TO STUDY THE CHILLER PLANT ROOM PERFORMANCE

SATHEESKUMAR A/L RAJADRAN

FACULTY OF ENGINEERING
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TO STUDY THE CHILLER PLANT ROOM PERFROMANCE

ABSTRACT

The chief concern of this project is about to study and develop the chiller plant room performance. The research report provides the findings of the investigations, the performances of the existing Chiller Plant Room 1 (CPR-1) at COMPANY ‘T’. The Chiller No.1 (Trane 450 RT) is operating at 371 RT/450 RT in 80% load cooling load of in average. The Chiller No.1 is operating with 80% of load with efficiency rate of 0.80 kW/RT in average, the chilled water pump is operating with efficiency of 0.48. The condenser water pump is operating with efficiency of 0.78 which is higher than the recommended pump efficiency is 0.7. The cooling tower calculated efficiency for CT-2 is 26.2 USGPM/hp and CT-3 is 22.9 USGPM/hp and rated efficiency shall be more than 38.2 USGPM/hp. The investigations reveal that the Chiller No.1 is not operating in their optimum capacity. The chiller system need to replace with new one. The chilled water pump is operating below efficient level and required to replace or replace with additional variable speed drives. The condenser water pumps are operating efficiently with the optimum capacity. The Cooling towers operations are not efficient and is recommended to operate with a individual cooling tower. Recommendations are provided to improve the CPR-1 system efficiency hence to provide energy savings.

MENGKAJI “CHILLER PLANT ROOM”

ABSTRAK

Kebimbangan utama projek ini adalah untuk mengkaji dan memajukan “Chiller Plant Room”. Laporan penyelidikan menyediakan penemuan siasatan, persembahan Alat Loji Chiller Room 1 (CPR-1) yang ada di COMPANY 'T'. The Chiller No.1 (Trane 450 RT) beroperasi di 371 RT / 450 RT dalam beban penyejukan beban 80% secara purata. The Chiller No.1 beroperasi dengan 80% beban dengan kadar kecekapan 0.80 kW / RT secara Chilled Water Pump beroperasi dengan kecekapan 0.48. Pam kondenser beroperasi dengan kecekapan 0.78 yang lebih tinggi daripada kecekapan pam yang dicadangkan ialah 0.7. Kecekapan yang dikira menara dingin untuk CT-2 ialah 26.2 USGPM / hp dan CT-3 ialah 22.9 USGPM / hp dan kecekapan diberi lebih daripada 38.2 USGPM / hp. Penyiasatan menunjukkan bahawa Chiller No.1 tidak beroperasi dalam kapasiti optimum. Chiller juga memerlukan penggantian. Pam Chilled water dibekalkan di bawah paras yang cekap dan memerlukan penggantian dan pemacu laju pembolehubah tambahan. Pam air pemeluwap beroperasi dengan cekap dengan kapasiti optimum. Operasi Cooling Tower tidak berkesan dan disyorkan untuk beroperasi dengan menara penyejukan tunggal. Cadangan disediakan bagi meningkatkan kecekapan sistem CPR-1 dengan itu untuk menyediakan penjimatan tenaga.

ACKNOWLEDGEMENTS

As I hereby want to say thanks to University of Malaya for giving an opportunity to do a research which can improvise my technical career in future.

Therefore I also thank to my supervisor Dr. Ong Hwai Chyuan who provides great supervise work and give lots of useful feedback during progression of my project. His advice, guidance and supports I deepest appreciated. I would not have successfully completed this project without his help.

Next I would like to express sincere gratitude to my friends and engineers for helping and guiding me in the process of getting a better understanding of my project requirements and also getting basic information of my project.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	:	area
A_V	:	surface area of water droplets per volume of tower
C	:	heat capacity
c	:	specific heat incompressible liquid
Cfm	:	air flow rate (cubic feet per minute)
C_r	:	ratio of heat capacities (minimum to maximum)
C_P	:	specific heat
D	:	diameter
f	:	friction factor
g	:	gravitational constant
Gc	:	mass velocity through the minimum free-flow area
h	:	heat transfer coefficient
h_A	:	heat conductance
h_a	:	enthalpy of air
h_d	:	diffusion mass transfer coefficient
$h_{ref.w}$	:	enthalpy of water above reference state of liquid water
IER	:	integral efficiency rating
k	:	thermal conductivity
L	:	length
LMTD	:	logarithmic mean temperature difference
N	:	Speed
n_f	:	number of tubes
P	:	pressure
$\dot{m}$	:	mass flow rate

R_f	:	fouling factor
T	:	Temperature
V	:	velocity
V_{max}	:	Velocity through the minimum free flow area
V	:	volume
V_t	:	total tower volume
$\dot{W}$	:	power
Z	:	elevation
Δ	:	change
η	:	efficiency
ε	:	roughness
ε_a	:	heat transfer effectiveness based with respect to the air-side
ε_{min}	:	heat transfer effectiveness based with respect to the side with the smallest heat capacity
ρ	:	density
σ	:	ratio of minimum free-flow frontal area
ROI	:	return of investment

CHAPTER 1: INTRODUCTION

1.1 Background

The Modern Industrial Chiller is fundamentally a cooling system that expels heat from one component (water/glycol/air) and stores into another (ambient air or water). The standard design is a system that cools 60° F water (water/glycol, or air) to 44° F and stores the heat into the ambient air at 95° F (or water at 85° F). This cooling technology is used by different industries to cool down the process machinery and the process utilizing from chiller to cool a medium like air or water (Ali F.Alajmi, 2014).

The chiller works basic chiller has two circuits:

1) the water circuit
2) the refrigeration circuit

In the water circuit, a pump circulates the water from the holding tank to the evaporator which cools the water by exchanging the heat to a refrigerant, the water then goes on to the process in a portable chiller or back to the tank in a packaged or central chiller.

In the refrigeration circuit, the evaporator heats up the liquid refrigerant into a gas cooling the water, the compressor builds the pressure of the refrigerant gas to a pressure (200 to 220 psi for Freon 22) so that the condenser can condense the gas back to a liquid (remove the heat gained) utilizing ambient air at 95° F or cooling tower water at 85° F.

In the case of an industrial chiller, the guideline is the same. Water is pumped to the chiller typically at 60° F and cooled to 44° F, when utilizing water/glycol solution can be cooled to 20° F. The heat is expelled from the condenser either by a plant cooling tower water system, or outdoor air for remote condenser and outdoor air cooled chillers, or by plant air for portable or indoor heat reclaim chillers (basic a cooling system, 2014).

COMPANY ‘T’ is one of the pioneers in the electronics industry in Malaysia and has a long presence in the Nation, through its entirely-owned subsidiary. Since they initially started the operations at Klang valley Facilitated commerce Zone in 1972, COMPANY ‘T’ Malaysia had expanded in size, manufacturing capacity and workforce. In 2011, COMPANY ‘T’ additionally extended its operations here through a merger and procurement process that saw the introduction of COMPANY ‘T’ Sdn Bhd.

In the COMPANY ‘T’ the chiller was installed on 1996 and operating until today. The standby chiller was installed on 2006. There are two sets of Chillers in this company. The operating Chillers are water cooled centrifugal type chillers. The chillers located at Chiller Plant Room 1 (CPR-1) at the COMPANY ‘T’. The chillers brands are Trane. The capacity of the chillers are 450 Refrigerant Tonnage (RT), And the 3 sets of cooling towers (2 duty / 1stand by) at the roof of the CPR-2, 3 sets of chilled water pumps (1 duty/ 2 stand by) in the Chiller plant room 1 and 3 sets of condenser water pumps (1 duty / 2 stand by) in the Chiller plant room 2.

1.2 Problem Statements

The COMPANY 'T' noticed the annual operation cost on the air-conditioning system is very high and is not performing efficiency. They decided to audit the air-conditioning system to enhance overall Chiller Plant Room 1 efficiency (kW/RT) which able to provides savings on the total operation cost annually.

1.3 Objective

To carry out the details study of the existing chiller plant room performance consist of the following:

a) To study the current loadings of the chillers, cooling towers and water pumps. Detail analysis shall be conducted, load profile, comparing actual conditions with the design.

b) To carry out site measurement for Chillers, Cooling Towers and Water Pumps equipment include, chilled water Supply/ Return Temperature, chilled / Condenser Water Flow, kW consumption and ambient temperature.

c) To compare and correlate with the operation peak and low peak times, ambient temperature during day, night, raining day, etc.

d) To study overall chiller plant room efficiency including Condenser pump, Chilled water pump, Cooling tower and overall plant efficiency (kW/ton).

e) To recommend for the improvement of overall air-conditioning system at COMPANY ‘T’.

1.4 Scope of the Project

The scope of the project is to compare the existing water cooled chiller system with the design data. The existing Chiller Plant Room 1 (CPR-1) consist of two units of water cooled Chillers, one is on duty and one is stand by unit.

Part of the scope, to study the current loading of the chiller and condenser pump, chilled water pump, cooling towers and overall plant efficiency.

As a conclusion the overall measured data, calculated data and design data are analyzed and tabulated with recommendation for the overall chiller plant room efficiency.

CHAPTER 2: LITERATURE REVIEW

In the air conditioning system has two types of chiller system. There are air cooled chiller and water cooled chiller. And the COMPANY 'T' currently using water cooled chiller system.

2.1 Chiller System

A chiller is a system that removes heat from liquid via vapor compression or absorption refrigerant cycle. This liquid would then be able to circulate through a heat exchanger to cool the equipment's, or another process of stream (for example, air or process water). As a vital result, refrigeration makes waste head that must be depleted to ambience, or for greater efficiency, recovered for heating purpose (Berg, 2003).

Chilled water is utilized to cool and dehumidify air in mid to extensive size commercial, industrial, and institutional facilities. Water cooled system can give efficiency and environmental and natural effect favorable circumstances over air cooled system (Stanford, 2012).

2.2 Air conditioning system

In air conditioning system, chilled water is normally distributed to heat exchanger or to coils in air handlers or different types of terminal devices which cool the air in their particular spaces. The water is recirculated to the chiller to be re-cooled. These cooling coils exchange sensible heat and latent heat from the air to chilled water, hence cooling and generally dehumidifying the air stream. A typical chiller for air conditioning applications is evaluated in the vicinity of 15 and 2000 tons (Merriam, 2012). Chilled water temperatures can extend from 35 ^{0}F to 45 ^{0}F. (2 ^{0}C to 7 ^{0}C), depending upon application requirements (Ashrae, 2010).

2.3 Industrial Application

In industrial application, chilled water or other from the chiller is pumped through process or research facility equipment's. The industrial chiller are used for controlled cooling of things, mechanism and production line apparatus in a wide of industries. They are frequently utilized as a part of the plastic factories, injection and molding, metal working cutting oils, chemical processing up paper and cement processing, food and beverage processing, power supplies, and power generation stations, semiconductors, compressed air and gas cooling. There are also utilized to cool high heat specialized things, for example hospital facilities, hotels and campuses.

2.3.1 Chiller Industrial Application

Chillers for industrial application can be common, where a single chiller serves numerous cooling needs or decentralized where every application or machine has its own chiller each approach has its advantages. It is also conceivable to have a blend of both centralized and decentralized chillers. Particularly if the cooling requirements are the same for a few application or utilization.

2.3.2 Water Cooled Chiller

Chilled water is utilized to cool and dehumidify air mid-to extensive size commercial, industrial and institutional facilities. Water chiller would be water cooled and air cooled Water cooled chiller join the utilization of cooling towers which enhance the chillers thermodynamic effectiveness when contrasted with air cooled chillers. This is because of heat rejection at neat the wet bulb temperature rather than higher (Morvarid Talaie, 2016).

Water cooled chiller are ordinarily expected for indoor installation and operations. There are cooled by a spate condenser water loop and connected with outdoor cooling towers to expel heat to the atmosphere. The ordinarily of the Water Cooled Chiller System shows, in Figure 2.1.

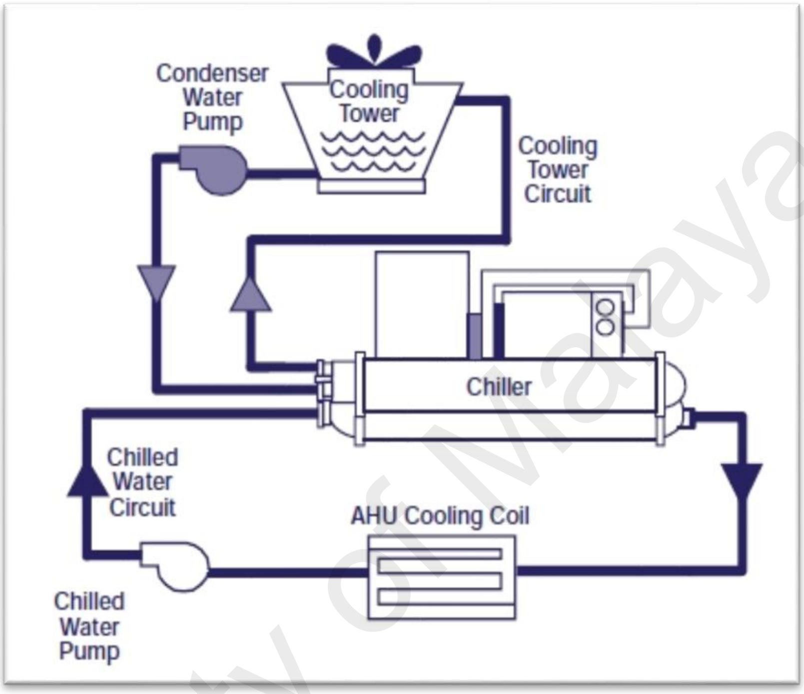

Figure 2.1: Typical Water Cooled Chiller System Schematic (Stanford, 2012).

Water cooled chillers are typically expected for indoor installation and operation. They are cooled by another condenser water loop and associated with cooling tower that's located at outdoor to remove heat to the environment. Figure 2.2 shows components of the water cooled chiller.

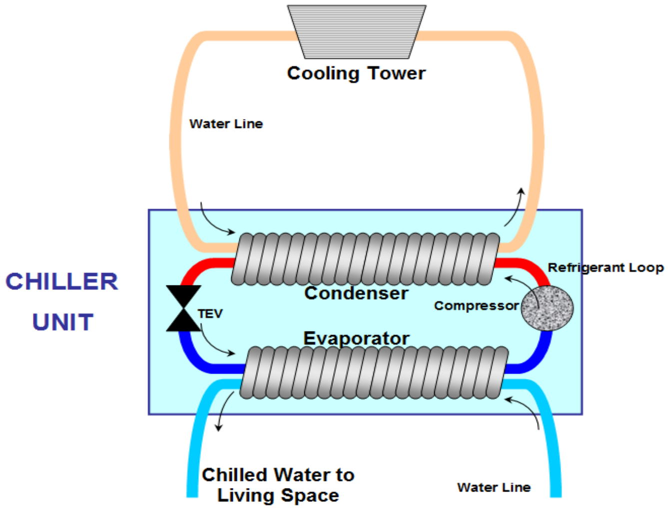

Figure 2.2: Components of the Water Cooled Chiller (Stanford, 2012).

Water chiller is an equipment for giving and supplying chilled water required for industrial cooling and air conditioning and also refrigeration system with below and over zero temperature. It's for the most part 7 ^{0}C – 12 ^{0}C. Vapor compression chiller works depends on vapor compression refrigeration cycle. These type of chillers need outdoor cool water or cooling tower from different source for condensing the refrigerant.

Water chillers in air conditioning system, gives chilled water required to fan coils and Air Handling Units systems and is heart of the system which climatic condition is application hindrances, for example, high altitude of installation place, high surrounding temperature and accessibility of value and fresh water. Water cooled chiller system are more efficient that air cooled chiller system for direct result of lower condensing temperatures.

Function of water cooled chillers with remote cooling tower which are introduce in free spaces like top of building are like cool water of chiller condenser is comparable of other refrigerant cycle.

2.3.3 Air Cooled Chiller

Air cooled and evaporative cooled chiller are proposed for outdoor installation and operation. Air cooled systems are straightforwardly cooled by ambient air temp being mechanically flowed specially through the machine's condenser coil to expel heat to atmosphere. Evaporative cooled machines are comparative, except they actualize a mist of water over the condenser coil to help in condenser cooling, making the system more proficient than a conventional air cooled system. No remote cooling tower is ordinarily required with both of these types of package air cooled or evaporative cooled chiller.

There are four fundamental types of compressors utilized as a part of water compression chillers. There are reciprocating compressor, scroll compressor, screw-driven compressor and centrifugal compressor. These four compressors would be powered by electric motors, steam, or gas turbines. They deliver their cooling impact through the reverse Rankine cycle or known as vapor compression (baran mohseni, 2016). With evaporative cooling heat rejection, their coefficients of performance (COP) are high, it's ordinarily at least 4.0.

$$\text{COP} = \frac{\text{COOLING POWER}}{\text{INPUT POWER}}$$

Recent vapor – compression chiller development depends on the "reverse Rankine" cycle called as vapor compression attached picture which diagrams the key parts of the chiller system.

Air cooled chiller are normally to the essential design of the system. This type of chiller is not to portability. Most portable chiller units will never be moved once installed. The term alludes to any chiller system that contains all of the majority of the fundamental components. The refrigeration circuit, pumps and reservoir. Figure 2.3 shows components of the Air cooled chiller.

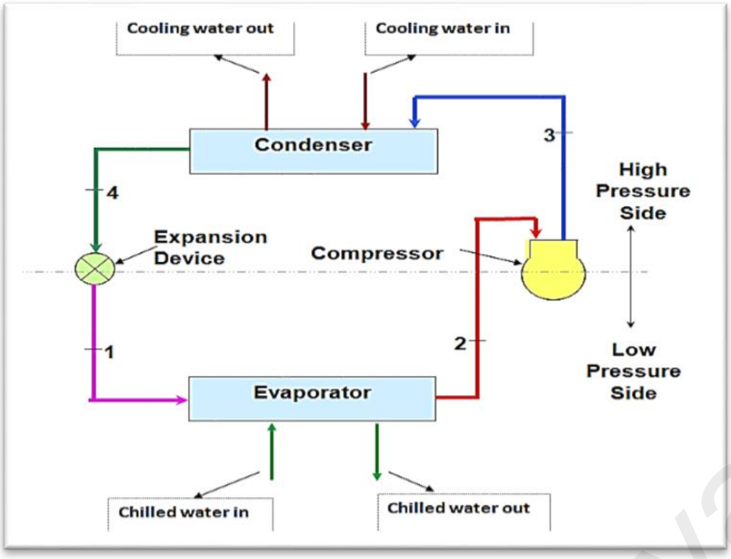

Figure 2.3: Typical Air Cooled Chiller System Schematic (baran mohseni, 2016)

Air cooled chiller capacity with remote or incorporated condensers which are installed in top of the building same like water cooled chiller. This is because utilizing of ambient air cooling impact and ability to heat dissipating of condenser to free space of conditions.

Essential components of air cooled chillers components of vapor compression cycle are condenser, compressor, evaporator, extension valve, associating pipes and refrigerant.

2.4 Key Components of the Chiller

Refrigeration compressor are basically a pump for refrigerant gas. The capacity of the compressor, and thus chiller cooling capacity is measured in refrigerant tonnage (RT), kilowatts input (kW), volumetric flow (m3/h, ft3/h) and horsepower (HP), the mechanism for compressing refrigerant gas varies amongst compressor, and each has own particular application. Basic refrigeration compressors incorporate reciprocating compressor, scroll compressor, screw compressor and centrifugal compressor. These compressor can be controlled by electric motors steam turbines or gas turbines. Compressor have a coordinated motor from particular producer or open drive enabling the association with another sort of mechanical connection. Compressor can likewise be either welded close or bolted together.

There are 2 types of Condensers, water cooled condenser and air cooled condenser. The condenser is a heat exchanger which enables heat to migrate from the refrigerant gas to either air or water. Air cooled condenser are made from copper tubes and aluminum blades. Copper tubes is usage for the refrigerants flow and the aluminum blades for the air flow. Every condenser has an alternate material cost and they shift regarding efficient. With evaporative cooling condensers coefficients of performance (COP) are slightly high and ordinarily at least 4.0.

Industrial chillers ordinarily come with complete packaged with closed loop system including the chiller unit, pump station with recirculating pump, condenser expansion valve, internal cold water control and no flow shutdown. The inside tank keeps up cold water temperature and prevents temperature spikes from occurring. Closed loop system industrial chillers recirculate a perfect coolant with condition added substances at constant temperature and pressure to build up the stability and reproducibility of water cooled machines and instruments. The water flows the chiller to the applications purpose of utilization.

If the water temperature is different between inlet and outlet are high, then at that point a large external water tank would be utilized to store the cold water. For this situation the chilled water is not going straight forwardly from the chiller to the system. But goes to the external water tank which acts as a sort of “temperature buffer.” The cold water is bigger than internal water goes from the external storage to the application and the return to with high temperature from the application goes back to the external storage. But not into the chiller.

The open loop industrial chillers control the temperature of a liquid in an open tank by always for recirculating. The liquid is drawn from the tank and pumped through the chiller and back to the tank. In industrial water chillers is the utilization of water cooling rather than air cooling. For this situation, the condenser does not cool the hot refrigerant with ambient air but rather than utilizes water that cooled by cooling tower. The process allows reduction in energy requirement by over 15% and furthermore allows a huge reduction in the size of the chiller, because of the small surface area of the water based condenser and the absence of fans. Furthermore, the absence of fans allows significantly reduces the noise level.

Most industrial chillers utilize refrigeration as the media for cooling, however some depends on less complex techniques such as air, water flowing over coils containing the coolant to control temperature. Water is the most regularly utilized coolant within the process chiller, despite the fact that coolant mixture “for the most part of water with a coolant added substance to upgrade heat dissipation” are often frequently (III, 2012).

2.5 Chiller – Main components

The main chiller components are the compressor, condenser, expansion valve, evaporator, control panel, control unit and makeup water tank.

2.5.1 Compressor

The compressor is the prime mover, it makes a pressure difference to move the refrigerant around the system. There are different design of refrigerant compressors, the most widely recognized being the centrifugal compressor as shown in Figure 2.4, screw compressor as shown in Figure 2.5, reciprocating compressor as shown in Figure 2.6 and scroll compressor as shown in Figure 2.7. Each type has its own particular advantage and disadvantage. It is constantly situated between the evaporator and the condenser. It is typically somewhat protected and will have an electrical motor connected as the main driving force, this will be either mounted internally or externally. Compressors can be to an extremely uproarious, as a rule a consistent profound rambling sound with an overlaying high pitch, hearing protection to be worn when in closeness to the chiller (Paul Evans, 2017).

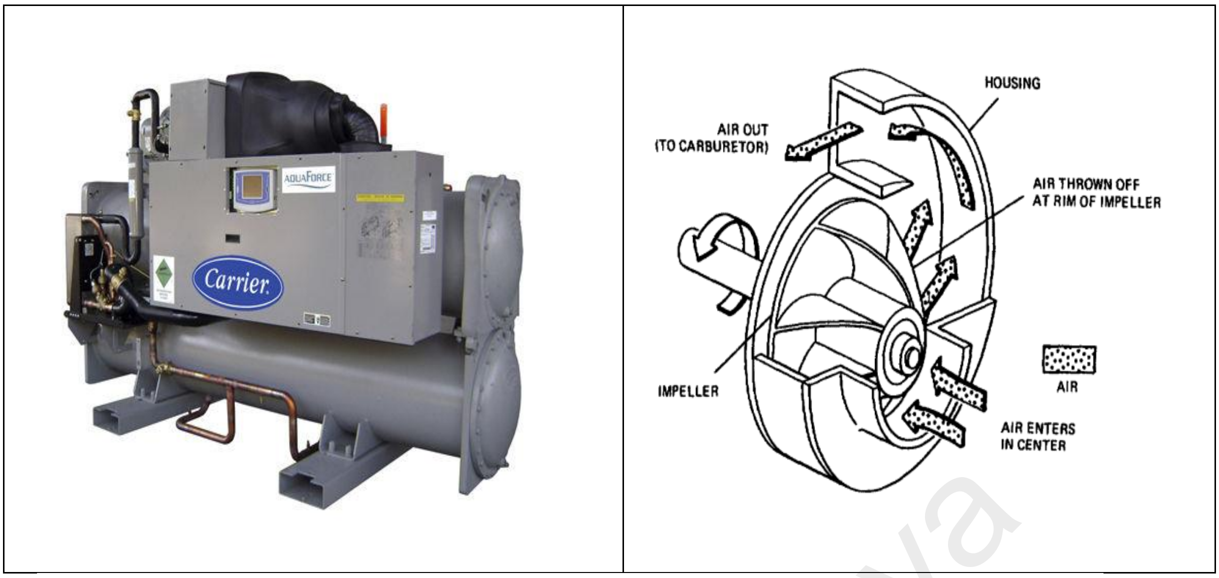

Figure 2.4: Centrifugal Type Compressor (Paul Evans, 2003)

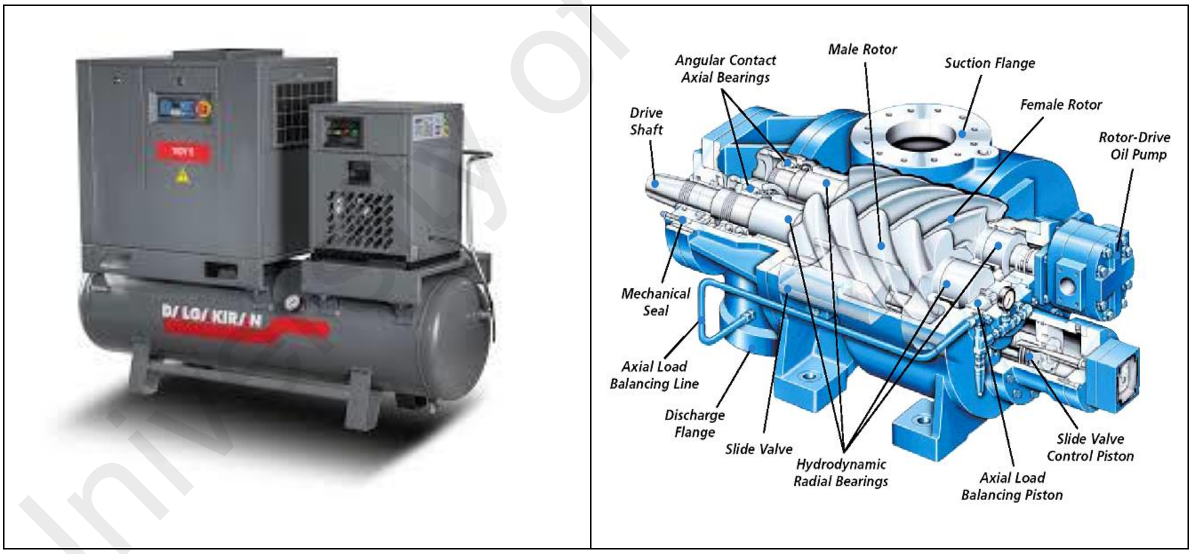

Figure 2.5: Screw Type Compressor (Atlas Copco, 20174)

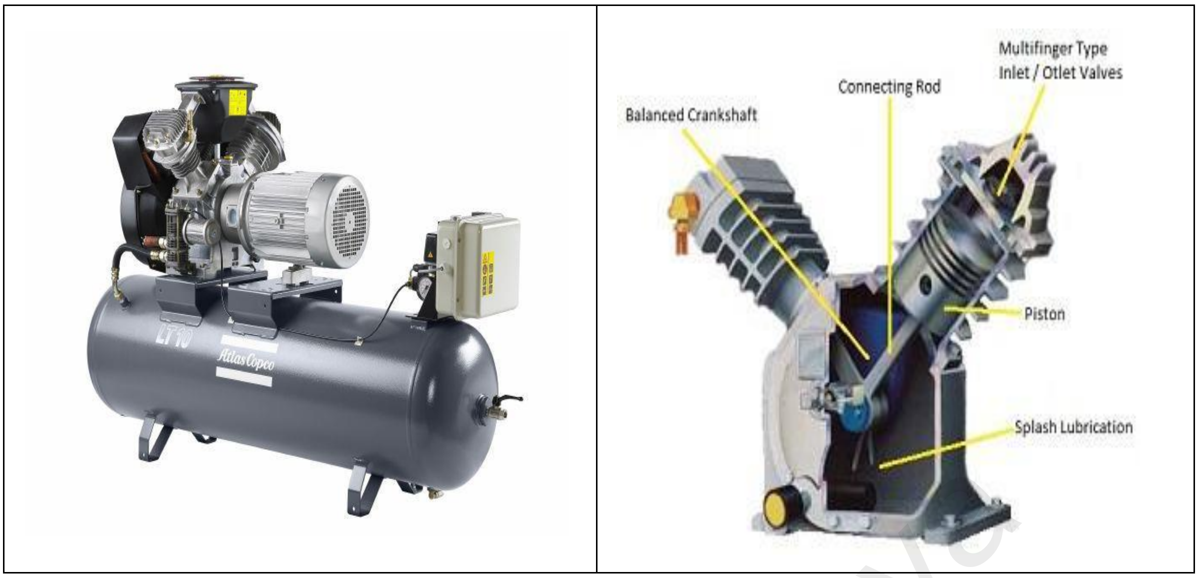

Figure 2.6: Reciprocating Type Compressor (Noria , 2015)

Figure 2.7: Scroll Type Compressor (Emerson, 2015)

2.5.2 Condenser

The condenser is located after the compressor. The purpose of the condenser is to remove the heat from the refrigerant which was absorbs in the evaporator. These things are two main principle sorts of condenser, air cooled and water cooled.

Water cooled condenser will repetitively cycle "Condenser water" between the cooling tower and the condenser, the hot refrigerant which enters from the compressor to the condenser, will move its heat into this water which is transported up to the cooling tower and rejected from the building. The refrigerant and the water do not mix they are kept isolated by a pipe wall, the water flows inside the pipe and the refrigerant flows on the outside. Figure 2.8 shows water cooled chiller condenser (Wilbert F.Stoecker, 2016).

Condenser on air cooled chiller will work marginally different, they do not utilize a cooling tower however rather blow air across the exposed condenser pipes with the refrigerant flowing this time within the tubes. Figure 2.9 shows air cooled chiller condenser (Alfa Laval, Richmond, VA, 2016).

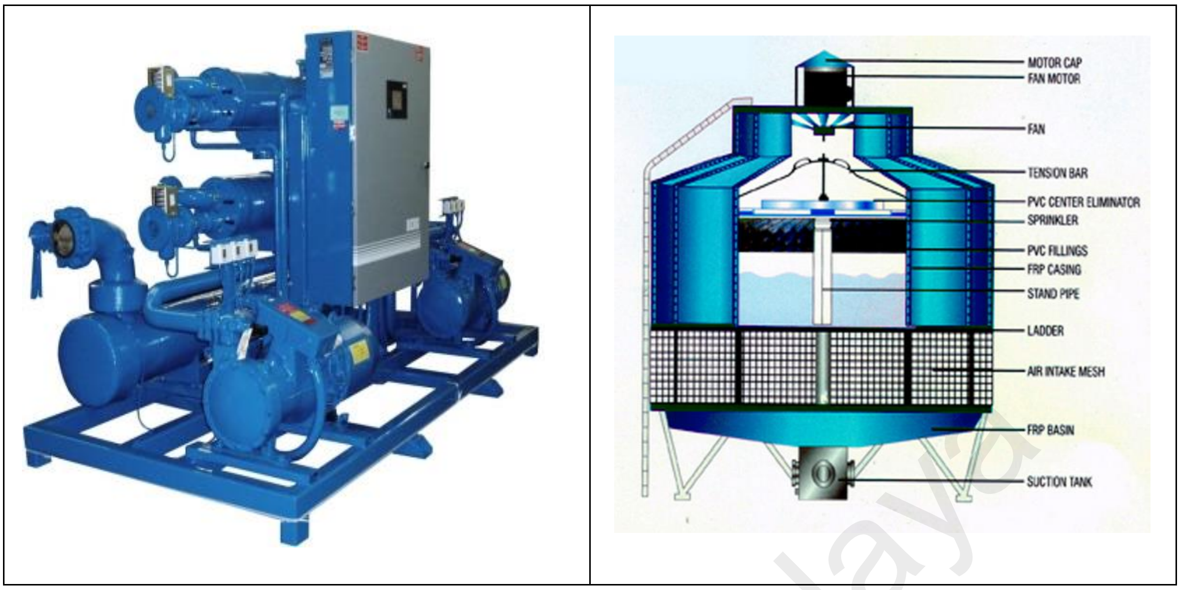

Figure 2.8: Water Cooled Chiller Condenser Unit (Cooling Tower) (Berg, 2003)

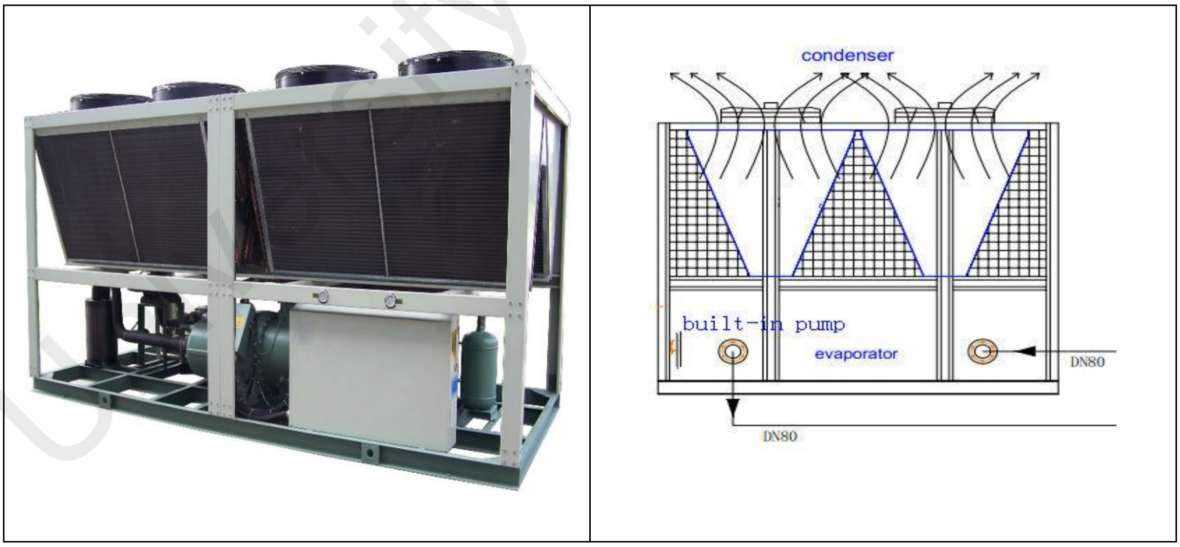

Figure 2.9: Air Cooled Chiller Condenser Unit (Paul Evans, 2003)

2.5.3 Water cooled expansion valve

The expansion valve is located between the condenser and the evaporator. Its purpose is to extend the refrigerant decreasing its pressure and increase its volume which will allow it to get the unwanted heat in the evaporator. There are a many different type of expansion valve, the most well-known at the thermal expansion valve and fixed orifice expansion valve (ZHE JIANG, 2015). Expansion valve shown in Figure 2.10:

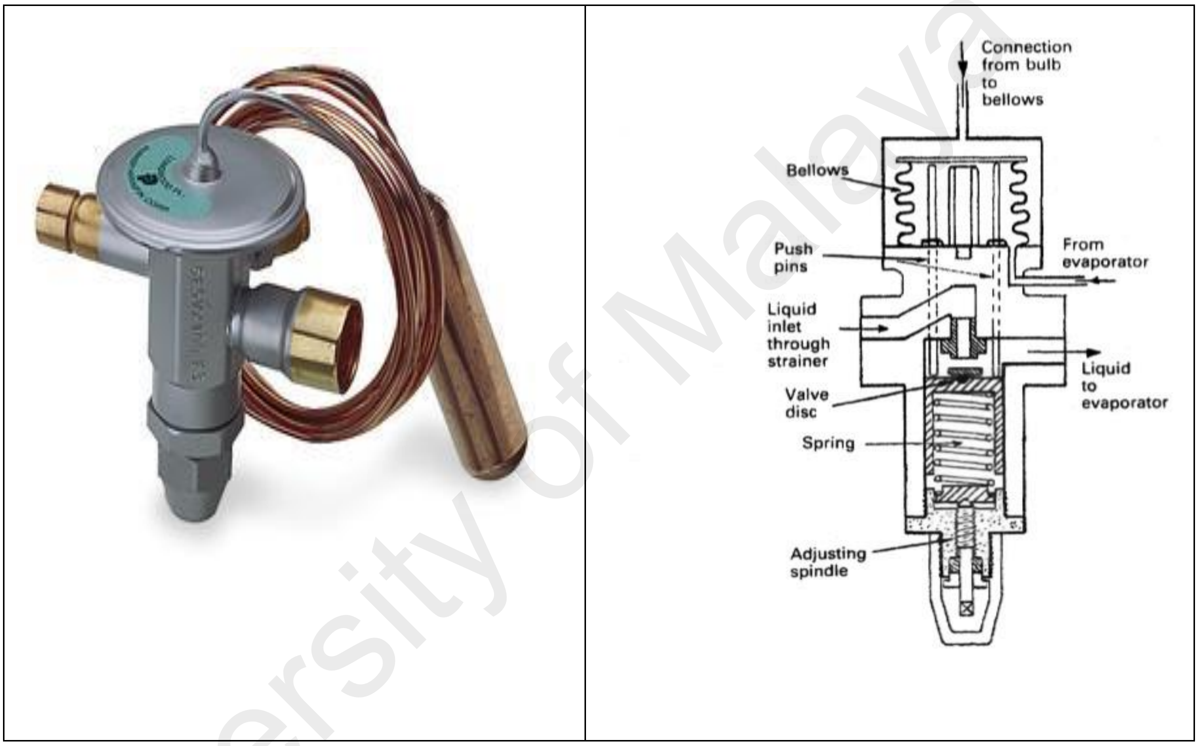

Figure 2.10: Thermal Expansion Valve (Berg, 2003)

2.5.4 Evaporator

The evaporator is located between the expansion valve and the compressor, its purpose is to gather the unwanted heat from the building and move this into the refrigerant with that it can be sent to the cooling tower and rejected. The water cools as the heat is extricated by the refrigerant, this "chilled water" is then pumped around the building to give air conditioning. This "chilled water" at that point comes back to the evaporator carrying with it any unwanted heat from the building.

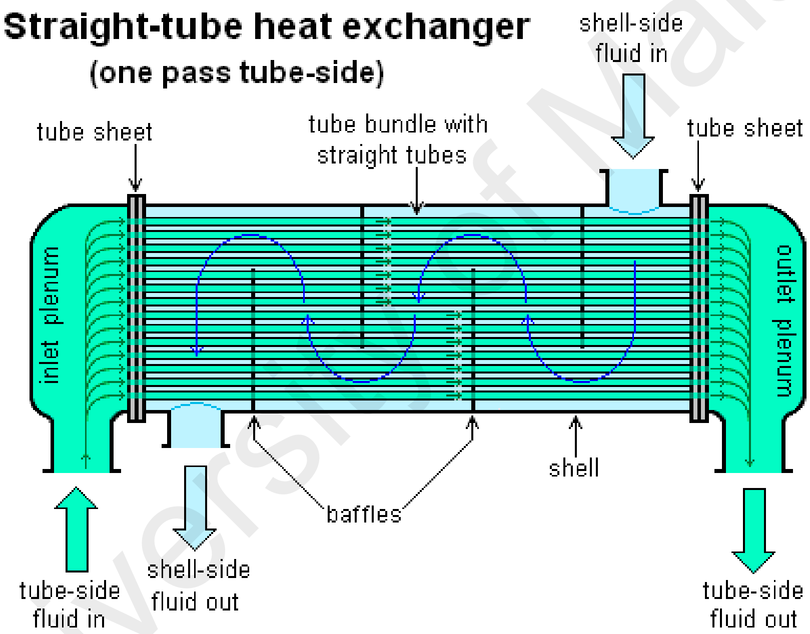

Figure 2.11: Evaporator (ZHE JIANG, 2015)

2.5.5 Control Panel

The control panel is either mounted straightforwardly to the chiller or it can be separate and mounted to the wall of the plant room with control cable links running between them. The reason for the control panel is to control the flow of electrical power to the chiller. These for the most part contain a starter, circuit breakers, speed controller and power checking equipment.

The controls units is normally mounted on the chiller. It is purpose is to monitor the different parts of the chillers performance and control these by making adjustment. The controls unit will generate cautions for the engineering terms safely close the system down to prevent the harm to the unit (RCS Nanterre, 2010). BMS connections are usually present to permit remote control and observing. Figure 2.11 shows Electrical control panel.

Figure 2.12: Electrical Control Panel (Noria , 2015)

CHAPTER 3: METHODOLOGY

The existing Chiller Plant Room 1 (CPR-1) consists of the following:

- 2 Nos. of Chiller (1 duty/ 1 stand by) in the CPR-1
- 3 Nos. of cooling towers (2 duty / 1stand by) at the roof of the CPR-2
- 3 Nos. of chilled water pumps (1 duty / 2 stand by) in the CPR-1
- 3 Nos. of condenser water pumps (1 duty / 2 stand by) in the CPR-2

3.1 Design Consideration

The CPR-1 analysis report depends on the data logging for a constant 4 days including the weekdays and weekends. The Chiller No.1 (Trane Chiller 450RT) data logging began from 15th September 2017 to 18Th September 2017.

Note: The Chiller No.2 (Carrier 500RT) is a standby unit. The chiller was not in operation and do not permit to turn ON for operation mode for measurement purpose.

3.2 Existing Chiller Capacity Data

In the COMPANY 'T' Chiller Plant Room 1 (CPR-1) consists of two numbers of water cooled chillers (1 duty and 1 stand by) unit. The Chiller details are tabulated in table below:

Table 3.1: Specification of the Chillers

No.	Brand	Model	Series No.	Tonnage (RT)	Installation Year	Mode
CH-1	TRANE	CVGF500	L01D08029	450	1996	DUTY
CH-2	CARRIER	19XL5353303 CR	5193J47899	500	2006	STAND BY

The existing Chiller design data is not available and the monitoring range details is based on the operation monitoring range points.

Table 3.2: Existing Chiller Monitoring Range Details

No.	Brand	Chiller Type	Refrigerant Type	Monitoring Range Based on the COMPANY 'T' Daily Chiller Log Sheet			
				CHW Supply (°F)	CHW Return (°F)	CW Supply (°F)	CW Return (°F)
CH-1	TRANE (450RT)	Centrifugal	134 A	42-46	<55	<90	<105

3.2.1 Chiller observation

This Chiller plant room 1 (CPR-1) supplies chilled water to AHUs and compressors in the building. Chiller No.1 is operating as duty and Chiller No.2 as a standby mode. The existing temperature gauges, pressure gauges with the ball valves on the chilled water pipes and condenser water pipes are noted as faulty. The photos below indicate the existing Chillers at the (CPR-1) and the site arrangement.

Figure 3.1 - Existing Trane Chiller Number One at the CPR-1.

Figure 3.2 - Existing Carrier Chiller Number Two at the CPR-1.

3.3 Existing Chilled Water Pump Capacity Data

In the COMPANY 'T' Chiller Plant Room 1 (CPR-1) consists of three numbers of chilled water pump (1 duty and 2 stand by) units. The details are tabulated in table below:

Table 3.3 - Chilled Water Pump Details in the Chiller Plant Room 1 (CPR-1)

No.	Brand	Model	Series No.	Installation Year	Impeller material	Shaft material
CHWP-1	AJAX ELITE	125-40-A20C	2006/0051	2006	Bronze	Stainless steel
CHWP-2	AJAX ELITE	125-40-A20C	2006/0051	2006	Bronze	Stainless steel
CHWP-3	AJAX ELITE	125-40-A20C	2006/0051	2006	Bronze	Stainless steel

The existing chilled water pump data is based on the details provided by COMPANY 'T' and the actual design data and pump curves are not available.

Table 3.4 - Technical Data of Chilled Water Pump

No.	Impeller Dia (mm)	Motor RPM	Head (m)	Power (kW)	Current (A)	Flow rate (m3/hr)	Design Mode	Actual Mode
CHWP-1	385	1465	50	45	85	204	Duty	Stand By
CHWP-2	385	1465	50	45	85	204	Stand By	Duty
CHWP-3	385	1465	50	45	85	204	Duty	Stand By

3.3.1 Chiller Water Pump Observation

CPR-1 consists of 3 Nos. chilled water pumps and are intended to operate with 2 Nos. of pumps as duty and 1 No. pump as standby. The pumps are operated with consistent speed to support the operation. The actual operation of the pumps are with 1 No. duty and 2 Nos. on standby. The photo below indicates the existing chilled water pumps at the Chiller plant room 1 (CPR-1) and the site arrangement

Figure 3.3 - Existing Chilled Water Pumps at the CPR-1

3.4 Existing Condenser Pump Capacity Data

In the COMPANY 'T' Chiller Plant Room 2 (CPR-2) consists of three numbers of condenser water pump (1 duty and 2 stand by) units. The details are tabulated in table below:

Table 3.5 - Condenser Water Pump in the Chiller plant room 1 (CPR-1)

No.	Brand	Model	Series No.	Installation Year	Impeller material	Shaft material
CDWP-1	AJAX ELITE	150-40-A20C	2006/0051	2006	Bronze	Stainless steel
CDWP-2	AJAX ELITE	150-40-A20C	2006/0051	2006	Bronze	Stainless steel
CDWP-3	AJAX ELITE	150-40-A20C	2006/0051	2006	Bronze	Stainless steel

The existing condenser water pump data is based on the details provided by COMPANY 'T' and the design data is unavailable.

Table 3.6 – Technical Data of Existing Condenser Water Pumps

No.	Impeller Dia (mm)	Motor RPM	Head (m)	Power (kW)	Current (A)	Flow rate (m3/hr)	Design Mode	Actual Mode
CDWP-1	359	1470	36	55	96	241	Duty	Stand By
CDWP-2	359	1470	36	55	96	241	Stand By	Duty
CDWP-3	359	1470	36	55	96	241	Duty	Stand By

3.4.1 Condenser Pump Observation

CPR-1 consist of 3 Nos. condenser water pumps and are intended to operate with 2 Nos. of pumps duty and 1 No. pump as standby. The pumps are operated with consistent speed to support the operation. The actual operation of the pumps are with 1 No. duty and 2 Nos. on standby. The photo below indicates the existing condenser water pumps for the Chiller plant room 1 (CPR-1) and the site arrangement

Figure 3.4 - Existing Condenser Water Pumps for the CPR-1

3.5 Existing Cooling Tower Capacity Data

In the COMPANY ‘T’ Chiller Plant Room 1 (CPR-1) consists of three numbers of cooling towers (2 duty and 1 stand by) units. The details are tabulated in table below:

Table 3.7 - Cooling Towers in the Chiller plant room 1 (CPR-1)

No.	Brand	Model	Series No.	Fan Motor (kW)	Mode	Installation Year
CT-1	BAC	700	33568	30	Stand by	N/A
CT-2	BAC	700	33568	30	Duty	N/A
CT-3	BAC	700	33568	30	Duty	N/A

Note: The existing cooling tower data based on the details provided by COMPANY ‘T’ and the design data is not available.

3.5.1 Cooling Tower Observation

In view of the site investigation, was noticed that the fan belts were loose. These were fixed before measurements. The photos below indicate the existing cooling towers for the Chiller Plant Room 1 (CPR-1) and the site arrangement. Existing cooling towers for the CPR-1 with 2 Nos. on duty and 1 No. stand by unit located at the CPR-2.

Figure 3.5 - Existing Cooling Towers for the CPR-1

Figure 3.6 - Top view for the Existing Cooling Towers for the CPR-1.

Figure 3.7 - Interior look for the Existing Cooling Towers for the CPR-1.

3.6 The Overall Chiller Plant Room 1 (CPR -1) Single Line Schematic Drawing

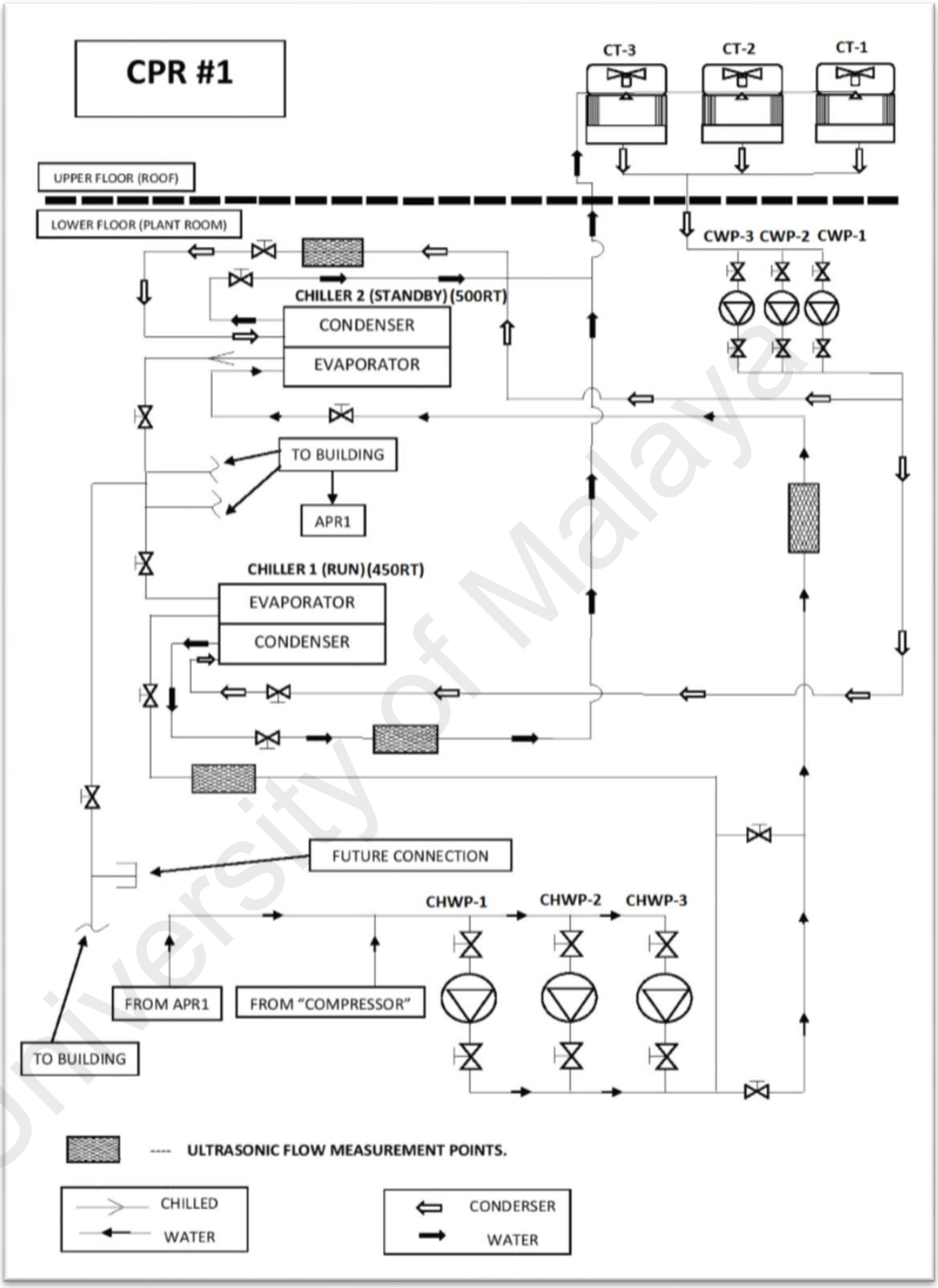

Figure 3.8 - Single Line Schematic Drawing

3.7 Instrumentation

Exact measuring instruments conforming to the Code on Environmental Sustainability Measures for existing building that is prevailing at the time of installation were utilized during the audit to accumulate data on the power consumption, temperatures and flow rate. The accompanying test instruments and tools was utilized to attempt the tests details within the procedure.

Table 3.8 - Instruments and Tools was used for taken results

WATER SYSTEM		
Ultrasonic Flow Meter	Micronics Portaflow 300 c/w Data Logger	Fluid Flow Rates
Electronic Manometer	Comdronic AC6	Fluid flow rate & Pressure
Pressure Gauges	Wika/Winters	Water Pressure Measurements.
ELECTRICAL MEASUREMENT		
Power Analyzer	Fluke 434	Electrical Current/Voltage Logging
TEMPERATURE MEASUREMENT		
Digital Thermometer	Fluke 52 II Dual Input Thermometer	Temperature Measurement /Logging
Digital Data Logging Thermometer	Thermo Recorder	Ambient Temperature and Humidity Logging

3.7.1 Test instruments listed

Figure 3.9 - Ultrasonic Flow Meter & Electronic Manometer

Figure 3.10 - Clamp Induction Ammeter & Power Analyzer

Figure 3.11 - Digital Thermometer & Digital Data Logging Thermometer

3.7.2 Measurement Method

For the CPR-1 measurements, two sets of instruments was utilized to carry out readings on both, the chilled water and condenser water loops as detailed below.

The unit of chilled water energy in Refrigeration Ton Hour (RTH) is measured and metered by recording the flow of water in cubic metre per minute multiplied by the measured differential temperature between the supply temperature and the return temperature of chilled water.

Fundamentally, the measurement of the chilled water energy involves the measurement of two quantities:

a) Quantity of flow rate of chilled water
b) Differential temperature of supply and return chilled water.

Power Analyser with direct KW measurements were utilized for logging of Chillers power (KW). Ammeters were utilized for pumps for single measurements.

3.7.3 Flow Measurement

The technique adopted for the flow measurement of chilled water will be through the use of non-intrusive ultra-sonic measurement method. The principle of the ultra-sonic flow measurement is through the use of two transducers clamped onto the chilled water pipe as shown in figure 3.12.

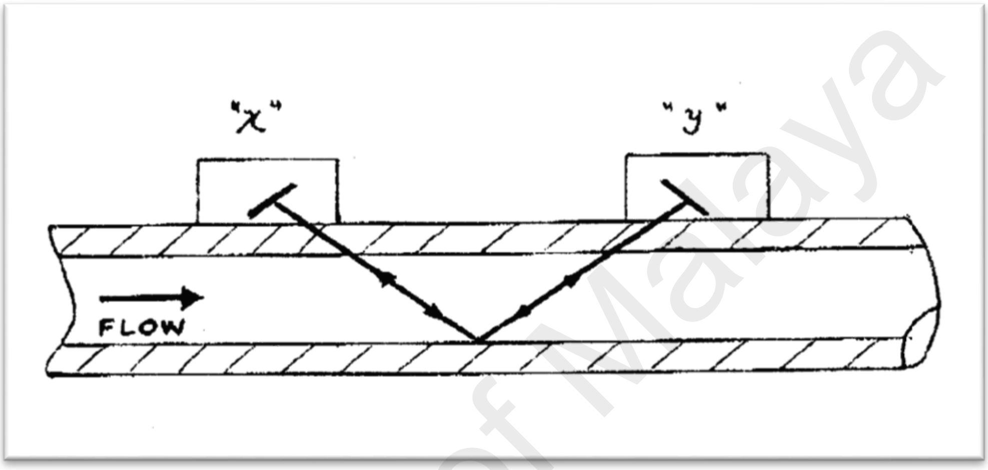

Figure 3.12 – Chilled Water Flow Measurement

At the point when the ultrasound is transmitted from transducer "*X*" to transducer "*Y*", the speed at which the sound travels through the liquid is accelerated slightly by the velocity of the liquid. If ultrasound is transmitted in the opposite direction from "*Y*" to "*X*", the speed is decelerated, because the sound is travelling against the flow of the liquid.

The difference in time taken by ultrasound to travel the similar distance but in opposite directions is directly proportional to the flow velocity of the liquid.

With the knowledge of the pipe cross-sectional area, the volumetric flow of the liquid can be easily calculated from the flow velocity.

Along this lines with the utilization of this "Transit time" ultrasonic flow meter, the liquid flow within a closed pipe was measured accurately without the need for any mechanical devices to be inserted through the pipe wall to intrude into the flow system.

3.7.4 Temperature Measurement

For the temperature measurement, digital thermometers (Fluke model No.52) with dual channel input and data logging capability was utilized.

As there are no accessible ports within the pipes work for actual water temperature measurements, pipe surface temperatures was not taken.

3.7.5 Electrical Measurement

Electrical measurements was taken at the Chiller DB. Real time readings was logged for the voltage and currents for all 3 phase supplies for a consistent period of 4 days.

3.7.6 Pump Test

Pump tests was performed on the 3 Nos. of chilled water pumps and Condenser water pumps. Test techniques incorporated the following for each of the pumps:-

a) Operational pump pressures for the chilled and condenser water pumps was carried out.
b) Motor running currents were measured.
c) Plot measurements on performance curves and determine approximate flow rate value.

The following tests were not carried out at site as COMPANY 'T' was not able to make the systems accessible for testing and as the systems were in operations:

a) Shut-off head pressures for the chilled and condenser water pumps

b) Pump/motor drive speeds

3.8 Measurement Locations

The following locations shown for the ultrasonic flow rate measurements. Temperature measurements was taken as near to the Chillers as could be allowed.

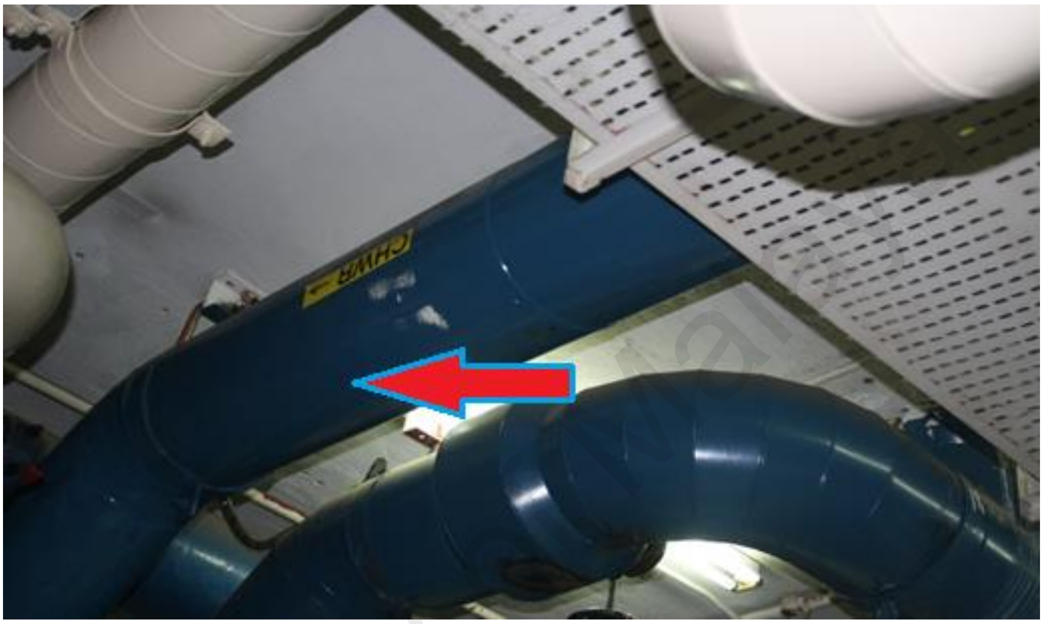

Figure 3.13 – Ultrasonic flow location for chilled water Supply line at Chiller 1

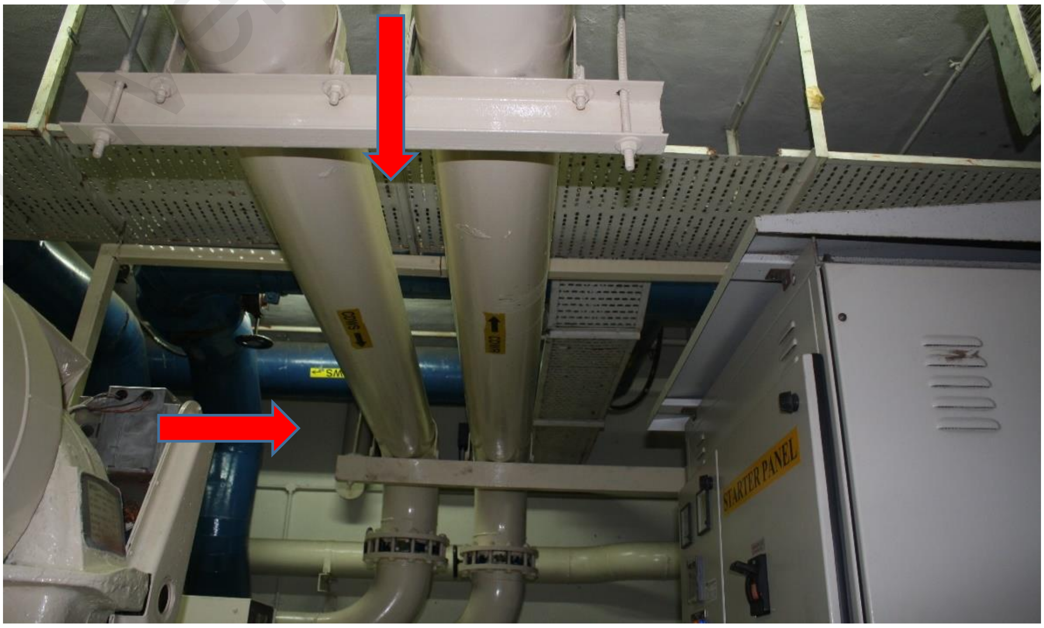

Figure 3.14 – Ultrasonic flow location for condenser water Supply line at Chiller 1

3.9 Instrument Measurement Accuracy

All the electrical instruments which are used for the Chiller Plant Room 1 (CPR-1) measurements are tabulated in table below with individual instruments measurement accuracy range.

Table 3.9 – Instruments measurement accuracy

No	Instrument	Purpose	Accuracy
1	Portaflow 300 Ultarsonic flowmeter	Ultrasonic water flow rate	2% +/- 0.002 m/s whichever greater
2	Portaflow SE Ultarsonic flowmeter	Ultrasonic water flow rate	+/- 1.3% of reading or +/- 0.1 m/s
3	Fluke 52-II Dual Input Thermometer	Temperature measurement	0.05% of reading +/- 0.3 °C
4	Fluke 434 Power Quality Analyzer	Electrical power measurement	+/- 1.5% or +/- 10 counts
5	Kimo KT110 Temperature/Humidity Data logger	Ambient temperature/humidity measurement	Temperature +/- 0.4 (-20 to +70°C) Humidity-factory calibration uncertainty 0.88%RH
6	Comdronic AC 6	Differential water pressure measurement	0.3 to 1Kpa +/- 0.03 Kpa 1 to 10Kpa +/- 0.05Kpa 10 to 200 Kpa +/- 0.5% reading
7	Wika Pressure Gauge	Water pressure measurement	+/-1% of span

3.10 The formulas and calculation methods

Chiller Performance Analysis Calculations Standards and Formulas are shown below.

Chillers:

Under these assumptions, the first law of thermodynamics requires that the rate of heat transfer from the hot fluid to be equal to the rate of heat transfer to the cold one. That is,

$q = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in})$ …………………..(3.1)

from cooling tower fluid side heat transfer

And

$q = \dot{m}_h C_{ph}(T_{h,in} - T_{h,out})$ …………………..(3.2)

From the building fluid to the Chiller side heat transfer

Where the subscripts ***c*** and ***h*** stand for ***cold*** and ***hot*** fluids, respectively.

Of course ideally both will be equal but the difference is the losses. So the bigger the losses the less efficient the Chiller is.

Cooling towers

Cooling tower is just device that emit heat to the environment, so there is no efficiency calculation, but we can calculate the heat removed from the each cooling.

$q = \dot{m}C_p(T_{out} - T_{in})$ …………………..(3.3)

q – Amount of heat (kW)

$\dot{m}$ – Mass flow rate (L/s)

C_p – Specific heat of the working fluid (4.2 J/g ^{0}C)

T_{out} – Outlet temperature (degree Celsius, ^{0}C)

T_{in} – Temperature (degree Celsius, ^{0}C)

The power conversion of kW to BTU_{IT}/hr is given by the formula:

$\boldsymbol{P_{(BTU/hr)} = 3412.142 \cdot P_{(kW)}}$ …………………..(3.4)

For Chiller:

So the power *P* in refrigeration tons (RT) is equal to the power *P* in BTUs per hour (BTU/hr) divided by 12000:

$\boldsymbol{P_{(RT)} = P_{(BTU/hr)} / 12000}$ …………………..(3.5)

Chiller load

The Chiller load is calculated by measured cooling refrigerant ton (RT) divided with design capacity of Chiller (RT) and multiply with 100%.

Chiller load = (measured RT/ design RT) x 100% …………………..(3.6)

Kilowatt/RT

The term is defined as the ratio of energy consumption in *kW* to the rate of heat removal in *tons* at the rated condition. The lower the *kW/ton* the more efficient the system.

$kW/ton = P_c / E_r$ …………………..(3.7)

where

P_c = *energy consumption (kW)*

E_r = *heat removal (ton)*

Chilled Water and Condenser Water Pump Efficiency

The pump efficiency calculated by measured water power (kW) divided with shaft power (kW).

$\mathbf{E_f = P_W / P_S}$ …………………..(3.8)

Where:

E_f= efficiency

P_w= the water power

P_s= the shaft power

$\mathbf{P_w = Q \times g \times H}$ …………………..(3.9)

Where:

Q= Flow (L/s), H= Head (m), g = 9.810 m/s^2

$\mathbf{P_s = IV\sqrt{3}\ \cos\varphi}$ …………………..(3.10)

Where:

V = voltage (V), I = current (A, amps), *cos φ (power factor assumed to be 0.87)*

Note: The power factor of the motor are assumed as the documentation details are unavailable.

CHAPTER 4: RESULTS AND DISCUSSION

The COMPANY ‘T’ noticed that annual operation cost is very high in Air Conditioning system and the system was not performing efficiency. Due to that they decided to audit the air conditioning system to enhance overall Chiller Plant room 1 efficiency (kW/RT) which able to provide savings on the total operation annually.

4.1 Chiller Plant Room 1 (CPR-1) Measured Data

The following shows the COMPANY ‘T’ Chiller plant room 1 (CPR-1) measured data is shown below accordingly:

i. Chiller data consists of temperature, flow rate and power consumption.

ii. Chilled water pump data consists of flow rate, differential head, and motor power consumption.

iii. Condenser water pump data consists of flow rate, differential head, and motor power consumption.

iv. Cooling tower data consists of fan motor power consumption.

4.2 Existing Chiller Measured Data

In the COMPANY ‘T’ (CPR-1) consists of two numbers of water cooled (1 duty and 1 Stand by) are operating. The Chiller Number Two is stand by unit. The Chiller was not in operation and do not permit to On the Chiller for measurement purpose. Chiller No. 1 Trane 450RT in Operation. The details are tabulated in Table 4.1.

Table 4.1 – Chiller Capacity Details

No.	Brand	Model	Series No.	Tonnage (RT)	Installation Year	Mode
CH-1	TRANE	CVGF500	L01D08029	450	1996	DUTY

4.3 Existing Chilled Water Pump Measured Data

4.3.1 Existing Chilled Water Pump Capacity Details

In the COMPANY 'T' (CPR-1) consists of Three numbers of Chilled Water Pump (1 duty and 2 Stand by) are operating. Chilled water Pump number Two (CHWP-2) in Operation. The details tabulated in table below. The CHWP-1 & CHWP-3 is on standby mode during the measurements on 5th October 2017. So, the chilled water pump do not permit to turn ON for operation mode for measurement purpose. *NOTE: The measurements for the stand by CHWP-1 & CHWP-3 and closed head pump test were not carried out at COMPANY 'T' was not able to make the systems available for testing and as the systems were in operation.*

CHWP-2

The CHWP-2 was in operation and measured on 5th October 2017.

Table 4.2 – Existing Chilled Water Pump Measured Data

PUMP								MOTOR				
Impeller Dia (mm)	Flow rate L/s)		Design %	Differential Head (m)			Delta-P Head (m)	Output kw	Full Load Current (Amps)	Running Current (Amps)		
	Design	Measured		Design	Suction	Discharge				R	Y	B
385	56.7	88.9	156	50	25	51	26	45	85	81.9	81.1	81.2

4.3.2 Chilled Water Pumps Efficiency Analysis

The Chilled Water Pump Performance Curve and Efficiency Analysis is show below.

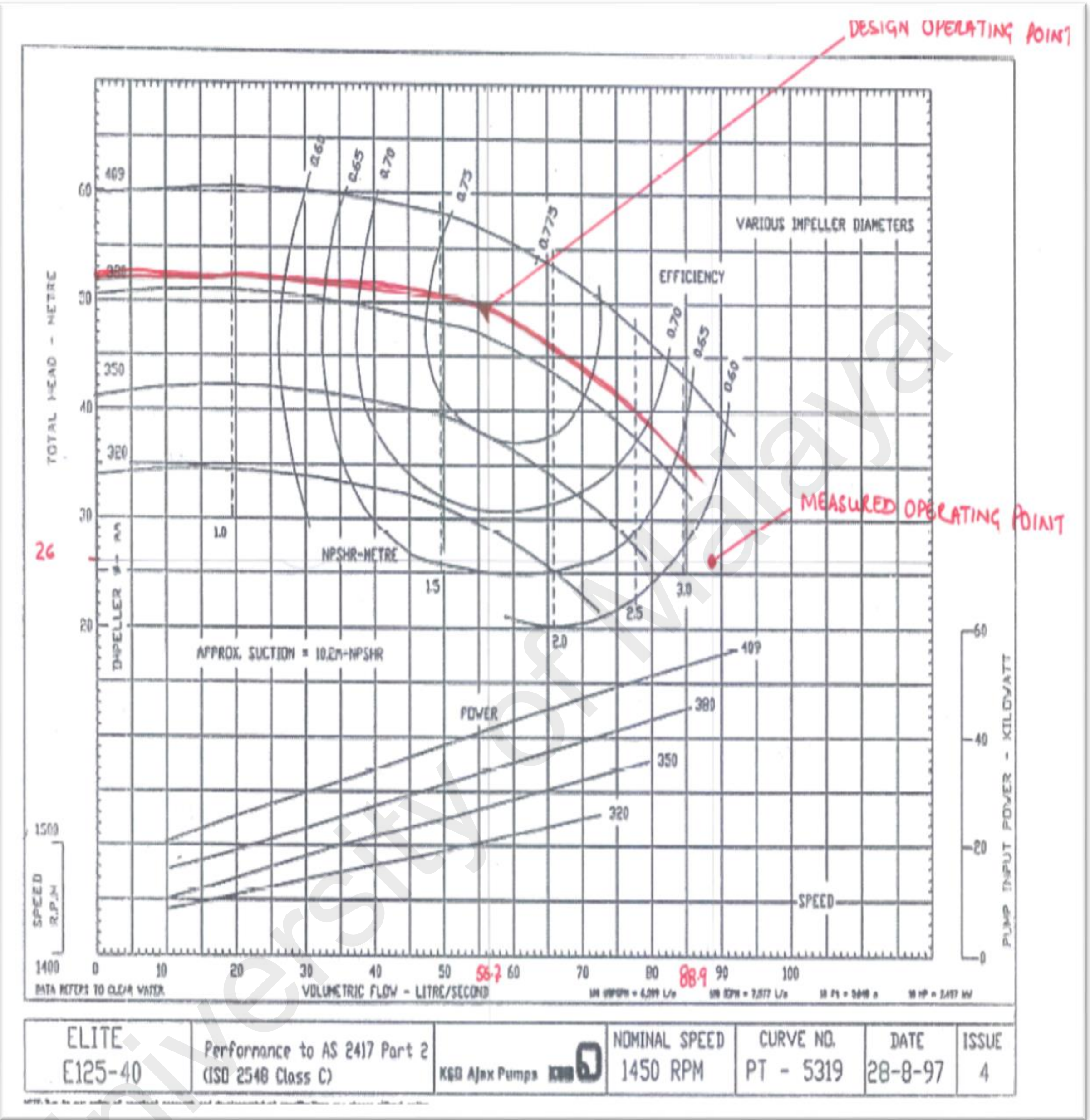

Figure 4.1 – Chilled Water Pump Curve Diagram from Ajax Pumps

The closed head pump test was not able to be carried out to confirm the impeller size due to the CPR-1 in operation.

The current operating and design points have been plotted on the given curve as shown in Figure 4.1. The curve is the best pump curve found for the specified model through online data.

As the measured ΔP of 26 meters is far below the design pressure of 50 meters, the measured point falls too far away to be plotted on the curve.

Using the measured flow rate from the ultrasonic flow meter, the operating point falls in an unreliable zone.

Based on the graph above, we can conclude that the pump is working in an inefficient region, away from the efficiency lines or outside the pump curve.

Based on the pump curve in Figure 4.1, the required (Net Positive Suction Head) NPSHR is 10.2m and the available NPSHA 26.2m, hence there is cavitation occurs during the pump operation.

COMPANY 'T' shall confirm the condenser water pump impeller size and the pump head with the original equipment manufacturer pump curve.

Chilled Water Pump Efficiency

$\mathbf{E_f = P_W / P_S}$

Where:

E_f= efficiency

P_w= the water power

P_s= the shaft power

$\mathbf{P_w = Q \times g \ X \ H}$

Where:

Q= Flow (L/s)

H= Head (m

g = 9.810 m/s^2

P_w =88.9 L/s x 9.810 g X 26

=23,114 watt

= 22.7 kW

$P_s = IV\sqrt{3}\,\cos\varphi$

$= 81.4 \times 415 \times \sqrt{3} \times 0.87$

$\mathbf{= 46.81\ kW}$

$\mathbf{E_f = P_W / P_S}$

$= 22.7 / 46.81$

$\mathbf{= 0.48}$

The current performance of the Chilled Water Pump is 0.48. The recommended of the Chilled Water Pump efficiency shall be 0.7.

4.4 Condenser Water Pump Measured Data

4.4.1 Existing Condenser Water Pump Operation Measured Data

Existing Condenser Water Pump 2 (CDWP-2)

In the COMPANY ‘T’ roof top of the (CPR-2) consists of Three numbers of Condenser Water Pump (1 duty and 2 Stand by) are operating. Condenser water Pump number Two (CDWP-2) in Operation. The CDWP-2 is on operation and measured on 13th October 2017. The details tabulated in Table 4.6.

Table 4.3 – Existing Condenser Water Pump Operation Measured Data

PUMP								MOTOR				
Impeller Dia (mm)	Flow rate L/s)		Design %	Differential Head (m)			Delta-P	Output kw	Full Load Current (Amps)	Running Current (Amps)		
	Design	Measured		Design	Suction	Discharge				R	Y	B
359	67	78	116	36	-1.63	18.36	20.0	55	96	43.2	42.1	43.7

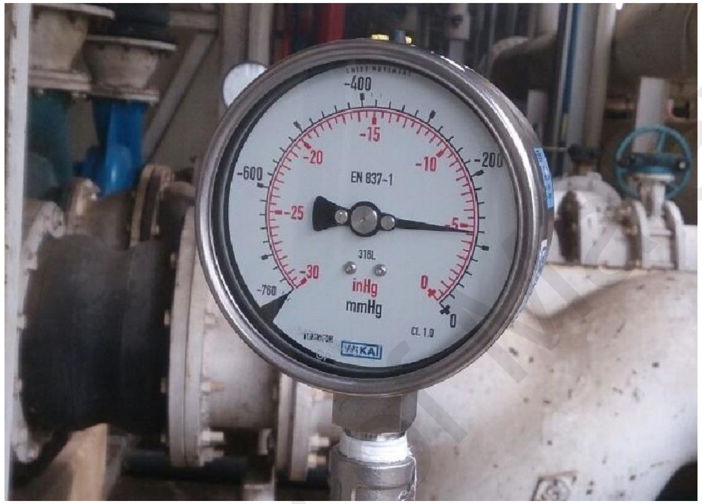

Figure 4.2 –The photo indicates that the CWP-2 suction Pressure is -1.63m.

The **CDWP-1 & CDWP-3 is on standby** and not able to measure on 13th October 2017.

NOTE: The measurements for the stand by CDWP-1 & CDWP-3 and closed head pump test were not carried out as COMPANY 'T' was unable to make the systems available for testing and as the systems were in operation.

4.4.2 Condenser Water Pump Efficiency Analysis

The Condenser Water Pump Performance Curve and Efficiency Analysis is show below.

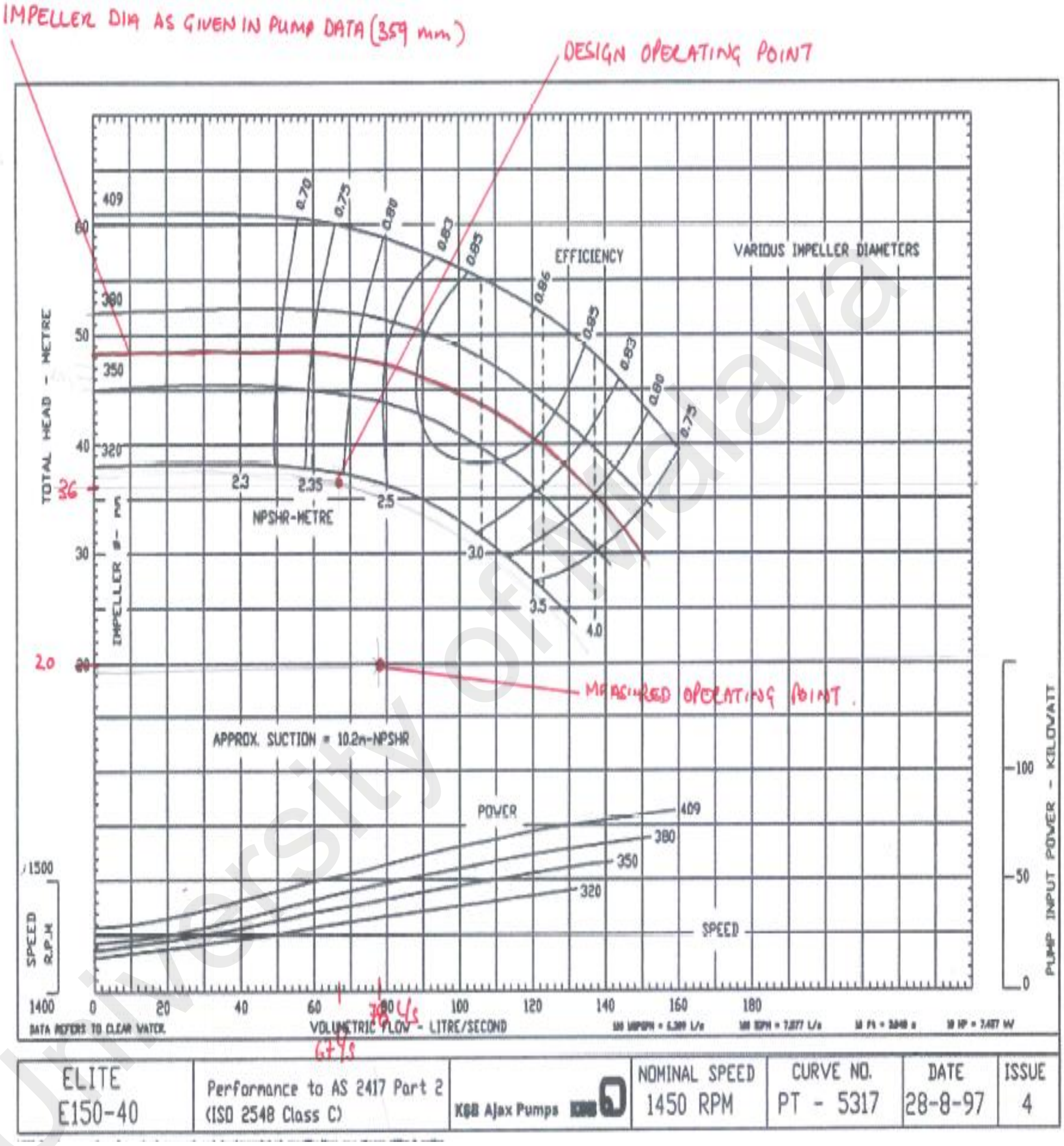

Figure 4.3 – Condenser Water Pump Curve Diagram from Ajax Pumps

As per the pump curve, the impeller size and design operating point do not match. This would suggest that either the current impeller is a 318mm diameter or that we are plotting the readings on the wrong curve.

The measured point of Δpressure and obtained flow rate from the ultrasonic flow meter confirms the same.

COMPANY ‘T’ shall confirm the condenser water pump impeller size and the pump head with the original equipment manufacturer pump curve.

Based on the pump curve above the required (Net Positive Suction Head) NPSHR is 10.2m and the available NPSHA is 0.89m. Thus, assuming the curve is correct the pump is operating at condition where cavitation occurs. It is an inefficient condition to have cavitation.

Based on the measured raw data the Condenser water pump efficiency is calculated as shown below:

Condenser Water Pump Efficiency

$$\mathbf{E_f = P_W / P_S}$$

Where:

E_f= efficiency

P_w= the water power

P_s= the shaft power

$$\mathbf{P_w = Q \times g \times H}$$

Where:

Q= Flow (L/s)

H= Head (feet)

g = 9.810 m/s^2

P_w =78 x 9.810 X 20

=15,304 watt

= 15.3 kW

$P_s = IV\sqrt{3}\ \cos\varphi$

$=43 \times 415 \times \sqrt{3} \times 0.87$

= 24.73 kW

$E_f = P_W / P_S$

$= 15.3 / 24.73$

$\mathbf{= 0.62}$

The current performance of the Condenser Water Pump is 0.62. The recommended of the Condenser Water Pump efficiency shall be 0.7.

Based on the calculated value (calculated HRT) the Condenser water pump efficiency is calculated as shown below:

Condenser Water Pump Efficiency

$\mathbf{E_f = P_W / P_S}$

Where:

E_f= efficiency

P_w= the water power

P_s= the shaft power

$\mathbf{P_w = Q \times g \times H}$

Where:

Q= Flow (L/s)

H= Head (feet)

g = 9.810 m/s^2

Note: 99 L/s is the calculated flow rate based on the calculated HRT value.

P_w =99 x 9.810 X 20

=19,424 watt

= 19.4 kW

P_s =IV√3 *cos φ*

=43 x 415 X √3 x 0.87

= 24.73 kW

E_f = P_W / P_S

=19.4 / 24.73

= 0.78

There 2 Condenser Water Pump in CPR-1. The performance of the Condenser Water Pump 1 is 0.62 and Condenser Water Pump 1 is 0.78. The recommended of the Condenser Water Pump efficiency shall be 0.7.

Note: 55 L/s is the calculated flow rate based on the calculated HRT value.

4.5 Existing Cooling Towers Measured Data

4.5.1 Existing Cooling Towers Capacity Details

In the COMPANY ‘T’ roof top of the (CPR-2) consists of Three numbers of Cooling Tower (2 duty and 1 Stand by) are operating. The Cooling Tower details tabulated in table below.

Table 4.4 - Existing Cooling Towers Water Capacity Details

No.	Brand	Model	Series No.	Fan Motor (kW)	Design Mode	Install -ation Year	*Tonnage RT	*Flow Rate USGPM	Mode
CT-1	BAC	700	33568	30	Stand by	NA	533	1600	Stand by
CT-2	BAC	700	33568	30	Duty	NA	533	1600	Duty
CT-3	BAC	700	33568	30	Duty	NA	533	1600	Duty

NOTE: The data is based on OEM details with reference to the model and series No. of the cooling tower. The remaining data is based on information provided by COMPANY ‘T’.

4.5.2 Existing Cooling Towers Measured Data

Existing Cooling Tower 1 (CT-1)

The CT-1 is in standby during the measurement on 13th October 2017.

*Note: *NA: Data is not available as the unit was in standby.*

4.5.3 Existing Cooling Tower 2 (CT-2)

In the COMPANY 'T' roof top of the (CPR-2) consists of Three numbers of Cooling Tower (2 duty and 1 Stand by) are operating. Cooling Tower number Two (CT-2) in Operation. The CT-2 is on operation and measured on 13th October 2017. The details tabulated in table below.

Table 4.5 - Existing Cooling Tower (CT-2) Measured Data

MOTOR						DRIVE			
Output (kW)	Frame No	Full Load Current (Amps)	Running Current (Amps)	Speed (RPM)		Fan Pulley (mm)	Fan Shaft (mm)	Motor Pulley (mm)	Motor shaft (mm)
				Design	Measured				
30	200 L	62	R: 36.7 Y: 36.1 B: 36.6	1480	*NA	760	60	200	55

*NOTE: *NA: Data is not available as unit was in service and could not be switched off to install magnetic sticker for the measurements.*

4.5.4 Existing Cooling Tower 3 (CT-3)

In the COMPANY 'T' roof top of the (CPR-2) consists of Three numbers of Cooling Tower (2 duty and 1 Stand by) are operating. Cooling Tower number Three (CT-3) in Operation. The CT-3 is on operation and measured on 13th October 2017. The details tabulated in table below.

Table 4.6 - Existing Cooling Tower (CT-3) Measured Data

MOTOR						DRIVE			
Output Kw	Frame No	Full Load Current (Amps)	Running Current (Amps)	Speed (RPM)		Fan Pulley (mm)	Fan Shaft (mm)	Motor Pulley (mm)	Motor shaft (mm)
				Design	Measured				
30	200 L	62	R: 41.5 Y: 41.3 B: 41.7	1480	*NA	760	60	200	55

*NOTE: *NA: Data is not available as unit was in service and could not be switched off to install magnetic sticker for the measurements. The CT-3 was noticed that the fan belts were loose during the measurements. The measurements for the CT-1, were not carried out as COMPANY 'T' was not able to make the systems available for testing and as the systems were in operation.*

4.5.5 Cooling Towers Performance Efficiency Analysis

The cooling towers with propeller or axial fan performance required shall be ≥38.2 GPM/hp with reference to CTI ATC-105 and CTI STD-201, Cooling Towers technology Institute standards.

The cooling tower performance is defined as the maximum flow rating of the tower divided by the fan nameplate rated motor power.

η = maximum flow rate (USGPM) / motor power (hp)

Rated efficiency for the existing cooling tower:

η = maximum flow rate (USGPM) / motor power (hp)

=1,600 USGPM / 50.96 hp

=**31.39 USGPM/hp**

Based Measured Data:

Existing operating efficiency for the operating cooling towers, CT-2 & CT-3:

$\eta_{CT\text{-}2}$ = maximum flow rate (USGPM) / motor power (hp)

= (1,368 USGPM / 2) / 29.9 hp

=**22.8 USGPM/hp**

η $_{CT-3}$ = maximum flow rate (USGPM) / motor power (hp)

= (1,368 USGPM / 2) / 34.12 hp

=**20.1 USGPM/hp**

Based Calculated Data:

Existing operating efficiency for the operating cooling towers, CT-2 & CT-3 based on the calculated HRT value:

Note: 99 L/s (1569 USGPM) is the calculated flow rate based on the calculated HRT value.

η $_{CT-2}$ = maximum flow rate (USGPM) / motor power (hp)

= (1569 USGPM / 2) / 29.9 hp

=**26.2 USGPM/hp**

η $_{CT-3}$ = maximum flow rate (USGPM) / motor power (hp)

= (1569 USGPM / 2) / 34.12 hp

=**22.9 USGPM/hp**

The present Number of cooling towers in operation are two numbers. The Cooling tower efficiency shall be reduced by operating with 1 No. Cooling tower only.

4.6 Existing Chiller Plant Room 1 (CPR-1) Performance & Efficiency Analysis

Existing CPR-1 performance and efficiency analysis of consists of the following equipment's.

- 2 Nos. of Chiller (1 duty/ 1 stand by) in the CPR-1
- 3 Nos. of cooling towers (2 duty / 1stand by) at the roof of the CPR-2
- 3 Nos. of chilled water pumps (1 duty / 2 stand by) in the CPR-1
- 3 Nos. of condenser water pumps (1 duty / 2 stand by) in the CPR-2

Based on that the COMPANY 'T' CPR-1 operation setting Standby unit Chiller, Cooling Tower, Chilled Water Pumps and Condenser water Pumps are unable to measured. Hence, the efficiency analyze for the standby equipment's for as above are not included in this report.

Table 4.7 - The data below is divided to 4 section based on 6 hour's time scale:

No.	Time
1	12.0 m to 6.00 am
2	6.00 am to 12 noon
3	12.00 noon to 6.00 pm
4	6.00 am to 12.00 am

4.6.1 Chiller No.1 (450 RT) Overall Performance

The overall Chiller No.1 evaporator data is summarized in the table below with the 6 hours timeframe from 15th September 2017 to 18th September 2017. Based on the tabulated graph, the Chiller performance / efficiency analysis parameter is calculated and summarized in the table below:

Table 4.8 – Chiller No.1 Evaporator measured and related computed data.

DATE	TIME	*TEMPEARTURE °C			*TEMPEARTURE °F			FLOW RATE (L/s)	*FLOW RATE (USGPM)	*COOLING KW	*COOLING TONNAGE (RT)	*CHILLER LOAD %	KILOWATT				*KW/RT
		CHWS	CHWR	DEL T	CHWS	CHWR	DEL T						R	Y	B	*TOTAL KW	
15.09.2017	12AM-6AM	5.50	9.55	4.05	41.90	49.19	7.29	78.60	1,245.97	1,331.00	378.46	84.10	98.00	99.00	99.80	296.80	0.78
	6AM-12PM	5.60	9.65	4.05	42.08	49.37	7.29	79.10	1,253.89	1,339.46	380.87	84.64	99.00	99.00	99.80	297.80	0.78
	12PM-6PM	5.60	9.45	3.85	42.08	49.01	6.93	80.80	1,280.84	1,300.68	369.84	82.19	98.00	99.00	99.00	296.00	0.80
	6PM-12AM	5.60	9.55	3.60	42.08	49.19	7.11	80.50	1,276.09	1,329.51	378.04	84.01	99.50	99.00	97.00	295.50	0.78
16.09.2017	12AM-6AM	5.60	9.65	3.30	42.08	49.37	7.29	79.80	1,264.99	1,351.32	384.22	85.38	98.90	97.00	99.00	294.90	0.77
	6AM-12PM	5.70	9.70	3.40	42.26	49.46	7.20	79.90	1,266.57	1,336.31	379.96	84.43	99.00	99.00	97.00	295.00	0.78
	12PM-6PM	5.70	9.63	3.93	42.26	49.33	7.07	78.61	1,246.13	1,291.72	367.28	81.62	97.00	98.00	98.90	293.90	0.80
	6PM-12AM	5.50	9.50	4.00	41.90	49.10	7.20	77.15	1,222.98	1,290.31	366.88	81.53	98.90	99.50	96.00	294.40	0.80
17.09.2017	12AM-6AM	5.60	9.60	4.00	42.08	49.28	7.20	78.26	1,240.58	1,308.88	372.16	82.70	97.50	99.00	99.90	296.40	0.80
	6AM-12PM	5.70	9.70	4.00	42.26	49.46	7.20	77.13	1,222.66	1,289.98	366.78	81.51	99.20	99.50	97.00	295.70	0.81
	12PM-6PM	5.60	9.60	3.60	42.08	49.28	7.20	77.18	1,223.46	1,290.82	367.02	81.56	97.00	99.00	99.00	295.00	0.80
	6PM-12AM	5.60	9.70	3.60	42.08	49.46	7.38	76.59	1,214.10	1,312.97	373.32	82.96	98.50	99.70	99.00	297.20	0.80
18.09.2017	12AM-6AM	5.60	9.57	3.50	42.08	49.23	7.15	76.84	1,218.07	1,275.49	362.66	80.59	99.00	99.00	98.00	296.00	0.82
	6AM-12PM	5.60	9.56	3.96	42.08	49.21	7.13	76.13	1,206.81	1,260.52	358.41	79.65	97.00	99.00	98.60	294.60	0.82
	12PM-6PM	5.60	9.51	3.91	42.08	49.12	7.04	77.45	1,227.74	1,266.19	360.02	80.00	99.00	98.00	98.50	295.50	0.82
	6PM-12AM	5.60	9.58	3.98	42.08	49.24	7.16	77.10	1,222.19	1,283.03	364.81	81.07	97.90	99.00	99.00	295.90	0.81

*NOTE: *All data are based on the calculated value from the measured raw data.*

4.6.2 Existing Trane Chiller No.1 (450RT) Simulated Design Data for Reference

The existing Trane Chiller No.1 simulated design data with reference from OEM (TRANE) for the 450 RT Chiller data is summarized in the table below.

Table 4.9: Trane 450RT simulated performance data.

Chiller % Load	Capacity (RT)	Evap Leaving Water Temp (F)	Evap Flow Rate (USGPM)	Evap Entering Water Temp (F)	Evap Pressure Drop (ft.H20)	Cond Entering Water Temp (F)	Condenser Flow Rate (USGPM)	Cond Leaving Water Temp (F)	Condenser Pressure Drop (ft.H20)	Power (kW)	Running Amps	Efficiency (kW/RT)
100	450	44	1075.4	54	11.54	87	1258.3	97	10.6	264.4	424.2	0.588
90	405	44	1075.4	53	11.57	87	1258.3	95.99	10.62	245.5	385.3	0.606
80	360	44	1075.4	52	11.59	87	1258.3	95.01	10.64	229.5	353.5	0.637
70	315	44	1075.4	51	11.61	87	1258.3	94.04	10.66	213.1	323.9	0.677
60	270	44	1075.4	50	11.63	87	1258.3	93.07	10.67	196.3	296.3	0.727
50	225	44	1075.4	49	11.66	87	1258.3	92.1	10.69	178.5	270	0.794
40	180	44	1075.4	48	11.68	87	1258.3	91.14	10.71	158.7	247.3	0.882
30	135	44	1075.4	47	11.7	87	1258.3	90.18	10.73	137.1	224.4	1.015
20	90	44	1075.4	46	11.72	87	1258.3	89.22	10.75	114.3	203.2	1.27
16	72	44	1075.4	45.6	11.73	87	1258.3	88.84	10.76	104.3	195	1.449

NOTE: The simulated data above based on the constant flow rate for the evaporator and condenser coil. The highlighted data, shows the design efficiency for the Chiller when the Chiller is loaded to 80%. The existing Chiller No.1 is operating with 78% - 80% load.

4.6.3 Existing Chiller NO.1 Overall Condenser Performance

The overall Chiller No.1 condenser data is summarized in the table below with the 6 hours timeframe from 22nd September 2017 to 25th September 2017. Based on the tabulated graph, the Chiller performance / efficiency analysis parameter is calculated and summarized in the table below:

Table 4.10: Chiller No.1 Condenser measured and related computed data:

DATE	TIME	** AMBIENT TEMPERATURE °C	AMBIENT TEMP (°F)	AMBIENT RH (%)	CHW °C	CWR °C	DEL T °C	CWS °F	CWR °F	DEL T °F	FLOW RATE (L/S)	* FLOW RATE (USGPM)	* HEAT REJECTION (KW)	* HEAT REJECTION (HRT)	COOLING TOWER LOAD %
22.09.2017	12AM-6AM	28.23	82.81	71.66	26.77	32.07	5.30	80.19	89.73	9.54	87.66	1,389.59	1,951.31	443.86	41.64
	6AM-12PM	32.72	90.90	58.68	27.01	32.34	5.33	80.62	90.21	9.59	87.73	1,390.70	1,963.92	446.73	41.91
	12PM-6PM	30.25	86.45	68.11	28.68	34.34	5.66	83.62	93.81	10.19	85.74	1,359.15	2,038.21	463.63	43.49
	6PM-12AM	27.61	81.70	72.76	28.04	33.53	5.49	82.47	92.35	9.88	85.79	1,359.94	1,978.15	449.96	42.21
23.09.2017	12AM-6AM	27.61	81.70	72.76	26.73	31.90	5.17	80.11	89.42	9.31	86.76	1,375.32	1,883.91	428.53	40.20
	6AM-12PM	28.92	84.06	73.98	27.69	33.02	5.33	81.84	91.44	9.59	86.29	1,367.87	1,931.69	439.39	41.22
	12PM-6PM	32.9	91.22	59.78	28.98	34.56	5.58	84.16	94.21	10.04	85.49	1,355.19	2,003.54	455.74	42.75
	6PM-12AM	30.47	86.85	66.82	28.18	33.64	5.46	82.72	92.55	9.83	85.54	1,355.98	1,961.60	446.20	41.86
24.09.2017	12AM-6AM	28.52	83.34	75.49	27.81	33.15	5.34	82.06	91.67	9.61	86.26	1,367.39	1,934.64	440.07	41.28
	6AM-12PM	29.55	85.19	73.16	28.22	33.74	5.52	82.80	92.73	9.94	85.39	1,353.60	1,979.68	450.31	42.24
	12PM-6PM	31.52	88.74	68.68	29.15	34.78	5.63	84.47	94.60	10.13	85.32	1,352.49	2,017.48	458.91	43.05
	6PM-12AM	29.19	84.54	78.11	28.67	34.20	5.53	83.61	93.56	9.95	84.64	1,341.71	1,965.85	447.17	41.95
25.09.2017	12AM-6AM	27.4	81.32	80.22	27.51	32.92	5.41	81.52	91.26	9.74	85.87	1,361.21	1,951.14	443.82	41.63
	6AM-12PM	27.24	81.03	83.21	27.51	32.80	5.29	81.52	91.04	9.52	85.89	1,361.53	1,908.30	434.08	40.72
	12PM-6PM	30.06	86.11	72.44	28.23	33.39	5.16	82.81	92.10	9.29	85.64	1,357.57	1,855.99	422.18	39.60
	6PM-12AM	30.55	86.99	70.83	28.70	34.69	5.99	83.66	94.44	10.78	85.88	1,361.37	2,160.57	491.46	46.10

*NOTE: *All data are based on the calculated value from the measured raw data.   **Data based on the psychometric chart*

4.7 Coefficient of Performance – COP for the Chiller No.1 (Trane 450RT)

The Coefficient of Performance - *CO*P - is the ratio between useful energy acquired and energy applied and can be expressed as below:

$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}} \quad \text{…………………..(4.1)}$$

The higher COP, more efficient system.

The maximum COP of a refrigerant cycle operates between temperature limit of T_L and T_H.

$$COP_{R,max} = COP_{R,rev} = COP_{R,Carnot} = \frac{T_L}{T_H - T_L} = \frac{1}{T_H/T_L - 1} \quad \text{…………..(4.2)}$$

The goal of energy analysis of a refrigerant system is to determine the components that can benefit the most by improvements.

The Chiller No.1 overall system power consumption kilowatt (kW) over Chiller Refrigerant Ton (RT) as tabulated below:

= CHILLER (kW Average of total electrical power consumption) + CHILLED WATER PUMP (kW total electrical power consumption) + CONDENSER WATER PUMP (kW total electrical power consumption) + COOLING TOWER (kW total electrical power consumption) / RT (Refrigerant tonnage, average of total cooling load)

= (295.66 + 49.9 + 26.4 +22.37 + 25.5) / 371

= 419.83 / 371

= 1.13 kW / RT

Table 4.11: The breakdown of the kW/RT for each Chiller system components.

Chiller kW/RT	Chilled Water Pump kW/RT	Condenser Water Pump kW/RT	Cooling Tower kW/RT
= 295.66/371 **= 0.80**	= 49.9/371 **= 0.13**	= 26.4/371 **= 0.07**	= (22.37+25.5)/371 **= 0.13**

Based on the value above, for the Chiller Plant Room 1 (CPR-1) the most efficient value to recommend for overall system is1.0 kW/RT. But the system is currently produce more than is 1.0 kW/RT.

4.8 Chilled Water System Efficiency

Chilled water system efficiency and energy savings can be calculated for the major components such as:

1. Chiller efficiency
2. Chiller water pump
3. Condenser water pump
4. Cooling tower (Negligible due to consumption on fan motor only)

4.8.1 Chiller Efficiency and Energy Savings

The sample of ROI is shown below to improve the overall chiller if the all the losses be gain and the efficiency is improve to 0.637 kW/RT based on Table 4.9.

Simulated design data with reference from the original equipment manufacturer.

The efficiency of the Chiller shall be decreased to 0.637 from the current operating efficiency of 0.8 kW/RT in average.

Table 4.12 - The sample of Chiller ROI

Unit	Chiller capacity (RT)	Current chiller capacity (RT)	Efficiency (kW/RT)	Operating power (kW)
Existing Chiller	450	371	0.8	295.66
*Proposed Chiller	450	371	0.637	229.5
			Net Saving In Operating Power	66.16

***NOTE:** The proposed chiller data and the efficiency obtain from the Table 4.17 with reference to original equipment manufacturer design data.*

Savings over a year:

66.16kW x 24hr x 365 days x RM0.35 = **RM 202,846.56**

4.8.2 Chilled Water Pump Efficiency and Energy Savings

The sample of ROI is shown below to improve the overall chilled water pump if the all the losses be gain and the efficiency is improve to 0.7 kW/RT.

The efficiency of the pump can be increase to 0.7 kW/RT by improving the delivery power and assuming the supplied power is the same.

We recommend the chilled water to be operated with 2 Nos. on duty to reduce the input power for the single pump or control via the variable speed drive.

Table 4.13 - The sample of Chilled Water Pump ROI

Operation	Supplied power, Ps (kW)	Delivery power, pw (kW)	Efficiency	Operating power (kW)
Existing Chilled water pump	46.81	22.9	0.48	23.91
Proposed Chilled water pump	46.81	32.7	0.7	14.11
			Net saving in operating power	9.8

Savings over a year:

9.8kW x 24hr x 365 days x RM0.35 = **RM 30,047.00**

4.8.3 Condenser Water Pump Efficiency and Energy Savings

The sample of ROI is shown below to improve the overall Condenser water pump if the all the losses be gain and the efficiency is improve to 0.7 kW/RT.

The efficiency of the pump can be increase to 0.7kW/RT by improving the delivery power and assuming the supplied power is the same.

Table 4.14 - The sample of Condenser Water Pump ROI

Operation	Supplied power, Ps (kW)	Delivery power, Pw (kW)	Efficiency	Operating power (kW)
Existing condenser water pump	24.73	15.33	0.62	9.4
Proposed condenser water pump	24.73	17.31	0.7	7.42
			Net saving in operating power	1.98

Savings over a year:

1.98kW x 24hr x 365 days x RM0.35/kW = **RM 6,071.00**

4.8.4 Total CPR-1 Estimated Savings per Year

= Chiller savings + Chiller water pump savings + Condenser water pump savings

= RM 202,846.56 + RM 30,047.00 + RM 6,071.00

= RM 238,964.56

NOTE: Cooling Tower electrical power usage is for the fan motors only which are running in constant mode. Hence, the total savings in operation cost for cooling towers are not calculated and are not included in the overall cost savings.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Based on the overall data, the CPR-1 system for Chiller No.1 (Trane Chiller 450RT) overall performance summarized are the Chilled water supply temperature within the range of 41°F to 42 °F, the Chilled water return temperature within the range of 49 °F to 50 °F. The delta T for the chilled water within the range of 7 °F to 8 °F. The chilled water flow rate within the range of 1200 to 1300 USGPM. The Chiller is loaded to 80% in average and operates at 371 RT/450 RT. The Chiller operates with 80% of load with efficiency of 0.80 kW/RT in average. The simulated Chiller data from Trane shows that the Chiller efficiency with 80% load and the Kw/RT is 0.637 kW/RT. The chilled water pump is operating with efficiency 0.49. And then the condenser water pump efficiency is 0.78. The both pumps are operates in constant speed with 1 no duty and 2 Nos. on standby mode. The Condenser water supply temperature within the range 80 °F to 84 °F and the Condenser water return temperature within the range is 89 °F to 95 °F. The delta T for the condenser water within the range of 9 °F to 11 °F. The ambient temperature and RH is within the range 80 °F to 90 °F and 60% to 80 %. The condenser water flow rate within the range of 1300 to 1400 USGPM. The Chiller condenser water estimated total flow rate 1600 USGPM, based ON BAC design data. The total heat rejection from the cooling towers is within the range 448 HRT with two numbers of cooling towers in operation. (Each cooling tower design capacity is 533RT). The exiting cooling towers operates with 38% load with the calculated HRT value. The cooling tower calculated efficiency for Cooling Tower 2 is 26.2 UGPM/hp and Cooling Tower 3 is 22.9 UGPM/hp. The rated efficiency shall be more than 38.2 USGPM/hp. The total CPR-1 estimated savings per year is RM 238,964.56, if the overall CPR-1 efficiency is improved to 1.13 kW/RT to 1.0 kW/RT then the chiller efficiency from 0.8 to 0.634 with current 80% load. Then the system will be in good performance.

5.2 Recommendation

5.2.1 Recommendation based on the observation:

- All the faulty temperature gauges, pressure gauges and the ball valves at the chilled water pipes and condenser water pipes shall be replaced.
- Test for the stand by chilled water pumps outside the factory to minimize the risk to operation.
- Test for the stand by condenser water pumps outside the factory to minimize the risk to operation.
- To tighten the cooling tower loosen fan motor belts.

5.2.2 Recommendation to improve the efficiency of the CPR-1:

- To implement variable speed drive (VSD) for the chilled water pumps to improve the efficiency of the system.
- To investigate the operation of the cooling tower fan motor belts and the mechanical components to improve the performance of the cooling towers.
- To implement variable speed drive (VSD) for the condenser water pumps to improve the efficiency of the system.
- To carry out the close pump head test and impeller size measurement to justify the pump performance characteristics curve for the chilled water pumps.
- To carry out the close pump head test and impeller size measurement to justify the pump performance characteristics curve for the condenser water pumps.
- To carry out the performance test, close pump head test and impeller size measurement to justify the pump performance characteristics curve for the stand by chilled water pumps.

- To carry out the performance test, close pump head test and impeller size measurement to justify the pump performance characteristics curve for the stand by condenser water pumps.
- To optimize the Cooling tower operation to at least 80% load with 1 no. of cooling tower. Current operation at approximate 30-40% is not recommended.
- Install digital power meters monitoring system for all individual chillers control panel – to monitor energy usage per chiller per RT during operation and to detect any fault in future.
- The existing CHWP-2 shall be replaced with new proposed pump to serve the system capacity of 1500USGPM with pump head of 20m. After the pump replacement, the operation of the CPR-1 shall be based on 1 No. duty CHWP and 2 Nos. CHWP stand by.
- To overhaul the existing chiller to improve the efficiency.
- To replace the existing chiller with new efficient water cooled chiller with similar capacity

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