as the demand for electricity is affected by population growth, Malaysia is considering the options for future energy sources to generate electricity to an industrialized nation. In addition to the conventional four-fuel mix, various national policies introduce the five-fuel mix strategy to diversify and expand resources to incorporate renewable energy and nuclear energy. Considering that Malaysia will become a net importer of energy by 2020, at least the increase in alternative energy shares will provide stable energy security, a more economical and greener climate (Daut, I, 2012).

Electrical energy is the world's highest-used type of energy where it reaches 20863 TWh in 2016 and 67.3% comes from fuel power generation that releases CO_2 into the atmosphere (IEA, 2018). United States Environmental Protection Agencies (2018) reported that one-third of its state electrical consumption was generated for 2013 by each of its residential, commercial and industrial users. From the percentage, 26% were used for air conditioning or HVAC, 20% for lighting, 16% for computers and appliances, 36% for other applications, and 2% for industrial water heating.

The situation is very close in Malaysia where, within an overall energy production of 110199.7 GWh, 23 percent of total energy demand comes from the domestic user, 36% from the commercial sector, 39% from the industrial sector, and typically 2% heads to others like public lighting (Energy Commission, 2016).

Malaysia's energy policy is determined by the Government of Malaysia. The Department of Electricity and Gas (now the Energy Commission of Malaysia) acts as a temporary regulator of other players in the energy sector including energy and services companies, research and development institutions and consumers. Government agencies contributing to this policy are the Ministry of Energy, Green Technology and Water Malaysia, the Energy Commission and the Malaysian Energy Center. Among the policy-based documents were the Petroleum Development Act 1974, 1975 National Petroleum Policy, 1980 National Degradation Policy, Electricity Supply Act 1990, Gas Supply Act 1993, Electricity Regulations 1994, Gas Supply Regulations and Energy Commission Act 2001 (Malaysia energy policy).

2.4 Internet of Things (IoT)

Madakam, (2015) has shown that, the Internet of Things is a ground breaking IT amphitheatre cultural shift. The term "Internet of Things" was derived from the two terms, the first term is "Internet" and the second word is "Things." It is a software application comprising millions of private, public, educational, business and government networks, ranging from local to international, interconnected by a wide range of digital, wireless and optical networking technologies. The Internet is a dynamic system of computer servers that use the common internet Protocol Suite (TCP / IP) to serve billions of users around the world. More than 100 countries are now linked through the Internet to share information, news and viewpoints. As of December 31, 2011, there were an estimated 2, 267, 233, 742 Internet users worldwide from the Universal Resource Location, as per the Internet World Statistics. It indicates that the Internet uses 32.7% of the entire population of the planet (Ramaswamy, 2015).

Energy management is the key to saving energy in any organization, and energy savings are a global need as they affect energy prices and carbon gas emissions into the atmosphere. IoT is the method of tracking, managing and conserving energy in a building or company because energy conservation is concerned with energy saving. This includes analyzing and collecting data, searching for energy-saving opportunities, implementing energy-saving opportunities, and monitoring progress on energy-saving. It is controlled by the user through the core of IoT which connects to the digital devices in any organisation for the conservation of energy (Tripathi, 2015).

2.5 Air Conditioner

Air conditioning is the process of removing heat and moisture from the interior of an occupied space to improve the comfort of occupants. Air conditioning can be used in both domestic and commercial environments. In the design of equipment for heating, ventilation and air conditioning (HVAC), there has been a growing use and urge to include a device and approach for regulating air flow to and from a confined space in which the level of humidity is regulated to the needs of the user's space (Fuhrman, 2016). A common issue in the design of forced air flow air conditioning cooling devices, nevertheless, is in specific the regulation of the fan or blower blowing indoor air to prevent evaporation of condensate collection on the cooling coil or heat exchanger and in any condensate collection panels that may be weaved in the air flow stream. Alternatively, in many air conditioning control systems, the operating cycle of the indoor ventilator can reintroduce moisture into the air flow that was extracted during a cooling operating cycle (Crawford, 2012).

First, the coil of the evaporator pumps cold refrigerant. A fan blows air over the coil and heat is absorbed by the refrigerant in the coil. The now-cool air to be pumped through home is expelled through ducts. It evaporates into a low-pressure gas as the refrigerant absorbs heat. Then, hot refrigerant gas with low pressure moves to the compressor, which increases the gas pressure and temperature. Besides, the condenser is moved by hot, high-pressure refrigerant gas. The gas releases heat, condensing it back into a liquid, as it does. Finally, the liquid refrigerant flows into the expansion tube, which controls the volume of refrigerant that passes to the evaporator. The refrigerant flows into the evaporator from here to circulate again the cooling cycle (Young, J, 2016).

2.6 Centralized Air conditioning system.

Centralized air conditioning is a device in which one or more fans and ductwork circulate air at a central location to and from the rooms. The air conditioner compressor's work is what makes the entire air conditioning system possible. The refrigerant gas compression allows it to discharge heat from the room, which is how the cool air is produced. The evaporator, condenser, and compressor are all located in a packed central air conditioner in one cabinet, which is usually placed on a roof or on a concrete slab next to the foundation of the house. Air supply and return ducts come from the inside through the outside wall or roof of the home to connect to the packed air conditioner, which is usually outside. Electric heating coils or a natural gas furnace are often included in packed air conditioners. The combination of air conditioning and central heating removes the need for a separate indoor furnace (Kim, 2015).

During warm weather indoor comfort centralized air conditioning helps maintain the home warm and decreases humidity. Then, when central air-conditioning unit extracts air out of the rooms in the home through return air ducts, air is drawn through an air filter that eliminates airborne particles such as dust and lint thus it cleans the air. The filtered air is then directed back to the rooms in the air supply ductwork. It is also a quieter operation because the compressor-bearing unit is mounted outside the building, its operating indoor sound level is much reduced than that of a stand-alone air-conditioning system (Cai, J. et al. 2015).

Basically Centralized Air Conditioning can be categorized into :-

Air cooled

- Uses finned tube coil condenser.
- Refrigerant flows through the refrigerant piping from evaporator to condenser.
- When refrigerant flows in the piping its pressure drops.
- So the length of refrigeration tubing and the distance between the condenser and evaporator should be kept minimum.

Water cooled

- Uses shell and tube type.
- Cooling water is pumped from tubes of the cooling towers at a high pressure.
- So it is easy to carry long distances
- The losses in the pressure of water accommodated by the sufficient capacity of the pump, which has low capital and running cost.
- Can be placed at any distance from the cooling equipment.
- For cooling loads between 100-125 tons-air cooled is used.
- Above 200 tons-water cooled is suitable.

Sub systems of Centralized Air Conditioning

i. Chilled water plant
ii. Condenser water system
iii. Air delivery system

2.6.1 Chilled water plant

The chilled water system supplies chilled water for the cooling needs of all the building's air-handling units (AHUs). This system includes a chilled water pump which circulates the chilled water through the chiller's evaporator section and through the cooling coils of the AHUs. This system also consist of four main components such as compressor, condenser, evaporator and expansion valve. The basic process of the system is first, the fans that pull air through the system, then evaporator coils that change refrigerant from liquid to gas. Compressor pressurizes refrigerant gas, condenser coils that turn refrigerant gas into a liquid, refrigerant lines that carry refrigerant between the coils, an expansion device that regulates refrigerant flowing to the evaporator. (Lee, M.Y. et al. 2013).

2.6.2 Evaporator coil (absorbing hot air inside a building)

The warm house air boils the cold refrigerant liquid into gases. A lot of heat being absorbed in the process, this is called the latent heat vaporization and makes very efficient heat transfer. Because the refrigerant is vaporizing in this coil, it is called evaporating coil (Yu, F.W. and Chan, K.T., 2008).

The evaporator is located between the expansion valve and the compressor, the object of which is to absorb the unwanted heat from the building and transfer it into the refrigerant so that it can be sent and rejected to the refrigerating tower. As the heat is drained by the refrigerant, the water cools down, this "chilled water" is then pumped around the building to provide air conditioning, this "chilled water" then flows to the evaporator removing any excess heat from the room (Cai, J. et al. 2015).

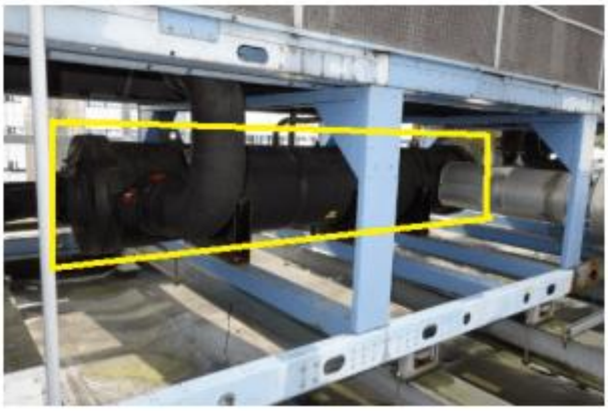

Figure 2.2(a) : Evaporator on an air cooled chiller

Figure 2.2(b) : Evaporator on a water cooled chiller

2.6.3 Compressor (heating up refrigerant)

Compressor handle the refrigerant in its gaseous state. By compressing the refrigerant gas, it does significantly increase its pressure in the compression chamber and thus the temperature also increases (Chan, K.T., 2008).

The compressor is the prime mover, generating a differential pressure to move the refrigerant around the device. Sagar, M.V (n.d.) has demonstrated that there are different designs of the refrigerant compressors, the most common being the compressors like centrifugal, screw, scroll and reciprocating. Every form has their own advantage and disadvantage. It is always positioned among condenser and evaporator. It is normally partially insulated and will have an electric motor connected as the driving force, it will either be placed inside or outside. Compressors can be extremely loud, generally a continuous deep droning sound with a high pitch overlay, it is best to wear earplugs when close to the chiller.

Figure 2.3(a) : Screw type compressor

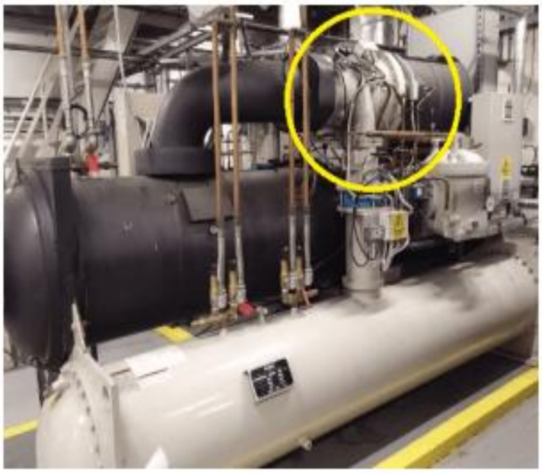

Figure 2.3(b) : Centrifugal type compressor

Figure 2.3(c) : Reciprocating type compressor

Figure 2.3(d) : Scroll type compressor

2.6.4 Condenser (exhausting hot air to the outside)

The compressor forces hot, high pressure refrigerant gas into condenser coil. Air blowing across the coil condenses the refrigerant from gas into a liquid. In the conversion from gas to liquid, lots of heat is released into the outside air (R.P. Mazzucchi. et al. 2006).

The condenser is positioned behind the compressor and before the valve for expansion. The condenser's aim is to absorb heat from the refrigerant that was trapped in the evaporator. There are two main condenser types, Air cooled, and Water cooled.

Water-cooled condensers must constantly cycle "Condenser water" between the cooling tower and the condenser, the hot refrigerant that reaches the condenser from the compressor, transmitting its heat from the building into this water that is transferred to the cooling tower and discarded. The refrigerant and the water are not combined by a pipe wall, the water is flowing inside the pipe and the refrigerant flows outside. Condensers on air-cooled chillers operate bit differently, they never use a cooling tower but blow air through the exposed condenser pipes with this time the refrigerant circulating inside the tube.

Figure 2.4(a) : Water cooled chiller condenser

Figure 2.4(b) : Air cooled chiller condenser

2.6.5 Expansion valve (cooling hot refrigerant liquid)

The capillary tube is a bottleneck designed to restrict the flow of refrigerant liquid at the discharge point of the bottleneck, the refrigerant is at a much lower pressure when the pressure is reduced the temperature also goes down the refrigerant coming out of the tube and is ready to go into the evaporator coil to collect more heat. (S. Zheng. et al. 2014).

The expansion valve is between the condenser and the evaporator. It is intended to expand the refrigerant by rising its pressure and increasing its volume which will allow it to absorb the unwanted heat in the evaporator. There are many different types of expansion valves, the most common at the thermal expansion valve, the thermal expansion valve controlled by the pilot, the electronic expansion valve and the expansion valve for fixed orifices.

Figure 2.5(a) : Electronic expansion valve

Figure 2.5(b) : Thermal expansion valve

2.6.6 Power unit

The power unit is either directly attached to the chiller, or it can be isolated and mounted to the plant room wall with power cables running between them. The power unit's aim is to regulate electric power flow to the chiller. Those usually include a starter, circuit breaker, speed controller, and power monitoring unit. Bhatia, A., et.al. (2011) found that A complex metering device usually based on the chilled water energy BTU / hr (calibrated from flow and temperature differential) is first calculated to convert to equivalent power units in kWH.

Figure 2.6 Electrical power unit

2.7 Condenser water system

B. K., Muthukumar (2017) states that, cooling tower system is mainly for refrigeration system which must also rejects the heat that it removed. There are two options for heat rejection, air cooled and water cooled. Air cooled units absorb heat from the indoor space and rejects it to ambient air. These are the most common system used in residential and light commercial application. Water cooled units absorb the heat from indoor space and eject it to water via cooling tower. This system is common in multistory offices, hotels, airports and shopping complexes. This also leads to higher coefficient of performance (COP).

Milosavljevic, (2001) claims that from the condenser inhaler, condenser water flow to the cooling tower with the help of centrifugal pump. This condenser water will pass through the rotating sprinkler blade of cooling tower. This rotating rotor blades using pressure generated by the condenser itself. Then, water will go down through the fins will reduce the speed of water going down. This can delay the time of the heat can be absorbed more efficiently by the surrounding air that passing through the fins. Air through the fins is forced by rotating fan on the sprinkler blade rotated by the motor. This fan rotates upwards, and this cause the air to move from bottom to up. Condenser water will be accumulated on the basin. Bouys connected to the makeup water tank, it works for adding water when the water level in basin decreases due to evaporation. Chilled water pass through cooling coil. In cooling coil, hot air will pass through filter, then cooling coil, then switch to cold air due to heat transfer through chilled water. After absorbing heat from hot air, the chill water now will become chill water return. Consider the cooling tower atop a typical office style building. A centrifugal pump transfers water between the chiller in the basement and the cooling tower on the roof, known as "condenser water" The chiller contributes heat to the condenser water, and the cooling tower refuses it into the atmosphere and cools it out. The heat it rejects is all of the building's excessive heat generated by the occupants, machines, sunshine, lighting. It must also reject the heat produced by the chiller compressor. (Zavaragh, H. G. et al. 2016).

The condenser water, for example, exits the chiller condenser at about 32 ° C and the pump sends that up to the cooling tower. The process has been structured in such a way that the condenser water that exits the cooling tower and re-enters the chiller condenser must be about 27 ° C in order to collect enough heat on the next cycle. (Prasanna, K. S. et al. 2013)

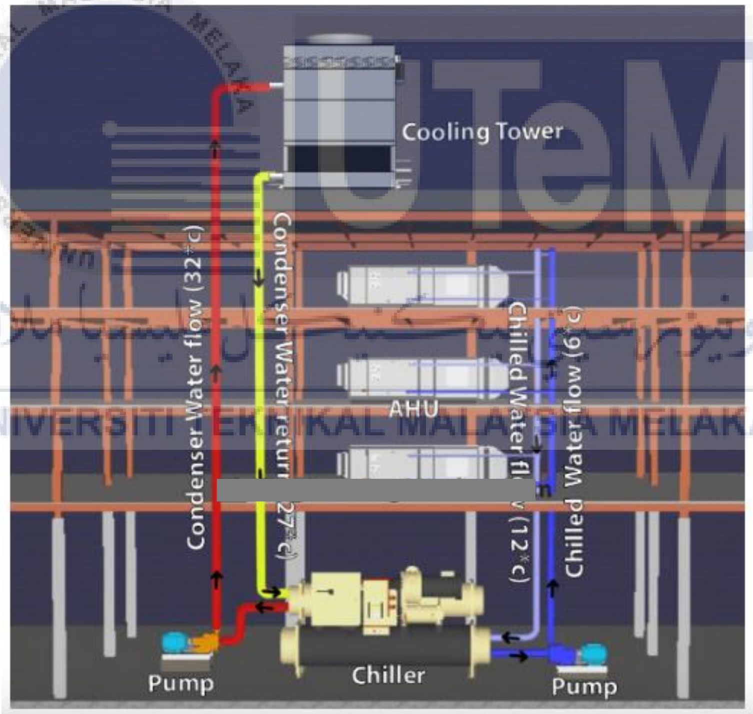

Figure 2.7 Condenser water system with chiller unit

Source : The Engineering Mindset.com

Fan, the fan draws cool ambient air in through the base filters and forces it out from the top of the cooling tower, bringing with it heat and moisture. Drive Belt and Drive Motor, the most easy way to turn the fan blades. Sai, B. B., Swathi, (2013) mentioned that, also it may be direct drive, chain driven or mounted gear. Drift Eliminator, his enables the air to change direction and condense some of the moisture in the exiting air which reduces operating expenses, Condenser Water Inlet, this is where the warm condenser water reaches the cooling tower. Spray Nozzles, these nozzles are forced into the warm condenser water, causing it to spill into a shower of tiny droplets. Fill Packaging, the condenser water spray droplets fall down this raising the surface area of the heat transfer and allowing the air (which flows in the opposite direction) to absorb some of the heat and moisture from the evaporation. Filter, it is from where the fan draws the air in. The filter restricts the amount of dirt and leaves that reach the refrigerated container. Then air enters here cooler and dryer, as it leaves at the tip, Condenser Water Outlet, this is where water from the condenser enters the cooling tower. This should leave at a temperature lower than when it enters at the top. Make-up Water, the basin of the cooling tower keeps a minimum water level. Water is lost from evaporation from the cooling tower but also when drains from the cooling tower to get rid of accumulated dirt and salt. Overflow, if the basin's level of water gets too high, it will flow over here and out into a drain. Drain, water will be drained for maintenance purposes from the cooling tower, but also periodically during regular service when the amount of impurities in the water is too high. The impurities are caused by the accumulation of dirt and salts that form when water evaporates and leaves these behind. Perhaps this is refer to "blowdown". (Busch, D.et al. 2011)

2.8 Air delivery system

Air Handling Unit (AHU)

An air handling unit is a device used to conditioned and circulate air as part of a heating, ventilating, and air conditioning (HVAC) system. An air handler is usually a large metal box containing a blower, heating or cooling elements filter racks or chambers, sound attenuators, and dampers. Air handlers usually connect a ductwork ventilation system that distributes the conditioned air through the building and returns it to the AHU. The components of AHU is supply duct, fan compartment, vibration isolator, heating and cooling coil, filter compartment and mixed air duct. (B.Venkateswara Reddy, 2013)

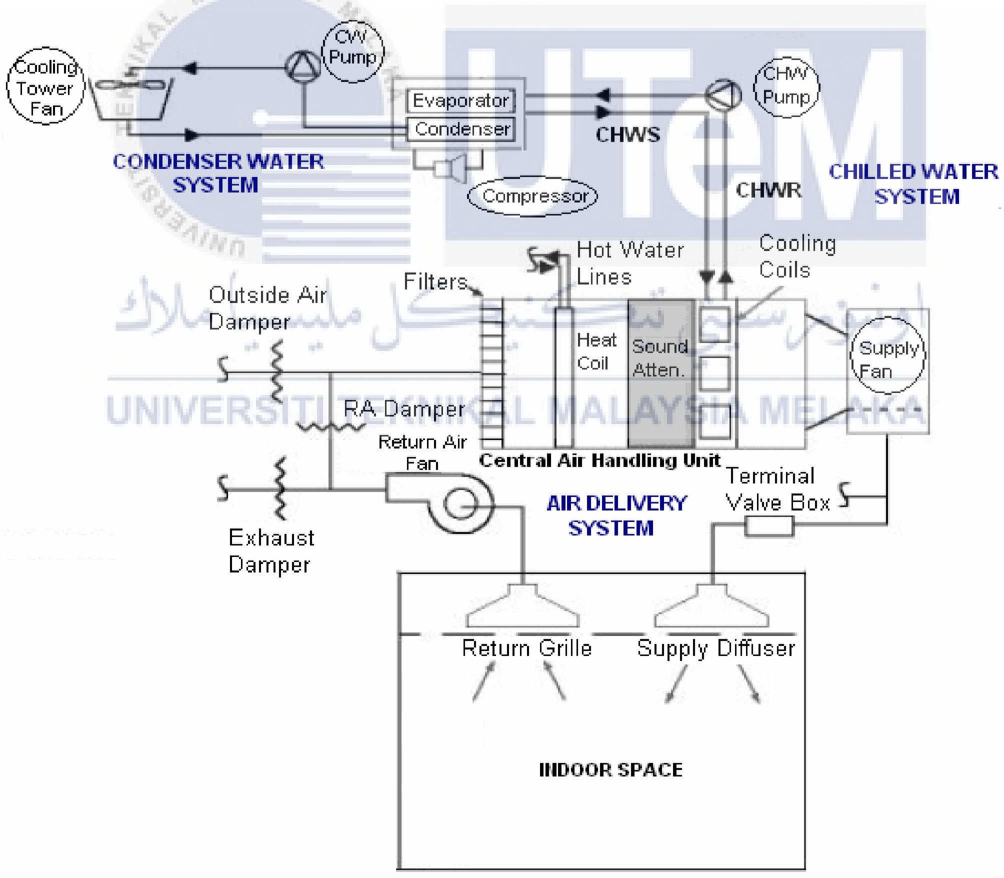

Figure 2.8 : Layout of overall chill water system

2.9 Coefficient of Performance (COP)

An air conditioner's coefficient of performance COP, is described as the ratio between the power output and the input. The power output indicates as relevant heat at a higher temperature than the surroundings while electricity or the direct use of fossil fuels supplies the energy input. The overall energy input to the system includes natural energy from the environment and the majority of the heat pump setups have such a COP greater than 1.0. In other words, by using electricity or fossil fuels, more usable energy is extracted from the device at the higher temperature than was supplied to it (McNevin, S.J., 2017).

The operating performance of a particular air-conditioning system can be best judged by identifying its Coefficient of Performance (COP). COP is described as the ratio of total heat removed by the system to the total input energy. The heat removed by air conditioning system could be calculated at the evaporator of the chiller, at the condenser of the chiller and at the Air Handling Units (AHUs). The definition of COP for an air-conditioning system can be described in the formula below:

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}} \qquad \text{(Eq 2.1)}$$

Air conditioning heat rejection is equivalent to the change in chilled water heat content through the condenser water heat exchanger. This can be calculated by using the following formula:

$$\text{AC Heat Rejection (kW)} = 4.18\ \frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C \qquad \text{(Eq 2.2)}$$

As shown in equation 2.5.5.1 and equation 2.5.5.2 where, *Q* is the chilled water flow in *kg/s*, *Tin* is temperature of the returned chilled water in $°C$, *Tout* is temperature of the leaving chilled water in $°C$.

2.10 Centralized Cooling System at UTeM library.

Centralized Cooling System Library UTeM uses the Water-Cooled Chiller System to meet most of its cooling demand. The system set-up is quite standard consisting of; on the chiller plant side, a set of primary and secondary chilled water pumps that send chilled water to the various AHUs and return it to the chiller, a set of condenser water pumps that send cooling water to cool down the chiller units and a set of cooling towers to cool down the cooling water. Whereas, on the air side consists of a set of AHU placed on each of the floors. There is only a single centralized chiller plant installed at Library. The plant is located in a dedicated area such as the Main Chiller Plant. Table below shows the chiller basic information that used to send and return the chilled water to the respective AHUs located in the buildings.

Table 2.1 : Centralised Air Conditioning System

Item	No of Unit	Figure
Chiller	3	
Condenser Water Pump	3	
Cooling Tower	2	
Chilled Water Pump	3	

AHU	12	

Table 2.2 : List of Chillers

Chiller ID	**Type**	**Brand**	**Model**	**Flow Rate (m^3/hr)**
Chiller 1	Centrifugal	YORK	YFS188S-115W	700
Chiller 2	Centrifugal	YORK	YFS188S-115W	700
Chiller 3	Centrifugal	YORK	YFS188S-115W	700

Table 2.3 List of Cooling Towers

Unit No	**Brand**	**Model**	**Type**	**Flow Rate (m^3/hr)**	**Cooling Capacity (kW)**
CT 1	Nihon spindle	CTA-200UK	Counter Flow	156	907
CT 2	Nihon Spindle	CTA-200UK	Counter Flow	156	907

Table 2.4 List of Condenser Water Pump

No.	Brand, Model	Type	Speed (rpm)	Rating Power (kW)
CHDP 1	Teco	Induction Motor	1455	11
CHDP 2	Teco	Induction Motor	1455	11
CHDP	Teco	Induction Motor	1455	11

Table 2.5 List of Chiller Water Pump

No.	Brand, Model	Type	Speed (rpm)	Rating Power (kW)
CHWP 1	Teco	Induction Motor	1455	11
CHWP 2	Teco	Induction Motor	1455	11
CHWP 3	Teco	Induction Motor	1455	11

Table 2.6 List of AHU

No.	Brand	Model	Fan speed (rpm)	Fan Motor (kW)
LG/1	YORK	YSM 30 × 50	1583	4.0
LG/2	YORK	YSM 40 × 60	1030	5.5
G/1	YORK	YSM 40 × 50	1566	5.5
G/2	YORK	YSM 40 × 60	1296	5.5

G/3	YORK	YSM 30 × 50	1589	4.0
L1/1	YORK	YSM 40 × 60	1357	5.5
L1/2	YORK	YSM 40 × 60	1357	5.5
L1/3	YORK	YSM 40 × 50	1715	4.0
L1/4	YORK	YSM 40 × 50	1439	4.0
L1/5	YORK	YSM 40 × 50	1439	4.0
L2/1	YORK	YSM 40 × 70	1157	5.5
L2/2	YORK	YSM 40 × 70	1157	5.5

(Source : Energy Audit Report Library Building Universiti Teknikal Malaysia Melaka 2016)

2.11 Energy Policy of UTeM

The UTeM energy policy was first adopted by the Center for Sustainability and Environment (CSE) or recognized as Pusat Kelestarian dan Alam Sekitar (PKA) on 9 June 2015. Energy policy is committed to constantly improving productivity and energy conservation across the campus in terms of teaching and learning, study and service operations. First, it also ensures that all energy consumption-related activities, rules and regulations are enforced by 23. In addition, the goal of this policy is to reduce energy use by 3 percent per year for one-meter square building space beginning in 2015.

The aim of UTeM Energy Policy is to enhance awareness of the important aspects of energy conservation and to enforce the conservation approach and to reduce energy costs in UTeM. In addition, the goal of this plan is to reduce energy use by 3 percent per annum for the building's one-meter square area beginning in 2015. According to the Center for Sustainability and Environment (CSE) UTeM, before the plan was adopted, the power baseline (kWh), the electricity use of 1,700,000 kWh in December 2014. After the beginning of UTeM energy policy, energy baseline has decreased to around 1,400,000 kWh in December 2015. Below in figure 2.6.1 shows the declaration of commitment of energy management guidelines and policy of Universiti Teknikal Malaysia Melaka (UTeM).

UTeM

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DASAR DAN GARIS PANDUAN PENGURUSAN TENAGA

ENERGY MANAGEMENT GUIDELINES AND POLICY

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEKLARASI KOMITMEN

DECLARATION OF COMMITMENT

Universiti Teknikal Malaysia Melaka (UTeM) komited:-

Universiti Teknikal Malaysia Melaka (UTeM) is committed :-

a. **Untuk menambahbaikkan kecekapan dan pemuliharaan tenaga, air dan bahan api kenderaan secara berterusan di seluruh kawasan kampus dalam menjayakan pengajaran dan pembelajaran, penyelidikan dan operasi perkhidmatan melalui pelaksanaan pengurusan tenaga yang cekap dan berkesan.**
To continuously improve efficiency and conservation of energy, water and vehicle fuel throughout the campus in order to carry out teaching and learning, research and service operation by implementing efficient and effective energy management.

b. **Untuk menangani dan bertindak terhadap pelbagai proses dan aktiviti yang akan memberi kesan kepada prestasi penggunaan tenaga, air dan bahan api kenderaan di semua kawasan kampus Universiti Teknikal Malaysia Melaka.**
To address and act towards various processes and activities which might have impact toward usage of energy, water and vehicle fuel at all premises within Universiti Teknikal Malaysia Melaka.

c. **Untuk memastikan pematuhan terhadap semua akta dan peraturan berkaitan pengurusan tenaga, air dan bahan api kenderaan yang cekap.**
To comply with acts and regulations of efficient management of electrical energy.

d. **Untuk mematuhi Peraturan-peraturan Pengurusan Tenaga Elektrik Dengan Cekap 2008, Akta Bekalan Elektrik 1990 dan perundangan lain yang berkaitan dengan pengurusan tenaga, air dan bahan api kenderaan.**
To comply with the Efficient Management of Electrical Energy Regulations 2008, Electricity Supply Act 1990 and other legislation related to the management of energy, water and vehicle fuel.

e. **Untuk memastikan pematuhan terhadap Garis Panduan Perolehan Hijau Kerajaan.**
To comply with the Government Green Procurement (GGP) Guidelines.

f. **Untuk menyediakan sumber bagi melaksanakan sistem pengurusan tenaga.**
To provide resources for the implementation of energy management system.

PROFESOR DATUK WIRA DR. RAHA ABDUL RAHIM
NAIB CANSELOR/*VICE CANCELLOR*
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Tarikh/*Date*:
8 / 11 / 2019

Figure 2.9 : Declaration of commitment

Source : Center for Sustainability and Environment (CSE)

2.12 Energy Consumption of UTeM Library

Table 2.7: Energy consumption record for Aug 2014-July 2015 of UTeM library.

Month	**kWh**
Aug-14	98,820
Sep-14	109,760
Oct-14	122,140
Nov-14	116,200
Dec-14	109,280
Jan-15	97,100
Feb-15	90,730
Mar-15	126,550
Apr-15	132,300
May-15	129,400
Jun-15	111,080
Jul-15	130,750
Total	1,374,110
Max	132,300
Min	90,730
Average	114,50

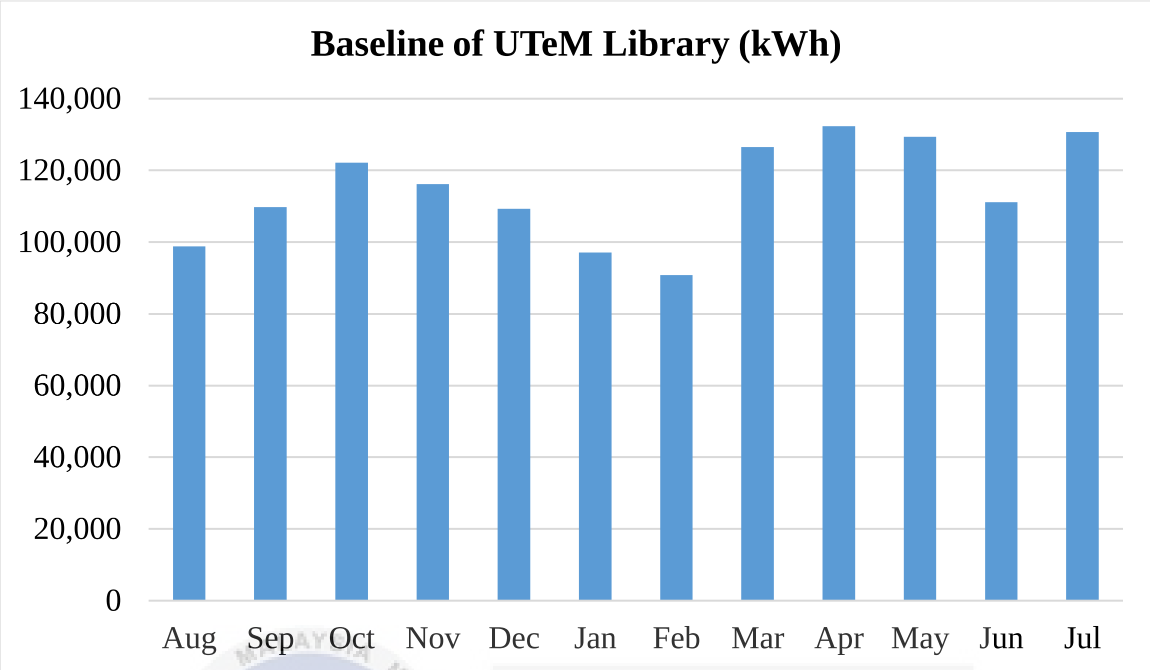

Figure 2.10 : Energy consumption (Aug 2014-July 2015) of UTeM library

(Source : Energy Audit report library UTeM)

Table 2.8 : Energy consumption record (July 2014-June 2015) of overall UTeM.

Month	kWh
Jul-14	1,306,621.00
Aug-14	1,327,291.00
Sep-14	1,640,025.00
Oct-14	1,617,286.00
Nov-14	1,561,161.00
Dec-14	1,703,293.00
Jan-15	1,434,815.00
Feb-15	1,155,469.00
Mar-15	1,512,537.00

Apr-15	1,614,452.00
May-15	1,511,777.00
Jun-15	1,456,892.00
Total	17,841,619.00
Max	1,703,293.00
Min	1,155,469.00
Average	1,486,801.58

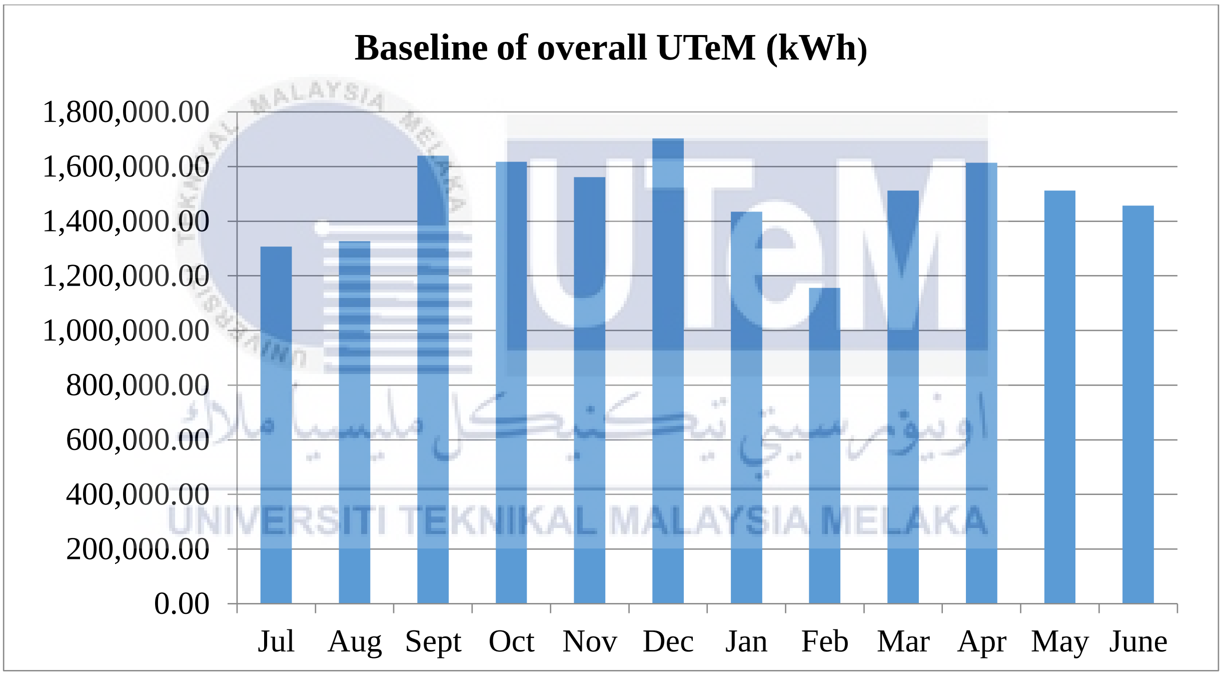

Figure 2.11: Energy consumption baseline (July 2014-June 2015) of overall UTeM.

(Source : Laporan Pengurusan Tenaga Pusat Kelestarian dan Alam Sekitar UTeM)

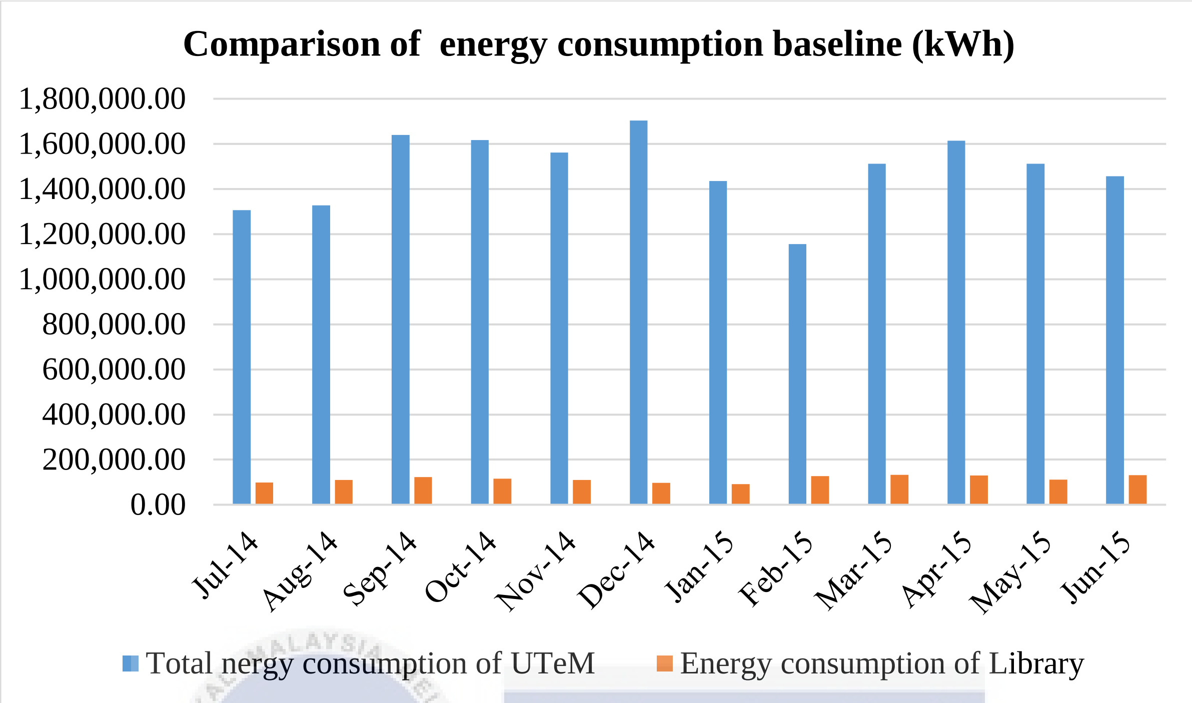

Figure 2.12: Comparison of energy consumption baseline (July 2014-June 2015)

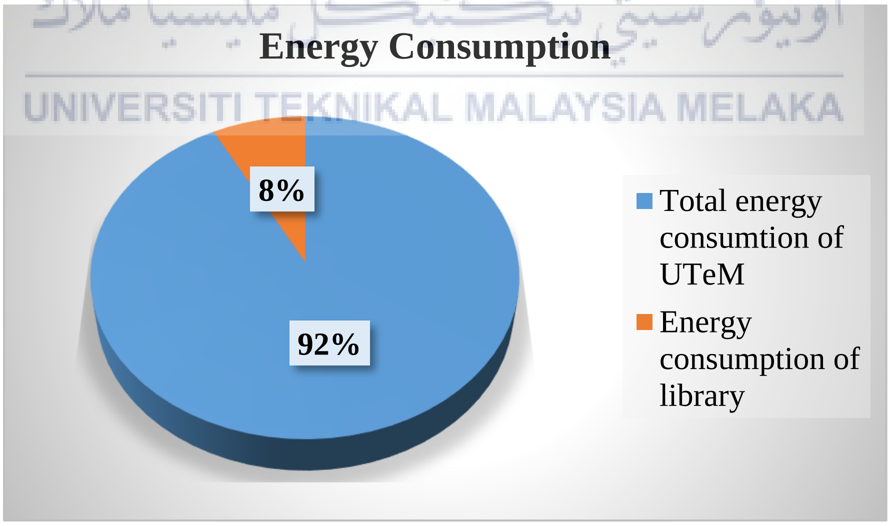

Figure 2.13: Energy consumption baseline (July 2014-June 2015) of overall.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses about the equipment and materials used in this thesis to obtain COP and power consumption of Laman Hikmah of UTeM. During the measurements to calculate the COP, all the temperatures, flowrate, and power consumption was recorded at the same time by connecting to the data power logger port in parallel. A probe sensor which was attached to the Dual Probe Temperature Data Logger, ultrasonic flow meter and power control unit will probe the interaction between a sample and the sensing materials in order to quantify the data. The data logger measures in a continuous stream mode until it is stopped by the user. Throughout measurement, each time new samples are recorded, they are transferred directly to the desktop software where they are processed and displayed, and also stored on disk if desired. However, the energy consumption data are gathered via available IoT energy management tools.

3.2 Project Flowchart

The project flowchart is the story or the flow of the project from the beginning until the end of the project. The figure 3.1 below shows the flowchart of this project.

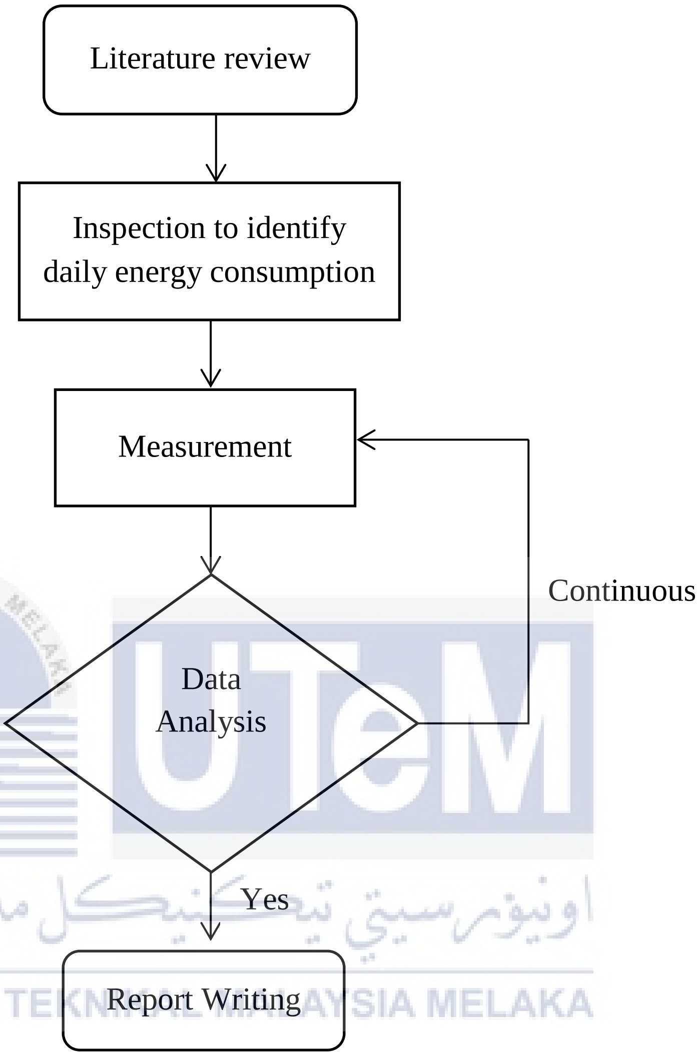

Figure 3.1 : The flowchart of the project.

3.3 Internet of Things (IoT) energy management.

Before the existence of IoT energy management, all electrical energy consumption data are recorded using manual data collection. Usually, the electrical energy consumption is gathered monthly from the Main Switch Board and Distribution Board energy meter and sub-meter. As for this project, the energy consumption data are gathered via available IoT energy management tools and compared with the manually gathered and also with the projected baseline data. Figure 3.2 shows the identical IoT energy management system framework used for this project. Figure 3.3 shows the equipment of IoT energy management system.

Buildings are key players when looking at end-use energy demand. It is for this reason that during the last few years, the Internet of Things (IoT) has been considered as a tool that could bring great opportunities for energy reduction via the accurate monitoring and control of a large variety of energy-related agents in buildings.

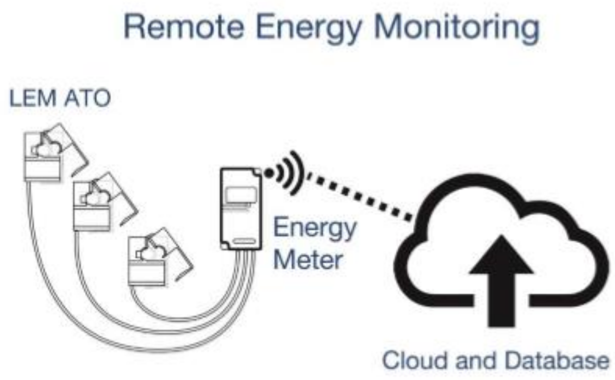

Figure 3.2: An identical IoT energy management framework.

(Source: LEM BLOG, 2018)

Figure 3.3: Smart Energy Meter and SEMonS wireless IoT module.

Table 3.1 : The IP Adress of Laman Hikmah UTeM

IP Address	Location	Connection	Remote Desktop IP Adress (anydesk)	Notes
10.8.5.100	Laman Hikmah	cable	644399591	Use UTeM wifi

UTeM library IoT of taking the data is through online in the website named ‘Emoncms’ only by using Utem wifi. By entering the IP address in the website of ‘Emoncms’-site home, can obtain list of energy consumption data of every 30 minutes which was recorded by Smart Energy Meter and SEMonS wireless IoT module. By enter Energy Meter Reading, kWh and Demand, kW into formulated IoT energy analysis raw table template for every month, can get Energy Meter Reading in kWh , Daily Consumption in kWh , Daily Maximum Demand in kW , Daily Energy Cost , Daily Average Max Demand Cost, Total Daily Cost in RM (Daily Energy Cost b + Max Demand Cost) and Cummulative Cost in RM.

Day	Date	Energy Meter Reading, kWh	Daily Consumption, kWh	Daily Maximum Demand, kW	Daily Energy Cost, RM (kWh x 0.365)	Daily Average Max Demand Cost, RM ((Max Demand x 30.3)/Day per month)	Total Daily Cost, RM (Daily Energy Cost + Max Demand Cost)	Cummulative Cost, RM		Date and Time	Demand, kW

Figure 3.4 : Raw table of IoT energy analysis

3.4 Power Energy Data Logger

The Power Energy Logger is designed to calculate, record and analyze the values of power (W, var, VA) and energy (kWh, kvarh, kVAh) values. Via its voltage inputs up to 1000 V, this standalone instrument is fitted with a self-powering system. It provides 5 voltage inputs and 4 current inputs. It is compatible with a range of current sensors to make it easier to use, and also automatically recognizes the sensors. Similar model is PEL 105 Power Energy Logger is easy to use with an all-terrain IP67 enclosure which can withstand shocks, UV rays and extreme temperatures. The PEL 105 logger can also be mounted directly at the top of an electricity pole, as a fixed equipment. Power loggers built on the different power supplies support to measure the relative value of each line on overall consumption; identifies the load profile for the installation and thus determines the improvement measures that could be take without interrupting the service.

The benefit of data power logger is to identify the energy, quality and waste at your plant, to ensure service reliability, report occasional voltage issues, detecting and avoiding power issues until they become unsustainable, simultaneously recording pattern, dynamic, event and harmonic data – saves time in identifying trouble areas, assist with the accurate capture of power and energy data needed to sustain optimum efficiency and reliability, data view at software included to allow easy analysis and reporting, real time display provides analytical capability on site, with one button access, all main measurement functions are available-removing ambiguity and error.

All the temperatures, flowrate, and power consumption was recorded at the same time by connecting to the data power logger in parallel. A probe sensor which was attached to the thermocouple, Dual Probe Temperature Data Logger, ultrasonic flow meter and power control unit will probe the interaction between a sample and the sensing materials in order to quantify the data. The data logger measures in a continuous stream mode until it is stopped by the user. Throughout calculation, each time new samples are recorded, they are transferred directly to the desktop software where they are processed and displayed, and also stored on disk if desired. An input signal shift is immediately noticeable. The measurement time in the device is not limited by the amount of memory which provides for very lengthy measurements.

Figure 3.5 : Power Energy Data Logger

3.5 Dual Probe Temperature Data Logger

Temperature data logger with 2 sensors (2 measuring point). The Dual Temperature Probe Logger allows the user to assess 2 data points with one single logger. With 2 probes, this data logger is suitable either for collecting data from a product within a process or for collecting data from two different product areas. Such interface offers the user a great deal of versatility, as well as a lot of details that a single probe logger cannot provide. 1 probe was used to measure the Chill water supply (CHWS) temperature which is temperature in and another probe is used to measure Chill water return (CHWR) temperature which is the temperature out of the chillers.

Figure 3.6 : Dual Temperature Probe Logger

3.6 Ultrasonic Flowmeter

Ultrasonic flowmeters utilize sound waves to determine the velocity of fluid flowing through a pipe. The frequencies of an ultrasonic wave emitted through a pipe and its fluid reflections are the same under no flow conditions. Because of the Doppler effect the frequency of the reflected wave is variable under flowing conditions. The frequency shift increases linearly as the fluid flows faster. The transmitter measures the signals and their reflections from the transmitted wave to determine the flow rate.

Figure 3.7 : Ultrasonic flowmeter

3.7 Calculation of Coefficient of Performance (COP)

In general, the thermal efficiency, η_{th}, of any heat engine as the ratio of the work it does, *W*, to the heat input at the high temperature, Q_H.

$$\eta_{th} = \frac{W}{Q_H} \qquad \text{(Eq 3.1)}$$

The thermal efficiency, η_{th}, represents the fraction of heat, Q_H, that is converted to work as shown in Equation 3.1.

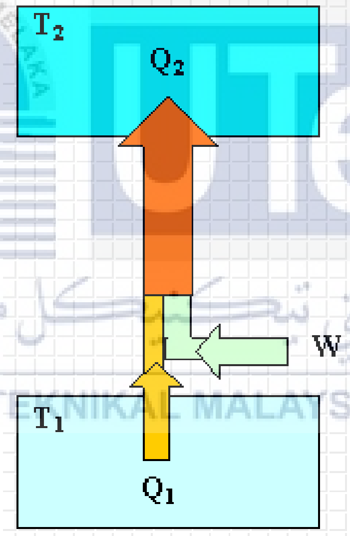

Figure 3.8 : Air Conditioner basic principle of operation

For an air conditioning system, thermal efficiency indicates the extent to which the energy added by work is converted to net heat output. The best air conditioning system is one that removes the greatest amount of heat for the least expenditure of mechanical work or electric energy. The relevant ratio is therefore the larger this ratio, the better the performance of air conditioner. This ratio is the coefficient of performance, denoted by COP. The coefficient of performance, COP, of an air conditioner is defined as the heat removed divided by the work done W to remove the heat.

$$COP = \frac{Q_{cold}}{W} \qquad \text{(Eq 3.2)}$$

As can be seen in equation 3.2, the better (more efficient) the air conditioner is when more heat Q_{cold} can be removed from the inside of the air conditioner for a given amount of work. Since the first law of thermodynamics must be valid also in this case (Q_{cold} + W = Q_{hot}), we can rewrite the above equation:

$$COP = \frac{Q_{cold}}{W} = \frac{Q_{cold}}{Q_{hot} - Q_{cold}} \qquad \text{(Eq 3.3)}$$

$$COP = \frac{T_{cold}}{T_{hot} - T_{cold}} \qquad \text{(Eq 3.4)}$$

$$\text{AC Heat Rejection (kW)} = 4.18\ \frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C \qquad \text{(Eq 3.5)}$$

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}} \qquad \text{(Eq 3.6)}$$

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter will discuss the result and analysis in correlation with the methodology which has been discussed in chapter 3. It will cover UTeM Laman Hikmah's Coefficient of Performance (COP) in relation with the energy usage (IoT Electrical Energy Consumption). One of the most important analysis in this chapter is cooling load, consumed by the chillers which have an effect on COP and also energy consumption.

4.2 Analysis on IoT Electrical Energy Consumption Profile

In an order to conduct the energy consumption analysis, duty center or building electrical energy consumption data is needed which is gathered by the newly installed SEMonS IoT energy data module. All data is then downloaded from Emoncms.org which is the service provider for the installation company. The downloaded data comes in ".csv" file format which must be further converted into ".xlsx" file format in order to conduct the analysis process. The data is then visualized into graphical form using Microsoft Excel to make the analysis process easier. To carry out this analysis specific 1 week was selected which is from 22 August 2019 until 28 August 2019. So, during that 1 week duration measurements of temperature supply and return, flowrate, power consumption was take to analyse the cooling load and also coefficient of performance.

Table 4.1 : Energy Meter Reading in kWh for 1 week.

Day	Date	Energy Meter Reading, kWh
Thursday	22-08-19 0:00	4,874.87
Friday	23-08-19 0:00	3,827.75
Saturday	24-08-19 0:00	1,300.13
Sunday	25-08-19 0:00	842.00
Monday	26-08-19 0:00	3,733.00
Tuesday	27-08-19 0:00	3,841.87
Wednesday	28-08-19 0:00	3,440.25

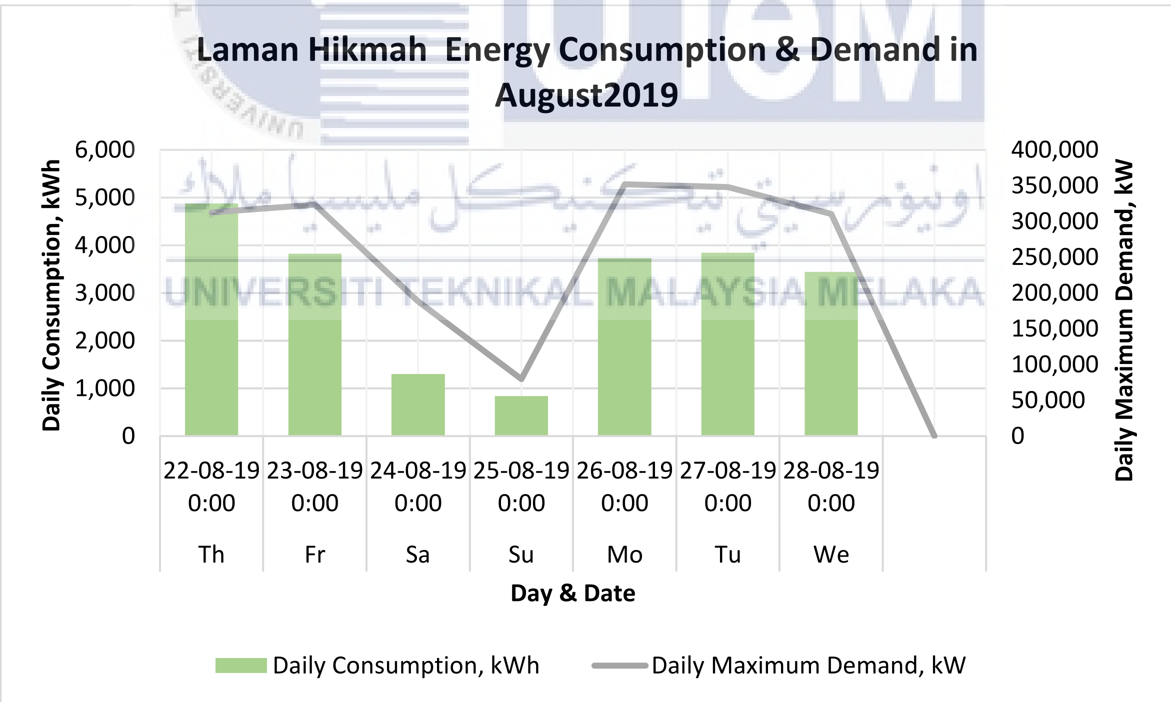

Figure 4.1 : Energy Meter Reading in kWh for 1 week.

Based on figure 4.1, it shows that the daily consumption, kWh and daily maximum demand, kW in Saturday and Sunday is less compare to other days. This is because less people during weekend so less power consumption.

Table 4.2 : Chiller operation timing for 1 week.

DATE	DAY	TIME	CHILLER OPERATION	
			CH#1	CH#2
22-08-19	Thu	0:00	ON	OFF
22-08-19	Thu	7:30	ON	ON
22-08-19	Thu	17:10	OFF	ON
22-08-19	Thu	21:50	OFF	OFF
23-08-19	Fri	7:30	OFF	ON
23-08-19	Fri	8:50	ON	ON
23-08-19	Fri	17:20	OFF	ON
23-08-19	Fri	21:50	OFF	OFF
24-08-19	Sat	10:10	OFF	ON
24-08-19	Sat	22:00	OFF	OFF
25-08-19	Sun	9:50	OFF	ON
25-08-19	Sun	22:00	OFF	OFF
26-08-19	Mon	7:40	ON	ON
26-08-19	Mon	17:20	OFF	ON
26-08-19	Mon	21:50	OFF	OFF
27-08-19	Tue	7:30	OFF	ON
27-08-19	Tue	8:00	ON	ON
27-08-19	Tue	18:00	OFF	ON
27-08-19	Tue	21:50	OFF	OFF
28-08-19	Wed	7:30	OFF	ON
28-08-19	Wed	8:20	ON	ON
28-08-19	Wed	17:10	OFF	ON
28-08-19	Wed	21:50	OFF	OFF

Building chillers are the single largest component of energy use in most institutional, commercial, and facilities. For certain installations, the building chillers can be related to more than 50% of the annual electricity consumption. The effective operation and maintenance of the building chillers should therefore be a high priority in any energy management plan for the plant.

To calculate the cooling load and coefficient of performance (COP), 1 week measurements and monitoring was done started on 22 August 2019 until 28 August 2019. The measurements which was taken is Temperature supply (Tin), Temperature return (Tout), Flowrate and also Power consumption.

4.3 Measurement of Temperature Supply and Return

The evaporator of the chiller is where the “chilled water” is generated. The “chilled water” leaves the evaporator is called temperature supply (Tin) and is pushed around the building by the chilled water pump. The cooled water flows in pipes known as "risers" up the height of the building to each floor. The chilled water branches off the risers into smaller diameter pipes which head to the Air Handling Units (AHU’s) to provide air conditioning. The temperature was measured using portable temperature meter. Figure 4.3 shows the temperature supply of chillers for 1 week from 22 August 2019 until 28 August 2019.

Table 4.3 : Temperature supply (Tin) of chiller.

	22.08.19 Thu	23.08.19 Fri	24.08.19 Sat	25.08.19 Sun	26.08.19 Mon	27.08.19 Tue	28.08.19 Wed
12:00:00 AM	6.7	16.0	15.7	9.7	8.6	18.1	10.9
1:00:00 AM	6.0	16.5	16.5	10.7	9.4	18.6	11.6
2:00:00 AM	6.0	17.0	17.1	11.8	10.5	19.3	12.2
3:00:00 AM	5.7	17.6	17.6	12.2	11.5	19.7	12.9
4:00:00 AM	5.7	18.1	17.8	13.1	12.0	20.1	13.7
5:00:00 AM	5.7	18.3	18.5	13.6	12.6	20.5	14.0
6:00:00 AM	5.7	18.8	18.8	14.3	13.5	20.5	14.9

7:00:00 AM	5.7	19.1	19.0	14.9	13.8	20.9	15.1
8:00:00 AM	7.4	11.9	19.4	15.2	10.6	18.4	6.3
9:00:00 AM	7.2	6.6	19.5	15.5	8.2	6.8	6.1
10:00:00 AM	6.8	7.6	12.5	7.5	7.0	7.4	6.4
11:00:00 AM	6.7	7.1	6.2	5.9	6.6	6.2	7.3
12:00:00 PM	7.0	6.7	6.1	6.0	7.5	7.7	7.3
1:00:00 PM	7.5	6.5	7.8	8.2	6.4	7.7	6.4
2:00:00 PM	6.6	6.4	7.0	6.3	6.7	6.8	6.2
3:00:00 PM	6.4	6.6	6.1	6.3	6.4	7.2	7.6
4:00:00 PM	6.6	6.6	6.1	6.7	6.5	6.6	6.7
5:00:00 PM	7.4	7.6	8.3	8.7	7.7	6.5	7.0
6:00:00 PM	9.7	9.5	6.8	6.1	11.7	6.0	9.7
7:00:00 PM	9.7	9.7	6.3	6.1	12.6	6.2	10.0
8:00:00 PM	9.6	9.5	6.6	7.3	12.7	6.2	10.0
9:00:00 PM	9.6	9.4	8.6	9.2	12.9	6.3	9.8
10:00:00 PM	15.2	15.1	9.1	8.4	17.4	9.6	15.4
11:00:00 PM	15.3	15.2	8.9	7.8	17.5	10.0	15.5

Based on figure 4.2, it is clearly noticed that, during peak hours, 10am until 5 pm, the the temperature supply is in low which means more cooled air was experienced by the occupants compare to other time.

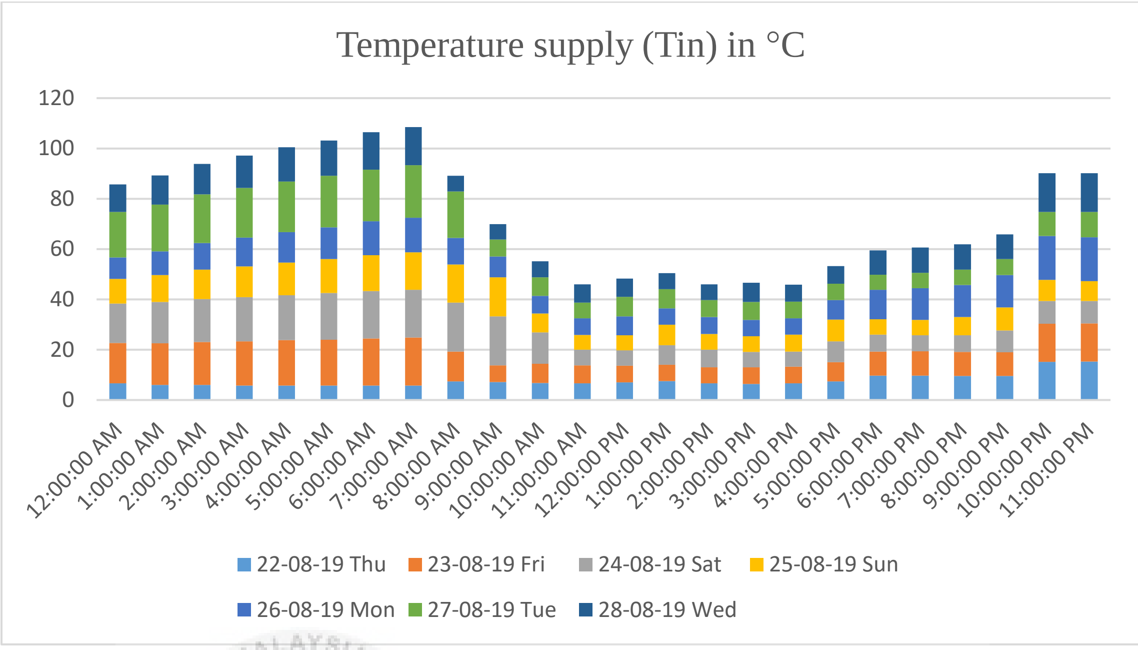

Figure 4.2 : Temperature supply (Tin) of chiller in °C.

When the chilled water leaves the cooling coil it will now be warmer and this is the temperature return (Tout). Then the warm chilled water returns via the return riser to the evaporator and once it enters the evaporator a refrigerant will absorb the unwanted heat and move it to the condenser. The cooled water then leaves the building cool again, ready to circulate around and absorb more unwanted heat.

Table 4.4 : Temperature return (Tout) of chiller.

	22.08.19 Thu	23.08.19 Fri	24.08.19 Sat	25.08.19 Sun	26.08.19 Mon	27.08.19 Tue	28.08.19 Wed
12:00:00 AM	7.3	15.4	15.4	8.9	8.8	17.7	10.4
1:00:00 AM	6.6	16.0	15.9	9.7	9.8	18.2	10.7
2:00:00 AM	6.6	16.5	16.3	10.5	10.8	18.6	11.2
3:00:00 AM	6.2	17.0	16.9	11.1	11.5	18.9	12.2
4:00:00 AM	6.2	17.5	17.2	11.9	12.2	19.3	12.7

5:00:00 AM	6.1	17.8	17.8	12.3	12.7	19.8	13.4
6:00:00 AM	6.0	18.4	18.2	13.2	13.3	20.2	14.1
7:00:00 AM	6.0	18.7	18.6	13.6	13.8	20.5	14.7
8:00:00 AM	11.6	15.8	19.0	14.4	15.4	19.1	7.8
9:00:00 AM	10.5	11.9	19.3	14.9	12.7	11.8	7.4
10:00:00 AM	10.6	10.9	16.4	11.1	11.8	10.9	11.0
11:00:00 AM	10.6	10.2	7.1	6.6	11.5	11.0	10.4
12:00:00 PM	10.4	10.2	7.0	6.4	11.1	11.3	10.4
1:00:00 PM	10.7	10.1	8.6	8.6	10.7	11.3	11.1
2:00:00 PM	10.7	10.1	7.8	6.7	10.7	11.1	10.9
3:00:00 PM	10.6	10.1	6.9	6.7	10.5	10.3	10.9
4:00:00 PM	10.6	10.2	6.9	7.2	10.6	7.8	10.7
5:00:00 PM	10.7	10.9	9.1	9.2	11.3	7.7	10.8
6:00:00 PM	13.4	13.2	7.5	6.5	15.1	6.3	13.6
7:00:00 PM	13.4	13.5	7.0	6.5	16.0	7.4	13.8
8:00:00 PM	13.3	13.2	7.4	7.7	16.1	7.4	13.8
9:00:00 PM	13.3	13.1	9.1	9.8	16.2	7.2	13.6
10:00:00 PM	14.3	14.3	7.7	7.6	16.7	8.6	14.6
11:00:00 PM	15.0	14.9	8.0	7.9	17.2	9.5	15.1

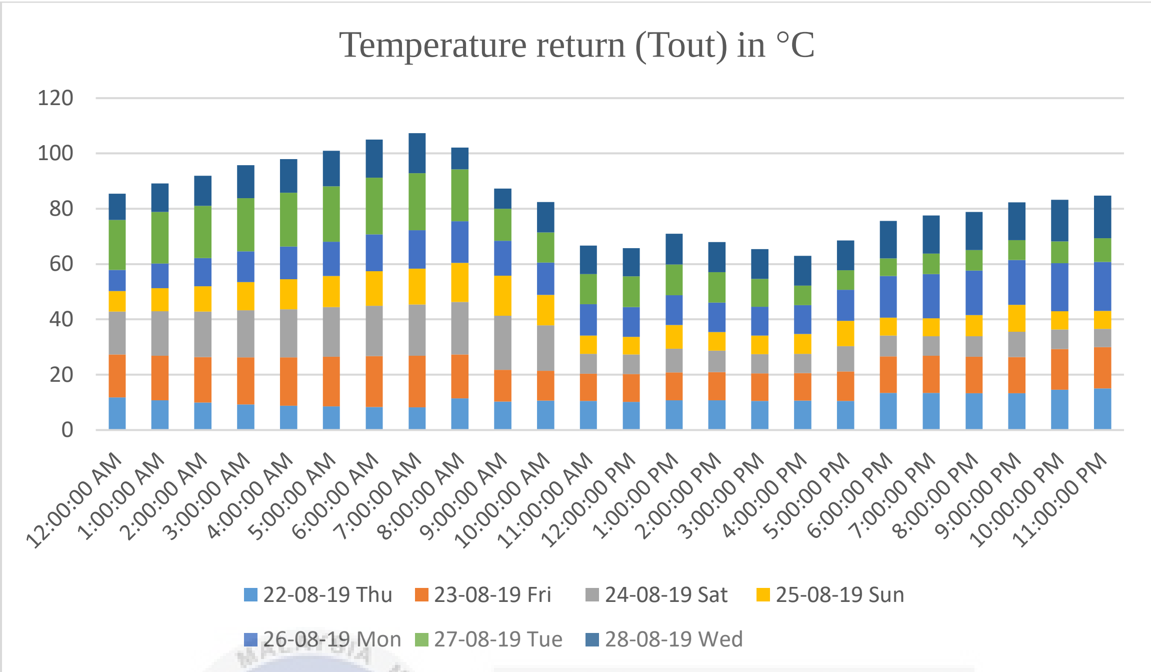

Figure 4.3 : Temperature return (Tout) of chiller

Based on figure 4.3, it is noticed that, the temperature return of the chillers is always higher compare to the temperature supply. This significantly shows that the chiller in a good condition as majority of the time the system able to absorb enough heat from the space.

4.4 Measurement of flowrate

Cooling water flows into a chiller, trapping heat by spindles or fins. The faster the water flows through the chiller, the quicker the heat is transferred by the chiller. The minimum flow rate of the chiller is the flow rate which produces a desired cooling rate if the device operates at 100 percent efficiency. In fact, without an even higher flow rate, the water will typically not cool at that rate as it absorbs and releases additional heat from unforeseen chiller regions. The measurement was taken using ultrasonic flow meter.

Table 4.5 : Flowrate in m³/hr of chillers

	22.08.19 Thu	23.08.19 Fri	24.08.19 Sat	25.08.19 Sun	26.08.19 Mon	27.08.19 Tue	28.08.19 Wed
12:00 AM	72.19	0	0	0	0	0	0
1:00:00 AM	72.4	0	0	0	0	0	0
2:00:00 AM	71.35	0	0	0	0	0	0
3:00:00 AM	72.01	0	0	0	0	0	0
4:00:00 AM	71.87	0	0	0	0	0	0
5:00:00 AM	71.62	0	0	0	0	0	0
6:00:00 AM	72.13	0	0	0	0	0	0
7:00:00 AM	72.7	0	0	0	0	0	0
8:00:00 AM	114.29	71.88	0	0	138.61	130.67	71.6
9:00:00 AM	111.66	119.1	0	0	137.21	129.01	107.53
10:00:00 AM	111.89	114.14	76.96	75.6	134.38	120.75	115.09
11:00:00 AM	108.58	122.58	74.82	75.18	126.03	119.65	118.89
12:00:00 PM	120.59	117.25	74.9	74.98	124.45	114.98	113.03
1:00:00 PM	110.57	111.57	74.56	74.75	123.83	116.07	112.74
2:00:00 PM	120	111.29	75.15	74.92	126.11	115.05	115.34
3:00:00 PM	110.82	111.3	75.29	74.91	124.25	116.36	116.79
4:00:00 PM	117.14	113.49	74.73	75.25	122.48	122.82	106.29
5:00:00 PM	116.78	119.35	75.02	74.53	122.71	110.9	124
6:00:00 PM	74.06	72.38	75.43	75.54	74.67	74.63	70.83
7:00:00 PM	72.92	73.43	74.64	74.99	74.93	75.05	70.86
8:00:00 PM	73.24	72.89	74.83	74.79	75.83	74.67	72.57

9:00:00 PM	72.65	73.26	74.51	74.93	74.26	68.48	71.31
10:00:00 PM	0	0	0	0	0	0	0
11:00:00 PM	0	0	0	0	0	0	0

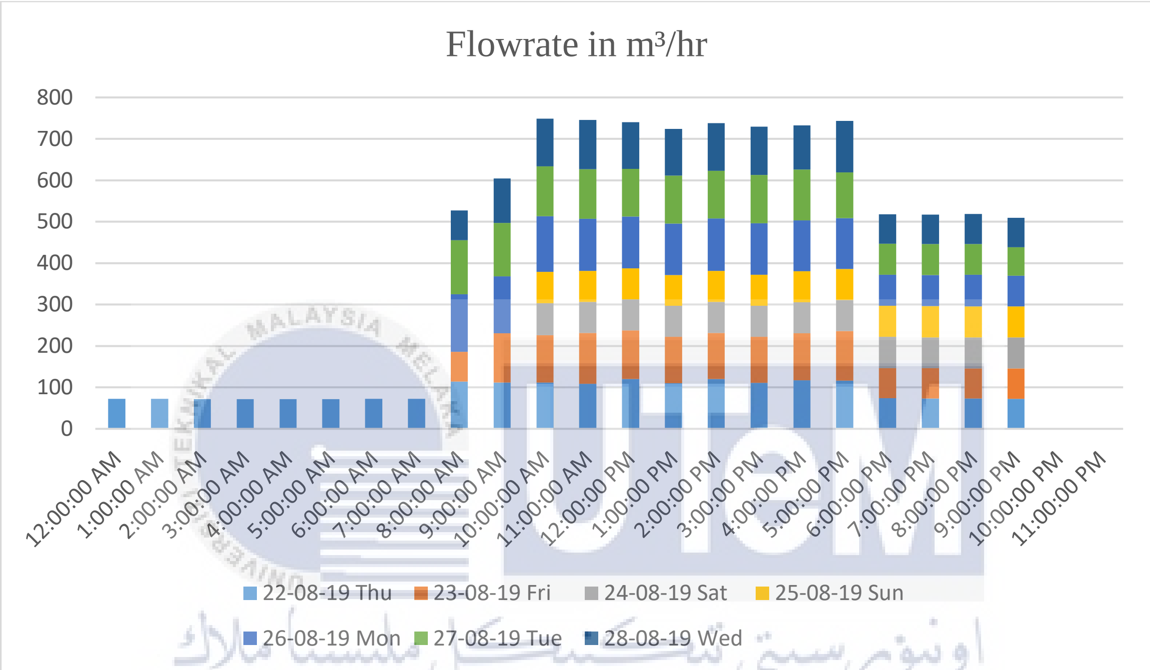

Figure 4.4 : Flowrate in m³/hr of chillers

Based on figure 4.4, it shows that basically there flowrate only starts at 8am onwards and being peak around 10am to 5pm. Due to weekend, the flowrate is less on Saturday and Sunday.

4.5 Measurement of Power Consumption

With smart meters, average power (kW) data is readily accessible from the local utility provider in intervals of 15-minute readings. In addition, a data power logger was temporarily installed on the facility's main panel to track usage.

Table 4.6 : Power consumed in kW of chillers

	22.08.19 Thu	23.08.19 Fri	24.08.19 Sat	25.08.19 Sun	26.08.19 Mon	27.08.19 Tue	28.08.19 Wed
12:00:00 AM	61729	0	0	0	0	0	0
1:00:00 AM	61137	0	0	0	0	0	0
2:00:00 AM	61005	0	0	0	0	0	0
3:00:00 AM	61118	0	0	0	0	0	0
4:00:00 AM	61294	0	0	0	0	0	0
5:00:00 AM	61178	0	0	0	0	0	0
6:00:00 AM	60621	0	0	0	0	0	0
7:00:00 AM	60894	0	0	0	0	0	0
8:00:00 AM	208347	116215	0	0	238991	185566	69204
9:00:00 AM	177463	216960	0	0	238552	228244	113655
10:00:00 AM	184679	199726	92479	82278	233819	201319	204099
11:00:00 AM	184446	180664	61332	61760	225099	203572	196439
12:00:00 PM	183053	179482	29394	29915	213695	206281	183033
1:00:00 PM	189893	177736	29704	29465	204611	207644	197732
2:00:00 PM	190255	177720	70129	60978	201749	201783	198861

3:00:00 PM	189637	179614	37734	29993	197363	188276	195728
4:00:00 PM	191987	179774	29556	29498	193867	115010	192331
5:00:00 PM	198396	201039	29656	30054	209580	114716	193862
6:00:00 PM	115093	114018	61633	61381	122308	84586	113889
7:00:00 PM	115453	113582	29558	29380	122570	59895	114057
8:00:00 PM	115285	113653	29545	29880	122793	60044	113447
9:00:00 PM	115508	113773	29857	30069	123067	59451	113608
10:00:00 PM	0	0	32337	32961	0	0	0
11:00:00 PM	0	0	0	0	0	0	0

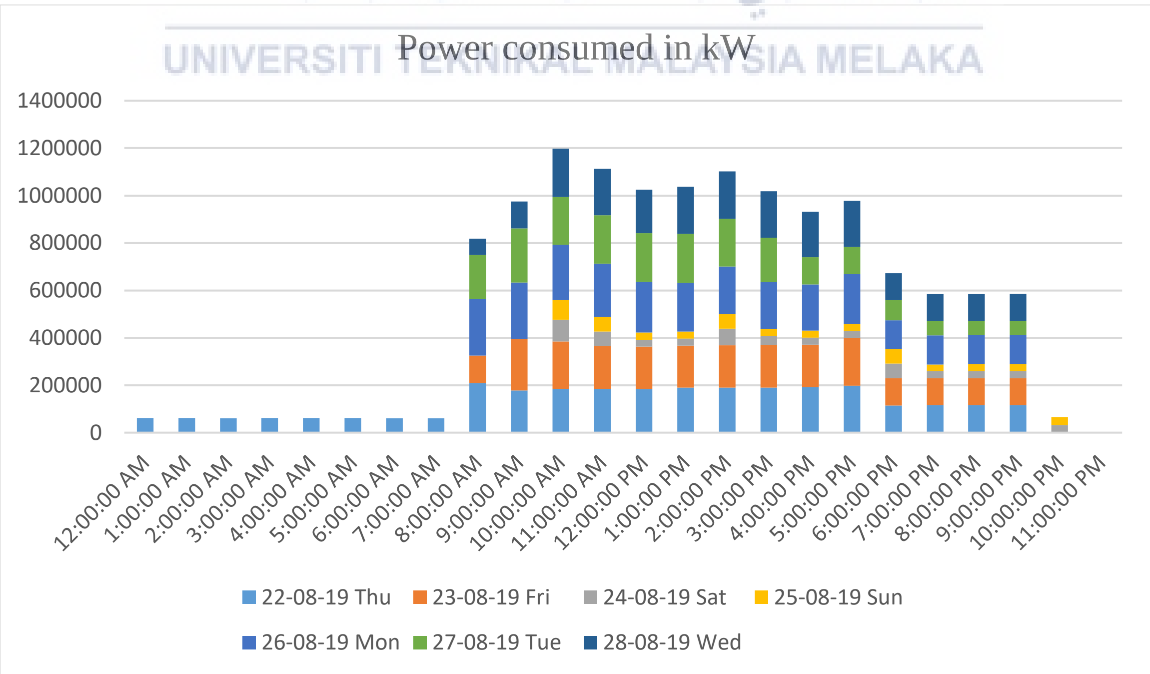

Figure 4.5 : Power consumed in kW of chillers

Based on figure 4.5, basically the power data was started 8am onwards. This also marked the least consumption on Saturday and Sunday due to weekend. The highest power consumption was on 10am.

4.6 Cooling Load

Chillers provide chilled water which is then used in the buildings to provide air conditioning. The amount of cooling they produce varies, and knowing how much cooling a chiller produces or is capable of producing is important. Firstly to perform this calculation we need to know a few things, the volume flow rate of water into the evaporator, the inlet and outlet chilled water temperature. The cooling load will be calculated using equation 4.6.1 then the coefficient of performance will be calculate using the equation 4.6.2 for each chiller.

$$\text{AC Heat Rejection (kW)} = 4.18\ \frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C \qquad \text{(Eq 4.1)}$$

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}} \qquad \text{(Eq 4.2)}$$

Table 4.7 : Cooling load in kW of chiller

	22.08.19 Thu	23.08.19 Fri	24.08.19 Sat	25.08.19 Sun	26.08.19 Mon	27.08.19 Tue	28.08.19 Wed
12:00:00 AM	8.382061	0	0	0	0	0	0
1:00:00 AM	8.406444	0	0	0	0	0	0
2:00:00 AM	8.284528	0	0	0	0	0	0

3:00:00 AM	8.361161	0	0	0	0	0	0
4:00:00 AM	8.344906	0	0	0	0	0	0
5:00:00 AM	8.315878	0	0	0	0	0	0
6:00:00 AM	8.375094	0	0	0	0	0	0
7:00:00 AM	8.441278	0	0	0	0	0	0
8:00:00 AM	597.1653	325.4966	0	0	675.9548	0	124.7033
9:00:00 AM	453.7738	636.1263	0	0	637.2642	713.0952	137.3397
10:00:00 AM	519.6669	556.6227	348.5005	316.008	655.3265	659.0978	574.6188
11:00:00 AM	516.9011	555.0831	78.1869	61.10463	643.8733	602.8779	565.9825
12:00:00 PM	602.0791	503.719	78.2705	34.82404	635.8012	587.420	472.4654
1:00:00 PM	487.8594	414.5445	69.25796	34.71722	603.8776	619.9428	615.2472
2:00:00 PM	599.1333	426.4262	69.806	34.79618	571.0681	547.7019	602.6515
3:00:00 PM	553.2996	465.234	69.93604	34.79153	577.0722	567.4489	569.5459
4:00:00 PM	571.2527	461.2108	69.41587	43.68681	568.8516	142.6077	543.0238
5:00:00 PM	596.616	595.888	69.68524	43.26881	598.4158	128.7672	619.1044
6:00:00 PM	318.17	310.9525	61.30783	35.08413	294.7806	25.99612	320.7419
7:00:00 PM	313.2724	323.9895	60.66573	34.82869	295.807	104.5697	312.6501

8:00:00 PM	314.6472	313.1435	69.50876	34.7358	299.36	104.0402	320.195
9:00:00 PM	312.1125	314.7331	43.25719	52.20123	284.5396	71.5616	314.6356
10:00:00 PM	0	0	0	0	0	0	0
11:00:00 PM	0	0	0	0	0	0	0

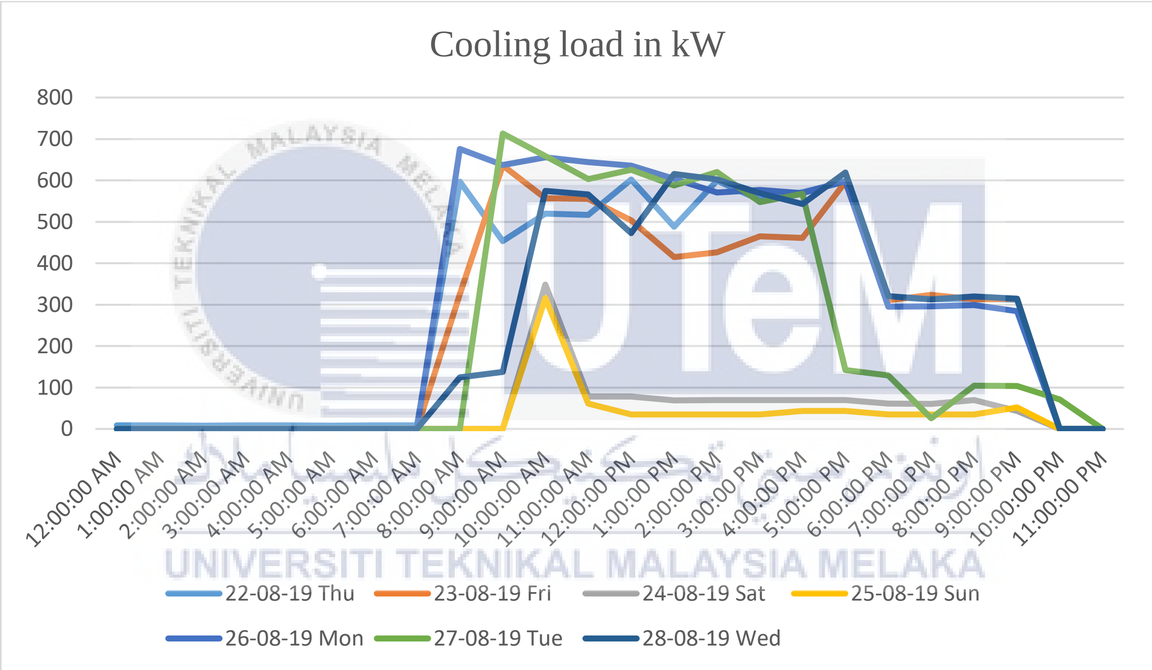

Figure 4.6 : Cooling load in kW of chiller

Based on figure 4.6, the cooling load shows highest data on weekdays and less data on Saturday and Sunday is only 9am to 11pm. Apparently, all cooling load is started to drop after 5pm onwards in each day which is after the working hours. The highest cooling load was mostly around 8am until 5pm.

4.7 Coefficient of Performance (COP)

The cooling efficiency of a chiller is expressed as its coefficient of performance (COP) or energy efficiency ratio (EER) which is the refrigeration capacity at full load (in watts)/electrical input power (in watts). The COP will be calculated using the equation below.

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}} \qquad \text{(Eq 4.3)}$$

Based on figure 4.7.1, Coefficient of performance (COP), chiller 1 shows a rapid increase and decrease tremendously. Apparently, the performance started to increase 8am onwards and end at 10pm.

Table 4.8 : Coefficient of performance (COP) of chiller

	22.08.19 Thu	23.08.19 Fri	24.08.19 Sat	25.08.19 Sun	26.08.19 Mon	27.08.19 Tue	28.08.19 Wed
12:00:00 AM	0.271576	0	0	0	0	0	0
1:00:00 AM	0.275003	0	0	0	0	0	0
2:00:00 AM	0.271602	0	0	0	0	0	0
3:00:00 AM	0.273612	0	0	0	0	0	0
4:00:00 AM	0.272291	0	0	0	0	0	0
5:00:00 AM	0.271858	0	0	0	0	0	0
6:00:00 AM	0.27631	0	0	0	0	0	0

7:00:00 AM	0.277245	0	0	0	0	0	0
8:00:00 AM	5.73241	5.601628	0	0	5.656738	7.685624	3.603882
9:00:00 AM	5.114011	5.8639964	0	0	5.34277	5.775404	2.416782
10:00:00 AM	5.627785	5.5738635	7.5369392	7.681377	5.605417	5.98928	5.630813
11:00:00 AM	5.604874	6.1449221	2.5496283	1.978745	5.720826	6.142016	5.762395
12:00:00 PM	6.578194	5.6130311	5.3257919	2.3282	5.950576	5.695311	5.162625
1:00:00 PM	5.138256	4.6647222	4.6630504	2.356426	5.90269	5.971208	6.223073
2:00:00 PM	6.298214	4.7988812	1.9908168	1.14127	5.661174	5.428623	6.061033
3:00:00 PM	5.835355	5.1803757	3.706792	2.319977	5.847826	6.027873	5.81974
4:00:00 PM	5.950952	5.1310347	4.6974026	2.962018	5.868472	2.479918	5.646763
5:00:00 PM	6.014396	5.9280544	4.6995714	2.905019	5.710619	2.244994	6.387063
6:00:00 PM	5.52892	5.4544462	1.9894481	1.143159	4.820299	0.614667	5.632534
7:00:00 PM	5.426886	5.7048938	4.1048605	2.370831	4.826744	3.491824	5.482396
8:00:00 PM	5.458644	5.5105195	4.7052805	2.32502	4.875848	3.465465	5.644838
9:00:00 PM	5.404217	5.5326501	2.897625	3.472096	4.624141	2.407455	5.538969
10:00:00 PM	0	0	0	0	0	0	0
11:00:00 PM	0	0	0	0	0	0	0

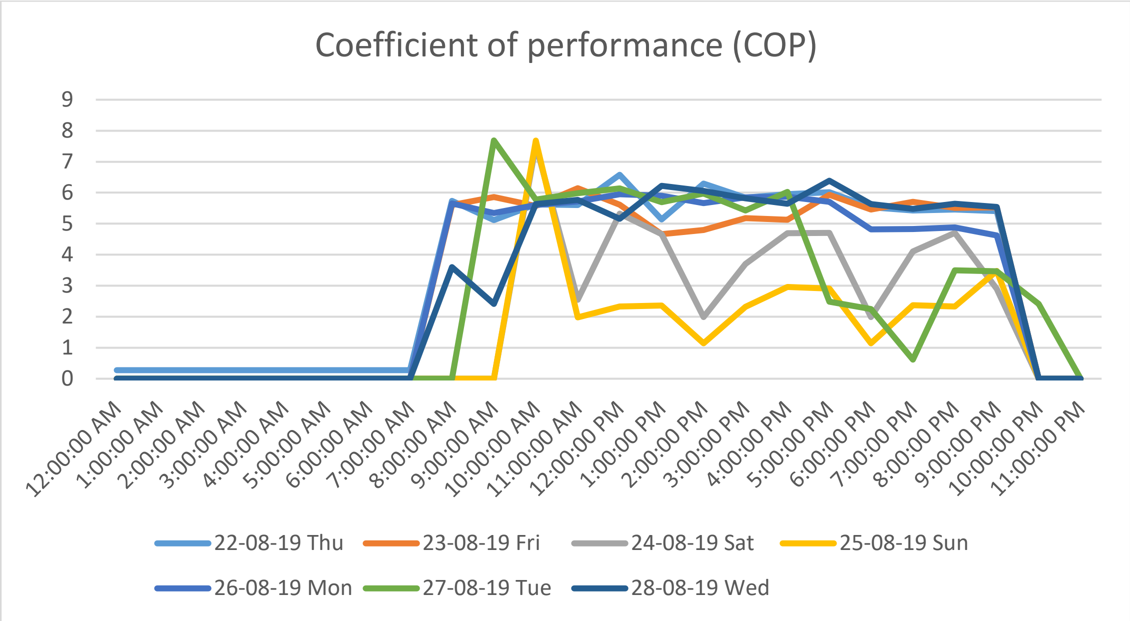

Figure 4.7 : Coefficient of performance (COP)

Based on figure 4.7 , Coefficient of performance (COP), chillers data shows a rapid increase and decrease tremendously. Apparently, the performance started to increase 8am onwards and end at 10pm. Approximately, majority of the time the chillers shows the COP range of 5 until 8 which is consider as excellent performance according to the ASHRAE table in figure 4.8. Except, on Saturday and Sunday which shows the range of 1 until 5. This is because, on weekend there is less occupant in the building in conjunction, air conditioner will be less in use. Moreover, according to the table 4.2, the operation hours of the chiller also not frequent as it only on once in a week. To sum up the COP data, it is concluded that the overall performance of the chiller is in excellent condition.

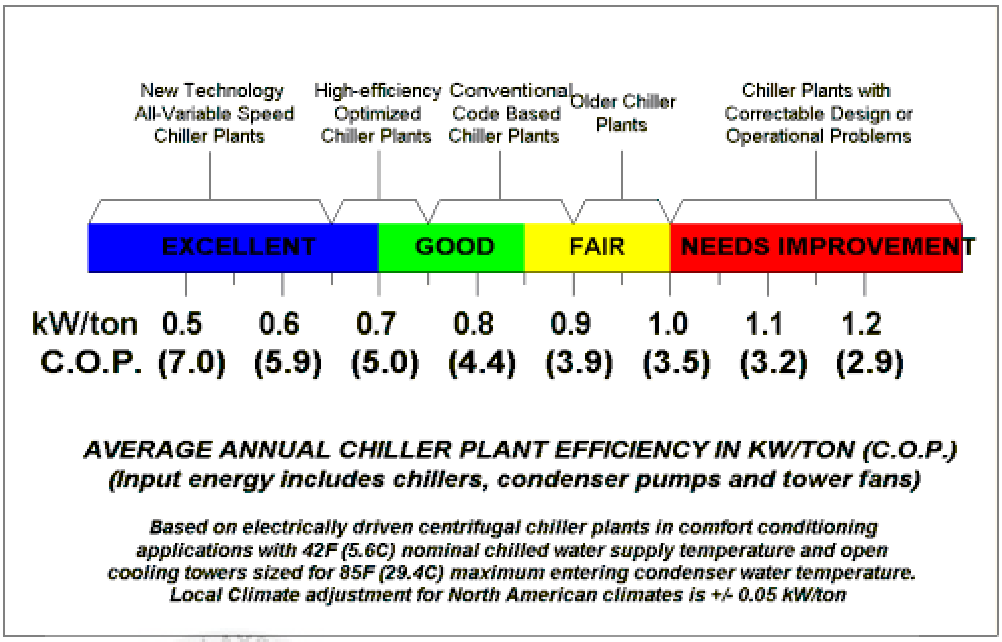

Figure 4.8 : Chiller plant performance indicator of ASHARE chart

Table 4.9 : Summary of chiller performance

Description	Flowrate (l/s)	CHWS (°C)	CHWR (°C)	Cooling Load (kWr)	Cooling Load (RT)	Power input (kWe)	Efficiency (COP)
Max	38.5	21.1	20.9	713.0952	202.77	238.991	7.685624
Min	19.02	5.5	6.0	8.284528	2.36	7.79	0.271576
Average	16.2	10.42064	11.8676	196.6713	55.92	77.08	4.339239

Based on the measured data for both chillers, the maximum flowrate of the chillers is 38*l/s*, the minimum flowrate of the chillers is 19.02*l/s* and the average flowrate is 16.2*l/s*. Then, the maximum chiller water supply temperature is 21.1°C, the minimum chiller water supply temperature is 5.5°C and the average chiller water supply temperature is 10.42°C. Next, the maximum chiller water return temperature is 20.9°C, the minimum chiller water return temperature is 6°C and the average chiller water return temperature is 11.86°C. After that, the cooling load was calculated. The maximum cooling load is 713kWr or 202RT, the minimum is 8.28kWr or 2.36RT and the average is 196.67kWr or 55.9RT. The maximum power input is 239kWe, minimum is 7.8kWe, average is 77.08kWe. Finally, the calculated COP shows the maximum value of 7.7, minimum of 0.27 and the average of 4.34.

According to the ASHRAE chart, the chillers is averagely in good condition since the average of COP is 4.34. This is because of the good operating practices which increase the chiller efficiency. Based on table 4.2, Chiller operation timing was taken for 1 week and it's shown that the operating system of the chillers is quiet frequent which gives the better coefficient of performance (COP). Except, on Saturday and Sunday which shows the range of 1 until 5. This is because, on weekend there is less occupant in the building in conjunction, air conditioner will be less in use. This good performance also obtain due to some other factors such as good energy management, good chiller maintenance practice, and operating hours by the authorities. Hence, it is now proven that this also leads to less electricity cost as well as gives convenient environment for the students in Laman Hikmah.

Table 4.10 : Comparison of COP with Power consumption

Day	COP	Power consumption by chiller (kW)	Overall power consumption (kW)
22.08.19 Thu	3.669618	117.62	4,874.87
23.08.19 Fri	5.551494	92.88	3,827.75
24.08.19 Sat	3.757736	21.11	1,300.13
25.08.19 Sun	2.289244	20.63	842.00
26.08.19 Mon	5.451079	109.38	3,733.00
27.08.19 Tue	4.39889	87.09	3,841.87
28.08.19 Wed	5.463612	91.39	3,440.25

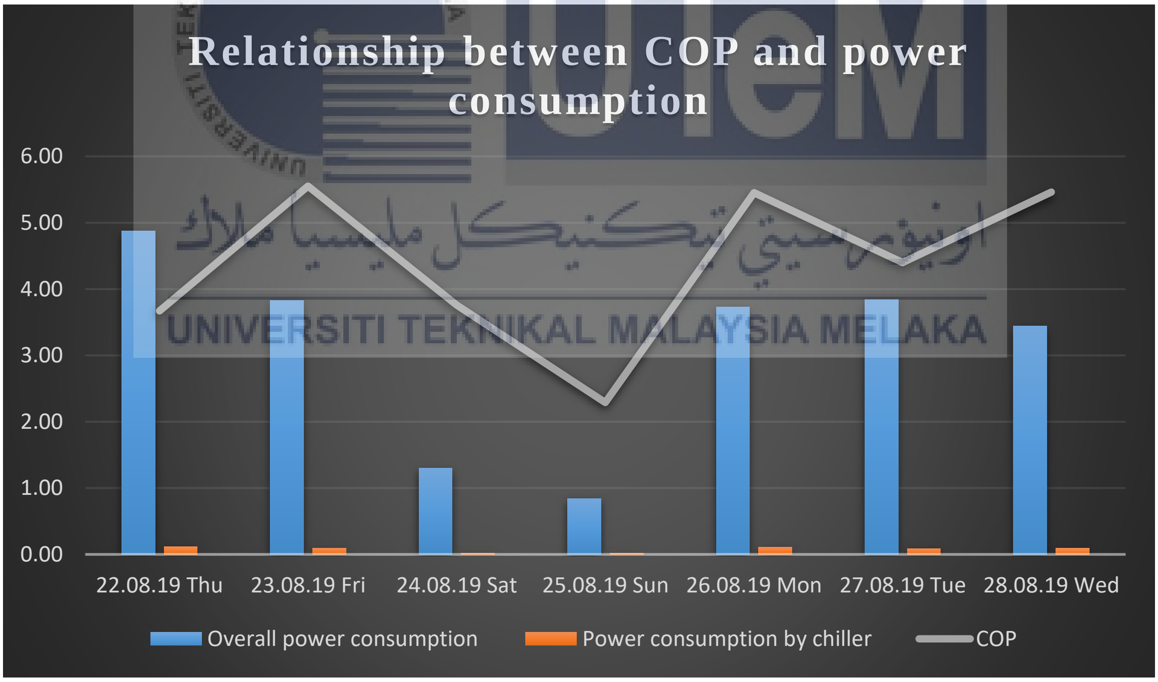

Figure 4.9 : Relationship between COP and power consumption

Based on figure 4.9, it was proven that, COP is being in a relation with energy consumption the building Laman Hikmah. It shows that, as the COP increases, the energy consumption will decrease. Hence, it is important to analyse the COP of any building.

4.8 Single Analysis

Figure 4.10 show the correlation between energy consumption which are considering variable factors such as Coefficient of Performance (COP) and Power consumtion. The single value of R2 is 0.3601 respectively.

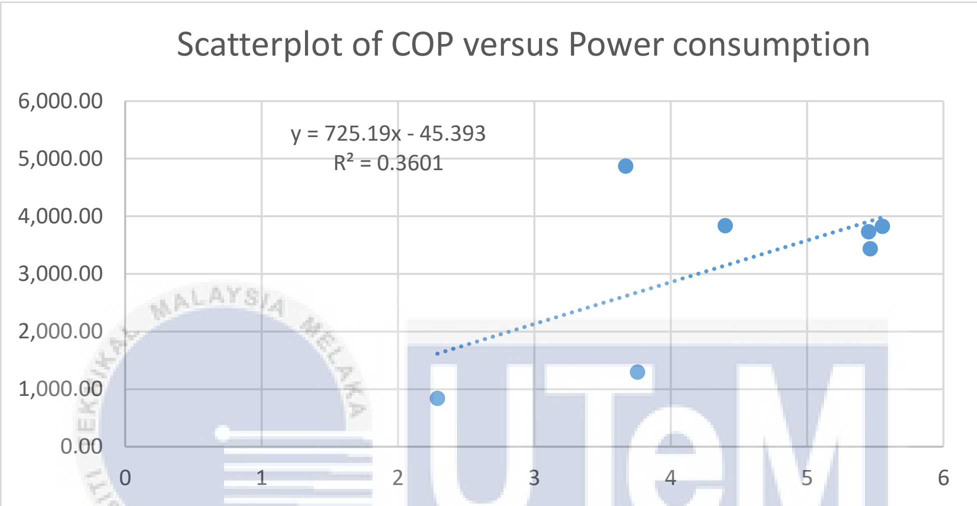

Figure 4.10 : Regression analysis of COP versus Power consumption

This scatterplot used for interpreting trends in statistical data of Coefficient of Performance (COP) versus power consumption of Laman Hikmah UTeM. Each observation (or point) in a scatterplot has two coordinates; the first corresponds to the COP of data in the pair. The second coordinate corresponds to the second piece power consumption of data in the pair. The point representing that observation is placed at the intersection of the two coordinates. The data show an uphill pattern as move from left to right, this indicates a positive relationship between COP and power consumption. A linear relationship between X (COP) and Y (Power consumption) exists because the pattern of X– and Y-values resembles a line, uphill (with a positive slope). The scatterplot show possible associations or relationships between two variables which is COP and power consumption. However, just because the graph shows something is going on, it doesn't mean that a cause-and-effect relationship exists. This graph is moderately strong, with a few potential outliers.

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.600066715
R Square	0.360080063
Adjusted R Square	0.232096075
Standard Error	1293.895681
Observations	7

ANOVA					
	df	***SS***	***MS***	***F***	***Significance F***
Regression	1	4710228.383	4710228.383	2.813477449	0.154319267
Residual	5	8370830.17	1674166.034		
Total	6	13081058.55			

	Coefficients	***Standard Error***	***t Stat***	***P-value***
Intercept	-45.39338033	1951.123887	-0.023265248	0.982338625
COP	725.1932771	432.346602	1.677342377	0.154319267

	Lower 95%	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	-5060.917002	4970.130241	-5060.917002	4970.130241
COP	-386.1890448	1836.575599	-386.1890448	1836.575599

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The efficiency coefficient is a number that defines the efficiency of air conditioners by comparing the heat absorbed from it to the work that had to be performed in order to do so. A better air conditioners will require fewer work to eliminate a given amount of heat, thus having a greater performance coefficient. COP or performance coefficient is the most essential energy-efficiency metric of any air conditioners. By definition, if we give it some energy input, COP is the ratio of how much useful cold an HVAC device will deliver. Basically, it tells us how much heat each watt can produce with every watt of energy we pay.

The first objective, to obtain the measurement of centralized and split unit Air-conditioning system's energy consumption at the building Laman Hikmah Library UTeM was achieved. The overall power consumption of the Laman Hikmah is gathered by the newly installed SEMonS IoT energy data module. All data is then downloaded from Emoncms.org which is the service provider for the installation company. The downloaded data comes in ".csv" file format which must be further converted into ".xlsx" file format in order to conduct the analysis process. The data is then visualized into graphical form using Microsoft Excel to make the analysis process easier. The load apportioning of the overall energy consumption will be included by the energy consumed by AHU load, Lighting, Chillers and others. Compare all the loads, chillers consume highest energy which is 50%. The power consumed by chillers was measured using data power logger. Whereby, during the 1 week of energy audit, the power logger will be connected to the main power supply. Thus, it will show the energy consumed by the chillers.

The second objective, to establish the relationship between the power consumption and coefficient of performance of Air conditioning at Laman Hikmah Library UTeM also achieved. Weekend, Saturday and Sunday has the least amount of power consumption and COP. Moreover, according to table 4.2, it's shown that the operation hours of the chiller also lesser compare to weekdays as only chiller 2 will be operated once in a day. Except the weekend, the weekdays, Monday to Friday significantly shows that the higher the COP, the lesser the power consumption. This also clearly shows that, as the COP increases, the cooling load (heat rejection) also increases and power consumption decreases. Hence, based on figure 4.9 and 4.10, this statement have been proven whereby, the highest power consumption by the chiller is 117.62kW with the lowest COP of 3.67, and the lowest power consumption by the chiller is 92.88kW with the highest COP of 5.55. So, there is a strong relationship between COP and energy consumption in Laman Hikmah UTeM and it's essential to perform energy audit and COP calculations in all the building in an order to find out the chiller performance. By calculating COP also we can identify the chiller performance according to the ASHRAE table and if it does not comply with the standard then we can figure out the counter measure action to improvise the chiller system. Moreover, based on figure 4.10, the regression analysis also shows the linear relationship between X (COP) and Y (Power consumption) exists because the pattern of X– and Y-values resembles a line, uphill (with a positive slope).

5.2 Recommendations

In a nutshell, now it's proven that coefficient of performance is being in a relation with energy consumption and playing a huge role in chiller's efficiency. According to ASHRAE table in figure 4.8, the COP must be 4.4. and above to get the good condition the 5 and above to get the excellent condition. So, it is necessary to make improvements in an order to increase the COP, decrease the power consumption, hence can decrease the electricity cost as well. COP also effect by other parameters such as temperature supply, temperature return, flowrate, and cooling load. So the improvements should be taken in all aspects in such a way of increasing the chiller's efficiency.

I. Replace the compressor with Compressor VFD retrofit

First and foremost, have to do modification at compressor. Generally, compressor allows low pressure refrigerant and compresses it to a high pressure. This is where the work is being done and what the electricity is used for. The compressor can be equipped with VFD's, variable frequency drives, enabling the chiller to operate effectively under component load conditions. It control speed of compressor, allows improved part load operation to suit actual load. However the efficiency at full load will be dropped due to inverter losses. For the majority of the year most chillers will run under partial load conditions so this is an appealing choice. Retrofitting a VFD could often result in energy savings of around 20%.

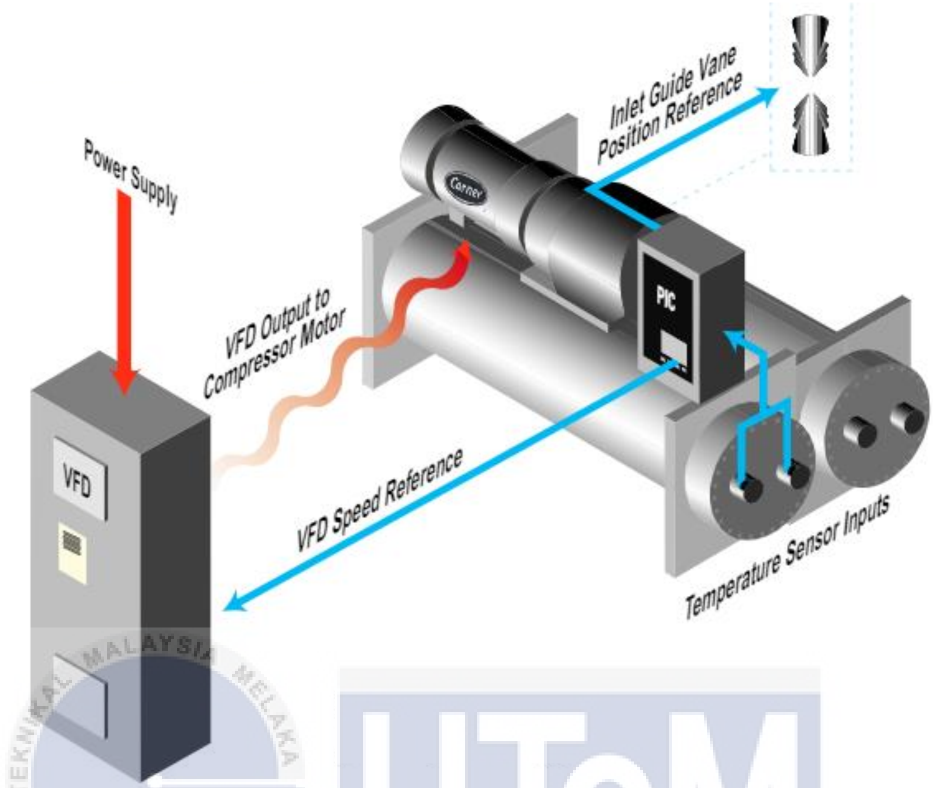

Figure 5.1 Compressor VFD retrofit

II. Cleaning the chiller

Each chiller is designed to have a certain amount of fouling, but over time biological growth, dust, foreign particles and internal rust particles will build up and line the surfaces of the pipes and heat exchangers causing the pumps to work harder but also decreasing the heat exchanger's ability to transfer thermal energy between the water and the coolant.

To sustain the system, proper water treatment should be carried out, can contact a local water treatment expert to evaluate the required chemicals and dosing intervals. Furthermore, the condenser and evaporator should be regularly physically washed. Water-cooled chillers are normally more energy-efficient than air-cooled chillers due to heat discharge at tower water. So, it is important to have a good maintenance and cleaning of the cooling tower.

The sum that we can save really relies on how much fouling the surfaces have built up. Cleaning heavily fouled chiller could lead to energy savings of up to 10% where 1-3% improvement will be seen as a lightly fouled chiller. That will depend on how much fouling is building up, and how long the chillers are going. Its best to keep a regular log of operating conditions and compare the overtime results, this will show when it is economical and isolate and clean the chiller.

III. Replace thermal expansion valve with an electronic expansion valve

The thermal expansion valve can be replaced by an electronic expansion valve that will provide much more stable superheat, particularly at low loads, and because it can respond to changes and monitor superheat with higher speed and precision because it is digital.

This does so by calculating the pressure as well as temperature at the evaporator outlet. The precision helps the condensing pressure to be minimized so that eventually the compressor doesn't have to work too hard. When replacing a thermal expansion valve with an electronic expansion valve, energy savings of about 14% can be achieved, although this varies with the chiller setting.

Table 5.1 : Criteria of Thermal expansion valve and Electronic expansion valve

Type	Criteria
Thermostatic Expansion Valve	• Low investment cost • Imprecise regulation • Limited accuracy for measuring overheating • More work required at lower ΔP when the condensation pressure is low.
Electronic Expansion Valve	• Extremely reliable • Optimizes overheating in the evaporator • Performs well at low ΔP when working at low condensing pressures • Improves compressor performance • Higher cost

IV. Chilled water reset

The temperature of the chilled water outlet has typically been adjusted, usually around 6 ° C somewhere but it is now routine trend to implement a chilled water reset strategy. During part load conditions, the chilled water reset allows the temperature of the chilled water to rise. This decreases the amount of work done by compressor chillers.

The increase of the temperature of the chilled water results in an increase of the refrigerant evaporator pressure. The compressor takes the refrigerant at the pressure of the evaporator and compresses it and raises the output of the condensers pressure, such that the higher the pressure of the evaporator the less work the compressor has to do to increase the pressure.

Chilled-water reset adjusts the setting point to boost chiller efficiency, decreased energy usage. Typically a chilled-water-reset technique increases the set-point temperature when the load on the building is less than expected terms and Conditions. The processing of warmer, chilled water decreases the burden on the compressor, which means less consumption by the chiller energy. Take into account centrifugal chiller with inlet and outlet water temperatures of 54 ° F and 44 ° F at design limits, respectively; and a reset of max 4 ° F. If the building load drops to 80% of the specification, the temperature of the water leaving the evaporator is reset up to 46 ° F by 2 ° F. When the load on the building begins to decrease, the set point will be adjusted upwards until it reaches a maximum reset point of 48 ° F (44 ° F fixed point + 4 ° F maximum reset). As a rule of thumb, increasing 1 ° F change in the temperature of the chilled-water decreases the chiller's energy consumption by an amount from 1% to 1.5%. While resetting the chill water temperature, other aspects also need to be considered such as energy consumption of the pump, humidity control, refrigerant flow and so on. Figure below shows the temperature condition of water chilling.

Conditions		Water Chilling Package
Leaving chilled water temperature	°C (°F)	6.67 (44)
Entering chilled water temperature	°C (°F)	12.22 (54)
Leaving condenser water temperature	°C (°F)	36.11 (97)
Entering condenser water temperature	°C (°F)	30.55 (87)
Fouling factor, water[c]		
Condenser	m^2 K/kW	0.044
Evaporator	m^2 K/kW	0.018
Condenser, ambient Temperature		
Air-cooled	°C	35.0 DB
Evaporatively-cooled	°C	24.0 WB

NOTES:
1. Data in this table apply to the following types of ACMV System Components: Centrifugal or Rotary or Reciprocating water-chilling packages complying to MS 2449.
2. Air-cooled unit ratings is rated at sea level at Barometric Pressure of 101.3 kPa.

Figure 5.2 : The temperature condition of water chilling based on Malaysia Standard

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APPENDIX

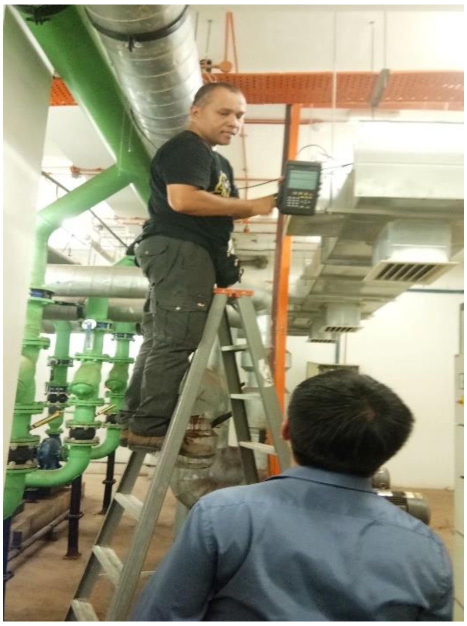
Preparing the data power logger to connect into power control unit.

Connecting varios snsor probe into data powerlogger

Various power of the chiller was clamped

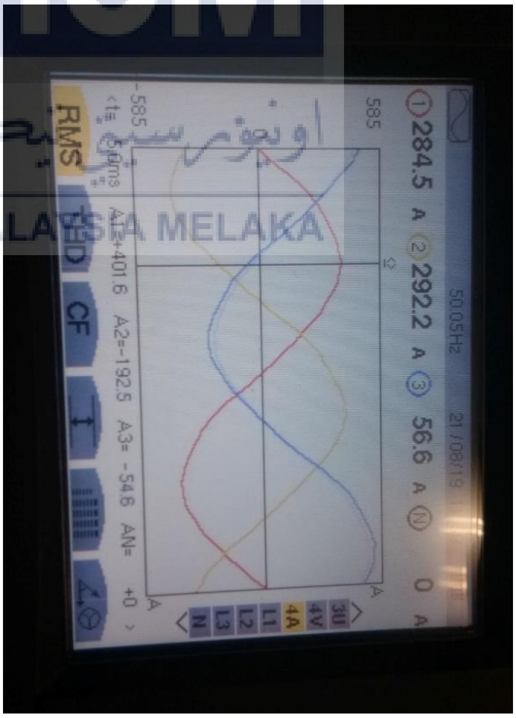
Measuring temperature using dual temperature probe data logger.

Welding to remove the insulated flowrate pipe for attach the ultrasonic power meter.



Flowrate was measured using ultrasonic flow meter

Measured data transferred automatically to the desktop software



Waveform displays on the data power logger based on the measurements.

Sample of calculation

To show the calculation of Cooling load and Coefficient of Performance (COP), a sample of data at 12pm was taken for each day.

	22.08.19 Thu	23.08.19 Fri	24.08.19 Sat	25.08.19 Sun	26.08.19 Mon	27.08.19 Tue	28.08.19 Wed
Tin (°C)	5.9	6.4	6.1	6.0	6.3	6.8	6.6
Tout (°C)	10.2	10.1	7.0	6.4	10.7	11.2	10.2
Flowrate (l/s)	33.5	32.57	20.81	20.83	34.57	31.94	31.4
Power (kWe)	183053	179482	29394	29915	213695	206281	183033
Cooling load (kWr)	602.0791	503.719	78.2705	34.82404	635.8012	587.420	472.4654
COP	6.578194	5.6130311	5.3257919	2.3282	5.950576	5.695311	5.162625

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C$

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

I. 22.08.19 THU

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C$

= 4.18 × 33.5 × [10.2-5.9] = <u>602kWr.</u>

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

= 602 ÷ $[\frac{183053}{2000}]$ = <u>6.57.</u>

II. 23.08.19 FRI

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C$

= 4.18 × 32.57 × [10.1-6.4] = <u>503.7kWr</u>

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

= 503.7 ÷ $[\frac{179482}{2000}]$ = <u>5.61.</u>

III. 24.08.19 SAT

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C$

= 4.18 × 20.81 × [7-6.1] = <u>78.3kWr</u>

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

$= 78.3 \div [\frac{29394}{2000}] = \underline{5.33}$

IV. 25.08.19 SUN

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\frac{l}{s} \times [Tout - Tin]°C$

$= 4.18 \times 20.83 \times [6.4\text{-}6] = \underline{34.82\text{kWr}}$

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

$= 34.82 \div [\frac{29915}{2000}] = \underline{2.33}$

V. 26.08.19 MON

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\frac{l}{s} \times [Tout - Tin]°C$

$= 4.18 \times 34.57 \times [10.7\text{-}6.3] = \underline{635.8\text{kWr}}$

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

$= 635.8 \div [\frac{213695}{2000}] = \underline{5.95}$

VI. 27.08.19 TUE

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C$

= 4.18 × 31.94 × [11.2-6.8] = <u>587.4kWr</u>

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

$= 584.4 \div [\frac{206281}{2000}] = \underline{5.7}$

VII. 28.08.19 WED

AC Heat Rejection (kW) = 4.18 $\frac{kJ}{kg.°C} \times Q\,\frac{l}{s} \times [Tout - Tin]°C$

= 4.18 × 31.4 × [10.2-6.6] = <u>472.5kWr</u>

$$COP = \frac{\text{AC System Total Rejected Heat Loss (kWr)}}{\text{AC System Total Electrical Load (kWe)}}$$

$= 472.5 \div [\frac{183033}{2000}] = \underline{5.16}$