ANALYSIS OF WATER-COOLED ELECTRIC CHILLER AT DISTRICT COOLING PLANT

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MECHANICAL ENGINEERING

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22205

Dissertation submitted in fulfillment of

as a Requirement for the

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With Honours

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Ir. Dr. Mohd Amin Abdul Majid)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NUR SYAHIRAH BINTI JA'AFAR

ABSTRACT

Universiti Teknologi PETRONAS (UTP) uses district cooling (DC) system for air-conditioning purpose. The UTP GDC plant produces chilled water. Chilled water is produced by chiller namely the Electric Chiller (EC). This study investigated the performance of water-cooled electric chiller by evaluating Coefficient of Performance method (COP) under theoretical and actual operating conditions. Microsoft Excel spreadsheet software was used to evaluate the COP. Historical data from UTP GDC were used for analysis. Evaluated COP for the electric chiller varies from 3.12 to 7.11.

TABLE OF CONTENTS

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Firstly, I would like to extend my gratefulness towards the almighty Allah as I am able to complete my final year project. It was a period with ups and downs but I am glad that I made it to the end.

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CHAPTER 1

INTRODUCTION

1.1 Background

Humid and tropical weather are common in Malaysia with over 25°C in average per year. With the increase of the average maximum temperature over the years, residents opted to install air-conditioning system to cool the building. Over the past few decades, demand for space cooling has increased significantly, significantly affecting electricity consumption. Here in Malaysia, located in Southeast Asia, from the year of 2010, the demand consumption of cooling has increases to approximately 70- 75% of the total energy consumption.

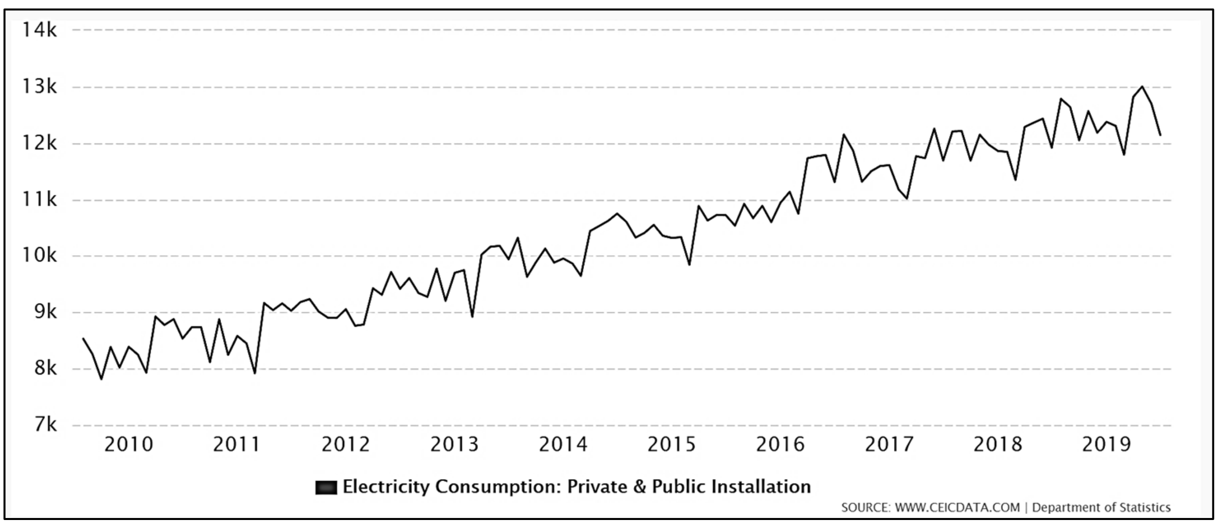


Figure 1: Electricity Consumption from Year 2010 to 2019

It is expected in the year of 2020, the energy demand in Malaysia will be reaching 116 Million ton of oil equivalents (Mtoe) with more than 50% of the energy are used in air conditioning and refrigeration system for occupancy building (Malaysian Energy Commision,2018). Major concern towards the global warming due to the rise of usage from the consumption of energy in buildings has been one of the utmost important issues to investigate. The International Energy Outlook in 2019 reported that there will be a significant grow of global energy consumption by the year of 2018-2050 by nearly 50%. The usage of energy by this sector is almost uncontrolled with rapid increase over the year that will directly impact the global warming. Seeking real solution to this dilemma is critical. Many studies, empirical analysis and energy consultant repeated claims that there is large unexploited economic potential for saving energy. The estimated range for this potential is in the range of 10-20%.

In Malaysia, district cooling plants are one of many ways to efficiently translates both capital and running cost savings. Flexibility are offers in in operating district cooling plant as each building can use as much or as little cooling as needed without worrying about chiller size or capacity [3]. District cooling plant comprises of 3 main components which are;

- Central Chiller Plant
- Distribution Network
- User Station

One of the integral parts in HVAC system are the chiller systems and has been continuously used for cooling purposes in centralized air conditioning system. The common type of chiller are the air-cooled chiller and the water- cooled chiller. Even though both chillers comprise of the same basic components; evaporator, compression, expansion valve and condenser, the only thing that differentiate both the chillers is by determining the way heat is rejected from the system. Both air-cooled and water-cooled utilize closed loop refrigeration circuit. Compressor circulates the refrigerant through the compressor which then the expansion device meters it. The evaporator then extracts the heat, lowers the fluid temperature all together while rising the refrigerant temperature. Extracted heat from the system will then be expelled out from the system. This process falls to the condenser and how the condenser cools the refrigerant becomes the key factor between air-cooled and water-cooled chillers.

Water-cooled chiller in district cooling is mainly used to provide cooling in commercial building [1] The application of a district cooling is used particularly in highly populated cities with water shortage problem with moderate electricity consumptions. District cooling are known as the central source in producing and distributing chilled water to target facilities as a way to provide air-conditioning. Chillers in district cooling has always been regarded as one of the important components. Vapor-compression chillers and absorption chillers are two general types of chiller used to produced chilled water that will later be distributed through networks of pipes and ducts. Air Handling Unit will then be receiving the chilled water for air conditioning purposes.

Here in Universiti Teknologi PETRONAS, district cooling system are used for the air-conditioning system. Named as UTP Gas District Cooling Plant (UTP GDC Plant), it provides chilled water to the campus.

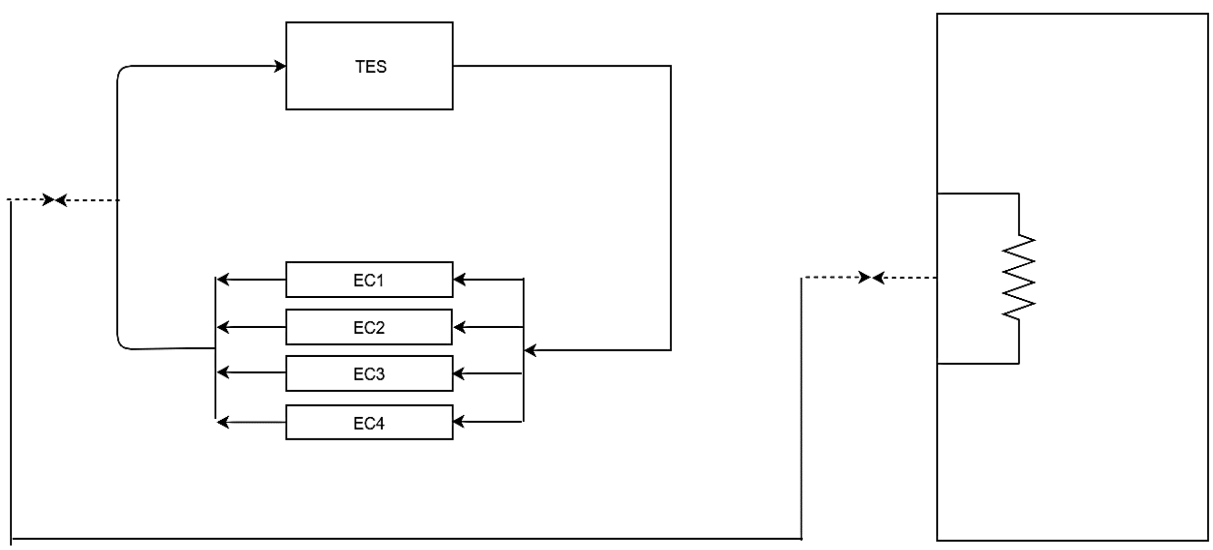


Figure 1.1 : Chiller System in UTP Gas District Cooling Plant

The current production of chilled water supply to the UTP campus comes four units of Electric Chillers (EC) as well as two unit of Steam Absorption Chiller (SAC). The cooling capacity for the electric chillers are designed for 325 Refrigeration Ton (325 RT). Electric chiller works closely with the Thermal Energy Storage Tank (TES) to provide chilled water supply from 8.00 PM to 6.00 AM during the non-peak hour as requirement of electricity by the campus. This is called as the full loading condition for the electric chillers while during the peak hour, the electric chiller will work in part load condition. Chilled water supply in UTP are crucially dependent to the chillers capacity and condition, so the focus of this study is on the performance analysis for Water-Cooled Electric Chiller in UTP GDC mainly on the Coefficient of Performance (COP).

1.2 Problem Statement

With almost half of the consumption of energy in commercial buildings are accounted by the HVAC systems with chiller being the major energy consumer. With approximation of 40% of the energy out of the total of 100% of the energy consumed by the chiller, companies must bear the operation cost due to its high electrical power demand. The performance of a chiller cooling system is regarded as highly efficient when producing the maximum Refrigeration Ton (RT) with low kilowatt (kW) usage. Chillers are usually designed to operate at partial load with a rare case of operating in full load conditions. Therefore, running chiller at its full load will resulted in sapping extra power. Hence, Coefficient of Performance (COP) is used as a method to determine the best optimizing performance and efficiency of Water-Cooled Electric chiller operating under partial and full load in UTP GDC Plant.

1.1 Objectives

The objectives of this project are:

i. To analyze the coefficient performance of water-cooled electric chiller for partial load and full load evaluation under theoretical and actual condition.

iii. To study the basic of a water-cooled electric chiller used in the industry.

1.2 Scope of Study

The scope of study of this project will covers analysis of Coefficient of Performance (COP) for water-cooled electric chiller especially Electric Chiller A (EC-0122A) in UTP GDC. The COP for the electric chiller were evaluated in a month of January 2020.

CHAPTER 2

LITERATURE REVIEW

Focus on theory of refrigeration cycle for vapour-compression is given in this chapter as to explains the basic principle and working mechanism for Electric Chillers in UTP. As electric chillers mentioned in this project is a water-cooled electric chiller, reviews will be based in research journals on the topic of water-cooled electric chiller is done with the focus on full load and partial load condition.

2.1 Water-Cooled Chiller Characteristics

The use of the cooling tower gives water-cooled systems an efficiency edge over air-cooled systems and RTUs. In addition, unlike RTUs, which circulate cool air through ducts, all chillers circulate chilled water to air-handler units, where fans push air across heat exchanger coils to deliver cooling. Because they circulate water, which is more energy dense than air, water-cooled chillers can offer a more efficient and effective cooling option than RTUs. Water-cooled chillers are most commonly used in buildings larger than 200,000 square feet, where the cooling load is large enough for increased efficiency gains to offset the higher equipment cost. However, they're also a viable choice in smaller buildings with more than two stories because they don't have to push air through ducts across multiple stories. Potential applications for water-cooled chillers include multistory structures, universities, large office buildings, and hospitals.

2.2 Efficiency of Chiller Plant System

According to Neidlinger [1] over 50 percent of electrical power are consumed from the use of chiller. This makes chiller as the dominant power usage throughout the whole system. Neidlinger also added with the support from Waste Reduction Partners Organization (2010), that more than 120000 chillers in United States are operating inefficiently with more than 30% excess of energy used.

Currently, most of the chiller available runs at full load with speed compressors being constant at all time. This is the most conventional way of running the chiller. But, full load operation of chiller does not contribute in reducing the power consumption of energy. Instead, the power run inefficiently with excess energy. According to Energy Design Resources [2] selection of chillers usually based on the design rated cooling capability, but they rarely operate under this condition.

Another statistic by Energy Design Resources also shows that the cooling in office buildings only peaks at few hours per year [2]. Light to moderate load (50 – 75% load) are used based on the cooling load profile of the building per year are shown in figure below.

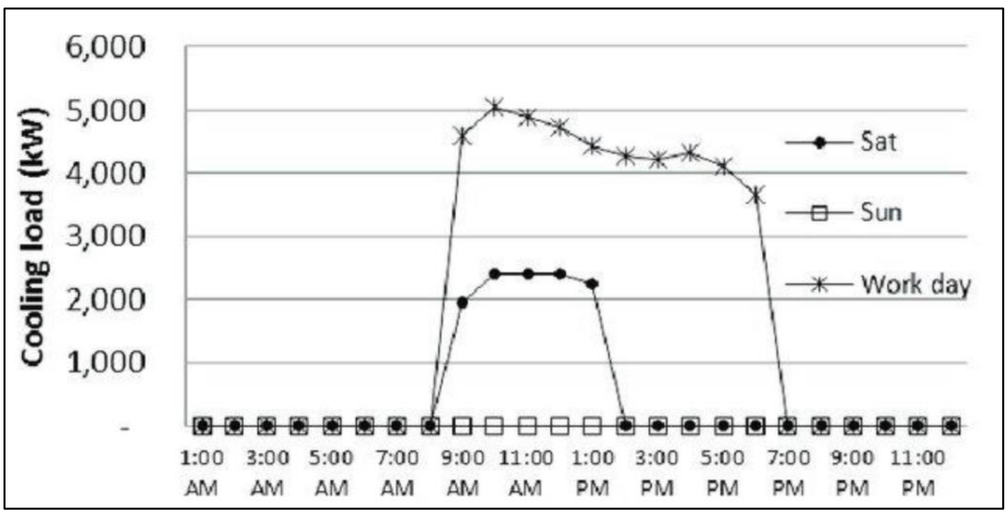


Figure 2.1: Cooling Load Profile of Building

A drop on chiller efficiency happens when system operates at full load at lower load conditions. Another significant drop in efficiency will be seen when the outdoor temperature is low with high level temperature setting in the condenser. Hence, the key to enhance the part load efficiency is to achieve building energy conservation [3].

2.3 Vapour-Compression Cycle

Electric chillers take in the concept of vapour-compression refrigeration cycle as its working mechanism [4]. Compressor is used to circulate the refrigerant around the system and is normally driven electrically by a motor [3]. The refrigerant however only circulates inside the system while alternatingly condensing and evaporating [4]. Evaporator, compressor, condenser and expansion devices are four main components in vapor-compression refrigeration cycle. However, usually the expansion valve is substituted with a throttling device as the power recovery is very small.

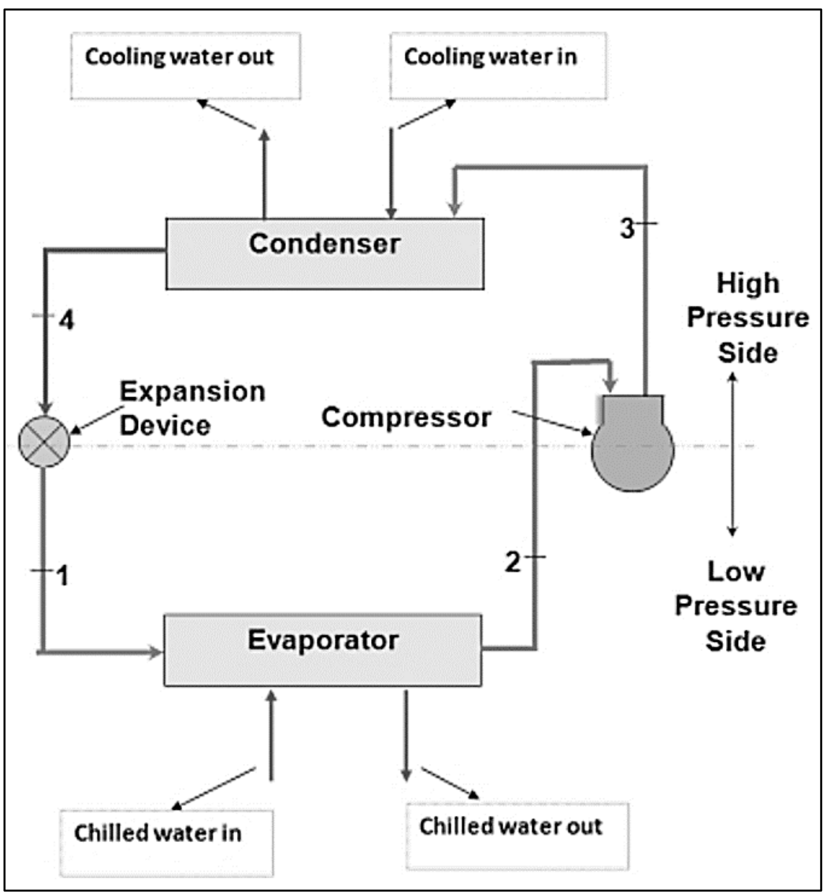


Figure 2.2: Simplified Diagram of Vapour-Compression Chiller

Type of compressor used in the chiller usually gives direct impact on reliability and efficiency of the system. Four different type of compressors are usually used in the vapor-compression chiller which are;

i. Reciprocating
ii. Helical-Rotary
iii. Scroll
iv. Centrifugal

Vapor Compression refrigeration cycle uses specific thermodynamic process that allows the refrigerant to undergo four stages.

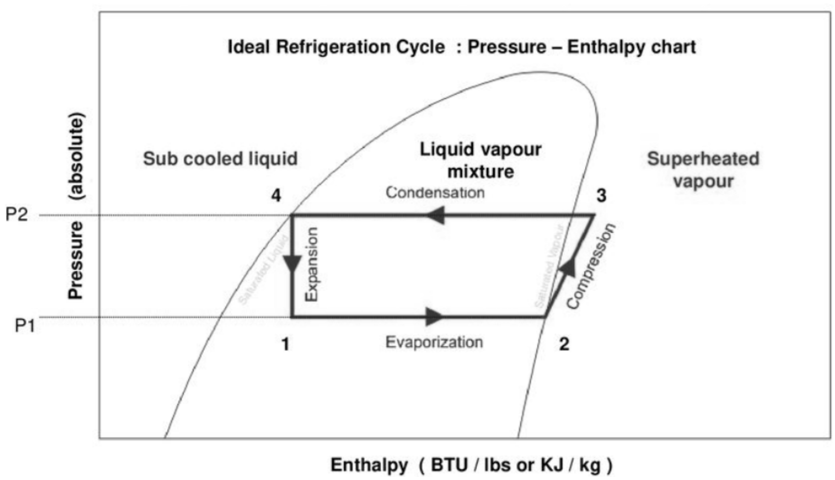


Figure 2.3: Ideal p-h Diagram for Vapour-Compression Refrigeration Cycle

For each stage, there are thermodynamics process happening at each stage that includes [6];

State	Stages	Process
1-2	Compression	Work is applied to compressor in reverse adiabatic process. It starts off as saturated vapor.
2-3	Condensing	Heat is removed from the system in this stage with reversible constant pressure process.
3-4	Expansion/Throttling	Throttling process done adiabatically while the enthalpy remains unchanged throughout the process.
4-1	Evaporation	Pressure are constant with heat is introduced to the system.

Chillers performance are deduced by measuring the coefficient of performance (COP). Coefficient of performance (COP) is ratio of cooling or heating capacity output over electric power input (kW) [5]. Higher COP denotes higher efficiency of the chiller [7]. Ideally in vapor-compression refrigeration cycle, if all the enthalpy value at all crucial points are determined, the ideal COP can easily be determined. H_1, h_2, h_3 and h_4 are regarded as crucial enthalpy point and can be determined using respective refrigerant property table provided that the pressure P_1 and P_2 are known. Theoretical COP can be calculated using the formula below to find the ideal vapor-compression cycle.

$$COP = \frac{Q_2}{W_c} = \frac{h_1 - h_4}{h_2 - h_1} \qquad 2.1$$

Heat is introduced into evaporated at Q_2 while work is applied at the compressor in stage 1. The condition however will never always be ideal, thus, to calculate the actual value of COP for vapor-compression refrigeration cycle the equation below are used.

$$COP = \frac{12000}{\frac{kW}{ton} \times 3417} \qquad 2.2$$

2.4 Chiller System Under Partial Load And Full Load Operating System

HVAC systems in general are designed to operate under wide range of loads. Equipment efficiency at full load condition determines that at full load, maximum load of energy is being used with efficiency rates changes during partial load. Most system or plants usually operates at full load or near full load condition. Partial load conditions are usually not discussed much. However, with the increment of the usage of HVAC applications, the partial loading in correlation with operating hours has become a significant topic to discuss. Full load efficiency of a chiller indicates chiller measured in accordance to the AHRI conditions by indicating the efficiency of chiller at peak load in energy-efficiency ratio (ERR) [7].

According to an article from Michaels Energy [7] , with air compressors the partial load efficiency depends on the unloading method. With inlet valve modulation-controlled air compressor may be using 70 percent of full load power even when idling while not generating compressed air at all. Part load efficiency is measured by integrated part-load value (IPLV) or non-standard part-load value (NPLV) with the dependency to AHRI part load test condition [8]. Both IPLV and NPLV using the weighted average formula with four operating load points will gives us the efficiency of the chiller in Btus per hour-watt. According to Michaels Energy, efficiency of the chiller will drop when operating with below 50 percent load and the key to enhancing the efficiency back is to not use an oversized motor [9]

The validation model of partial load performance can be developed in specification to discover the maximum coefficient of performance (COP) of chiller under various operating conditions[10]. Chan & Fu also stated that COP and efficiency are directly related to outdoor temperature with the control if condensing temperature at partial loading.

CHAPTER 3

METHODOLOGY

3.1 Project Flow Chart

A project flowchart was constructed to show the pathway in completing the project. It is then further divided by two phases for Final Year Project I (FYP 1) and Final Year Project II (FYP 2). The project flowchart is as below.

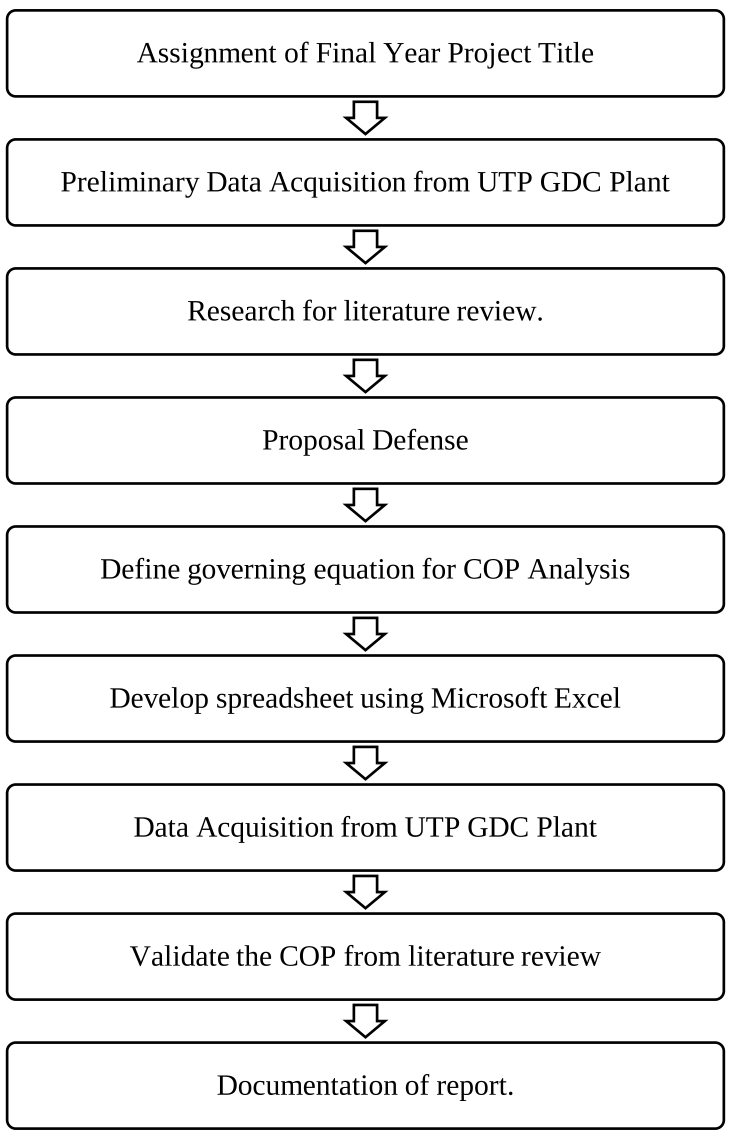


Figure 3.1: Flow chart for FYP I and FYP II

3.2 Project Gantt Chart

Table 1: Project Gantt Chart for FYP I

NO	TASK	1	2	3	4	5	6	7	8	9	11	12	13	14
1	Assignment of Project Title													
2	Literature Review													
3	Preliminary Data Acquisition from UTP GDC													
4	Writing for Proposal													
5	Submission for Project Proposal													
6	Proposal Defense													
7	Writing for Literature Review													
8	Submission of Pre-Interim Report													
9	Submission Interim Report													

Table 2: Project Gantt Chart for FYP II

NO	TASK	1	2	3	4	5	6	7	8	9	11	12	13	14
1	Data Acquisition from UTP GDC Plant													
2	Development of Microsoft Excel Spreadsheet Template													
3	Validating evaluated COP from Literature Review													
4	Submission of Progress Report													
5	Submission for Draft Final Report													
6	Submission of Technical Paper													
7	FYP Viva													
8	Submission of Project Dissertation													

3.3 Governing Equations

This subchapter will further discuss the equations used in analyzing the coefficient of performances for the electric chiller under theoretical and actual conditions.

3.3.1 Theoretical COP for Electric Chiller

A steady flow energy equation (S.F.E.E) for 1 kg refrigerant flow throughout the cycle are calculated as listed below in an ideal vapor-compression refrigeration cycle.

3.3.1.1 Compressor

$$W_C = (h_2 - h_1) \text{ kJ/kg}$$

3.3.1.2 Condenser

$$Q_1 = (h_2 - h_3) \text{ kJ/kg}$$

3.3.1.3 Expansion Valve

$$h_3 = h_4$$

3.3.1.4 Evaporator

$$Q_2 = (h_1 - h_4) \text{ kJ/kg}$$

Where W_c work into the compressor

Q_2 Net refrigeration effect

Determining the value for all the enthalpy at each point (h_1, h_2, h_3 and h_4) needs to be done with reference to the p-h diagram of the ideal vapor-compression refrigeration cycle. The p-h diagram as seen in Figure 5 as well as equation at 3.3 are used to calculate the theoretical COP of the water-cooled electric chiller.

$$COP = \frac{Q_2}{W_c} = \frac{h_1 - h_4}{h_2 - h_1} \quad 3.1$$

To determine the enthalpies value at all the state, the temperature of saturation evaporator as well as saturation temperature of the condenser are to be known. These two parameters are independent parameters. Condenser saturation temperature can be obtained from data gained from UTP GDC Plant while the temperature for evaporator saturation can be calculated using Equation 3.3. Condenser saturation temperature are regarded the same as ambient temperature in this study. Data collected from UTP GDC Plant recorded ambient temperature at maximum, minimum and average temperature. With no hourly ambient temperature recorded from UTP GDC Plant, this study will be assumed that minimum temperature runs from 8.00 PM to 8.00 AM while average ambient temperature runs from 8.00 AM to 8.00 PM.

For Q_2 calculation, the equation below is used.

$$Q_2 = m_w C_P (T_{chwr} - T_{chws}) \quad 3.2$$

Where Q_2 net refrigeration effect

m_w mass flow rate of chilled water (kg/s)

C_P specific heat capacity for water (4.19 kJ/kg°C)

T_{chwr} chilled water return temperature

T_{chws} chilled water supply temperature

For theoretical operating condition, evaporator saturation temperature (T_{ev}) is determined from equation below. For evaporator heat exchange efficiency (∈ev) is assumed to be 0.90 where 10 percent of heat exchange between chilled water and refrigerant is loss during the heat exchange process.

$$Q2 = mw\ Cpw\ \in ev\ (Tchwr - Tev) \qquad 3.3$$

To calculate the work input, Wc into the compressor, the compression process is assumed to be adiabatic, isentropic reversible compression where entropy at state 1 is the same as entropy at state 2 (s1 = s2). Through this assumption, Equation 3.4 and Equation 3.5 is used to calculate the work done by the compressor under isentropic compression.

$$W_c = m_r \times \left[\left(\frac{k}{k-1}\right)(P_1)(v_1)\left[\left(\frac{P_2}{P_1}\right)^{\left(\frac{k-1}{k}\right)} - 1\right]\right] \qquad 3.4$$

$$Q_2 = m_r(h_1 - h_4) \qquad 3.5$$

Where m_r mass flow rate of refrigerant (kg/s),

k	polytropic exponent for isentropic compression (k=1.21) [18],
P_1	pressure at evaporator saturation temperature, t1 (°C)
v_1	specific volume at state 1 (m3/kg)
P_2	pressure at condenser saturation temperature, t3 (kPa),
h_1	enthalpy at state 1 (kJ/kg) and
h_4	enthalpy at state 4 (kJ/kg).

3.3.2 Actual COP for Electric Chiller

To calculate the actual COP for the Electric Chiller, Equation 3.6 was used [19]. This equation was used by UTP GDC to calculate the COP of the Electric Chillers.

$$\text{COP} = \frac{\text{Refrigeration (RTh)}}{\text{Electricity (KWh)} \times 0.2844\,\frac{\text{RTh}}{\text{KWh}}} \qquad 3.6$$

The value of production of chilled water per hour (RTh) and electricity power consumed per hour (kW) can be determined from the data available from UTP GDC.

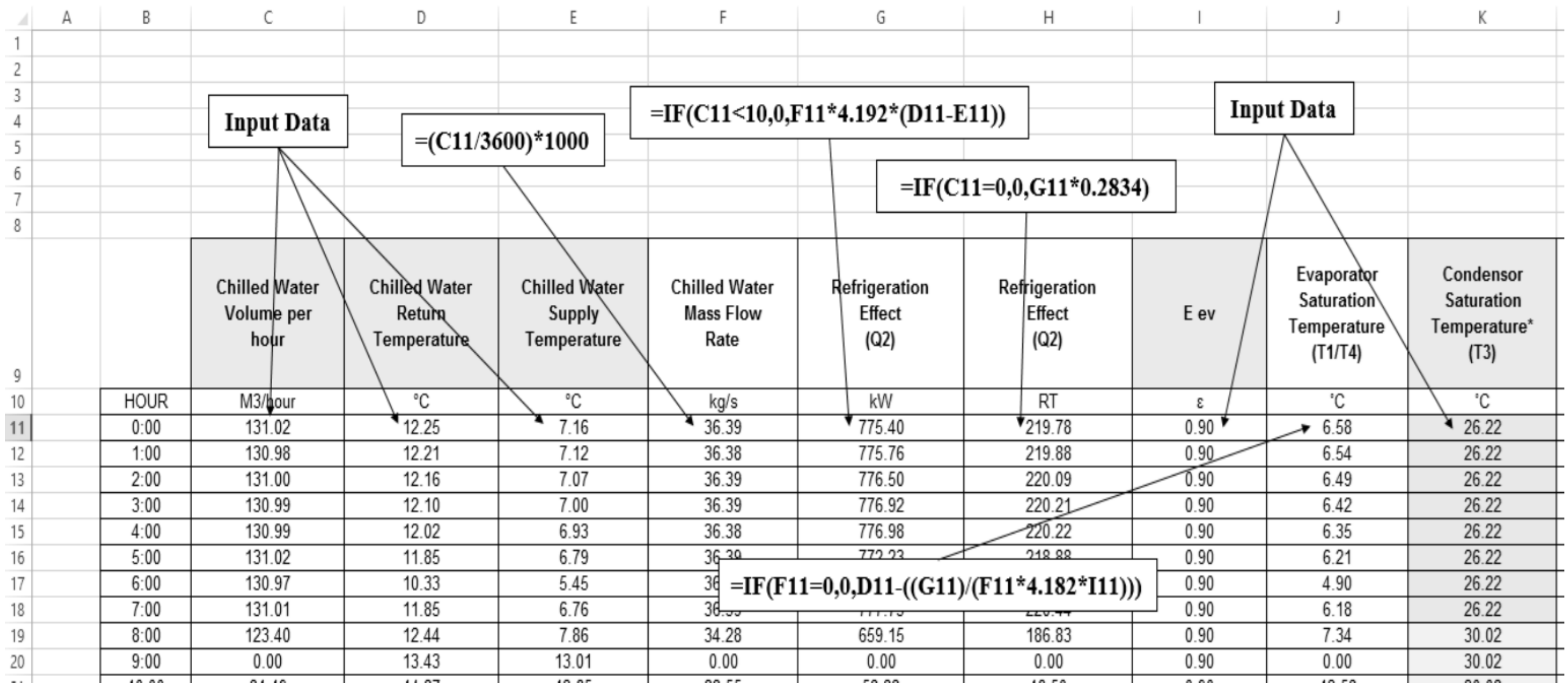
CHAPTER 4

RESULTS AND ANALYSIS

In this chapter, historical data obtained from UTP from December 2019 to February 2020 is analysed by using the governing equations in Section 3.4. To evaluate the COP of Electric Chiller A (EC-0121A), Microsoft Excel spreadsheets was developed. Evaluated COP's for this study is displayed in Section 4.2.

4.1 Microsoft Excel Spreadsheet

Microsoft Excel software was used to analyse the COP values of both EC-0121A and SAC-0131C. Four different Excel spreadsheets was developed in order to evaluate the COP of both chillers under theoretical and actual operating conditions. The evaluated COP values was displayed in graph format in order to see COP trends from January 2016 to March 2016. Examples of the developed Microsoft Excel spreadsheets can be seen in this section.



HOUR	Chilled Water Volume per hour	Chilled Water Return Temperature	Chilled Water Supply Temperature	Chilled Water Mass Flow Rate	Refrigeration Effect (Q2)	Refrigeration Effect (Q2)	E ev	Evaporator Saturation Temperature (T1/T4)	Condensor Saturation Temperature* (T3)
	M3/hour	°C	°C	kg/s	kW	RT	ε	'C	'C
0:00	131.02	12.25	7.16	36.39	775.40	219.78	0.90	6.58	26.22
1:00	130.98	12.21	7.12	36.38	775.76	219.88	0.90	6.54	26.22
2:00	131.00	12.16	7.07	36.39	776.50	220.09	0.90	6.49	26.22
3:00	130.99	12.10	7.00	36.39	776.92	220.21	0.90	6.42	26.22
4:00	130.99	12.02	6.93	36.38	776.98	220.22	0.90	6.35	26.22
5:00	131.02	11.85	6.79	36.39	772.23	218.88	0.90	6.21	26.22
6:00	130.97	10.33	5.45	[illegible]	[illegible]	[illegible]	0.90	4.90	26.22
7:00	131.01	11.85	6.76	[illegible]	[illegible]	[illegible]	0.90	6.18	26.22
8:00	123.40	12.44	7.86	34.28	659.15	186.83	0.90	7.34	30.02
9:00	0.00	13.43	13.01	0.00	0.00	0.00	0.90	0.00	30.02

Figure 4.1 : Theoretical COP Calculation using Microsoft Excel (1)

```
=IF(J11=0,0,FORECAST(J11,OFFSET($C$48:$C$92,MATCH(J11,$B$48:$B$92,1)-1,0,2),OFFSET($B$48:$B$92,MATCH(J11,$B$48:$B$92,1)-1,0,2)))
```

```
=IF(G11=0,"N.A.",G11/S11)
```

Evaporator Operating Pressure (P1)	Specific Volume at State 1 (v1)	Entropy at State 1/State 2 (s1/s2)	Condenser Operating Pressure (P2)	Entalphy at State 1 (h1)	Entalphy at State 3/4 (h3=h4)	Mass Flow Rate of Refrigerant in the cycle	W(in)	C.O.P (Full-Load)
kPa	M3/kg	kJ/kg K	kPa	kJ/kg	kJ/kg	kg/s	kW	%
369.49	0.0554	0.9281	689.99	254.25	88.15	4.67	148.98	5.2048
368.97	0.0555	0.9281	689.99	254.23	88.15	4.67	149.43	5.1915
368.25	0.0556	0.9281	689.99	254.20	88.15	4.68	150.11	5.1728
367.41	0.0557	0.9282	689.99	254.16	88.15	4.68	150.82	5.1514
366.42	0.0558	0.9282	689.99	254.12	88.15	4.68	151.57	5.1262
364.75	0.0561	0.9283	689.99	254.04	88.15	4.65	151.89	5.0840
348.63	0.0586	0.9289	689.99	253.29	88.15	4.50	158.64	4.6861
364.26	0.0561	0.9283	689.99	254.02	88.15	4.69	153.34	5.0719
379.09	0.0540	0.9277	770.58	264.67	93.60	4.09	160.97	4.3661
0.00	0.0693							
467.26	0.0441							
434.31	0.0473	0.9259	770.58	256.94	93.60	1.54	44.75	5.6043
371.53	0.0551	0.9280	770.58	254.34	93.60	4.64	176.63	4.2215
366.86	0.0558	0.9282	770.58	254.13	93.60	4.61	179.07	4.1365

```
=IF(OR(O11=0,L11=0,M11=0),0,(R11*((1.21/(1.21-1))*L11*M11*(((O11/L11)^(1.21-1/1.21))-1))))
```

Figure 4.2: Theoretical COP Calculation using Microsoft Excel (2)

4.2 Calculating COP of Electric Chiller

To calculate the theoretical COP for EC-0121A, Equation 3.1 was used. Example of the COP calculation are as follows:

<u>Input data from UTP GDC</u>

Chilled water production volume =131.01 m^3

Mass flow rate of chilled water = 36.39 kg/s

Temperature of Return Chilled water = 12.49 °C

Temperature of supply chilled water = 6.95 °C

Ambient air temperature (Average) = 30.3 °C

$Q_2 = m_w C_{pw} (T_{chwr} - T_{chws})$

Q_2 = (36.39) (4.19)(12.49- 6.95) Q_2 = 845.30 kW

$Q_2 = m_w C_{pw} \epsilon_{ev} (T_{chwr} - T_{ev})$

845.30 = (36.39) (4.19) (0.90) (12.49 – T_{ev}) T_{ev} = 6.33 °C

At T_{ev} = 6.33°C, P_1 = 366.27 kPa

v_1 =0.0558 m^3/kg

s_1 = 0.9282 kJ/kg K

h_1 = 254.11 kJ/kg

Using T_{cd} = 30.3 °C, the COP was calculated as follows:

At T_{cd} = 30.3 °C, P_2 = 776.66 kPa

h_3 = 93.99 kJ/kg / h_4 = 93.99 kJ/kg

$$\dot{m} = \frac{Q_2}{h_1 - h_4}$$

$$\dot{m} = \frac{845.30}{254.11 - 93.99}$$

$\dot{m}$ = 5.28 kg/s

$$W_c = m_r \times \left[\left(\frac{k}{k-1}\right)(P_1)(v_1)\left[\left(\frac{P_2}{P_1}\right)^{\left(\frac{k-1}{k}\right)} - 1\right]\right]$$

$$= 5.28 \times \left[\left(\frac{1.21}{1.21-1}\right)(366.27)(0.0558)\left[\left(\frac{776.66}{366.27}^{\left(\frac{1.21-1}{1.21}\right)}\right) - 1\right]\right]$$

$= 207.87$ kW

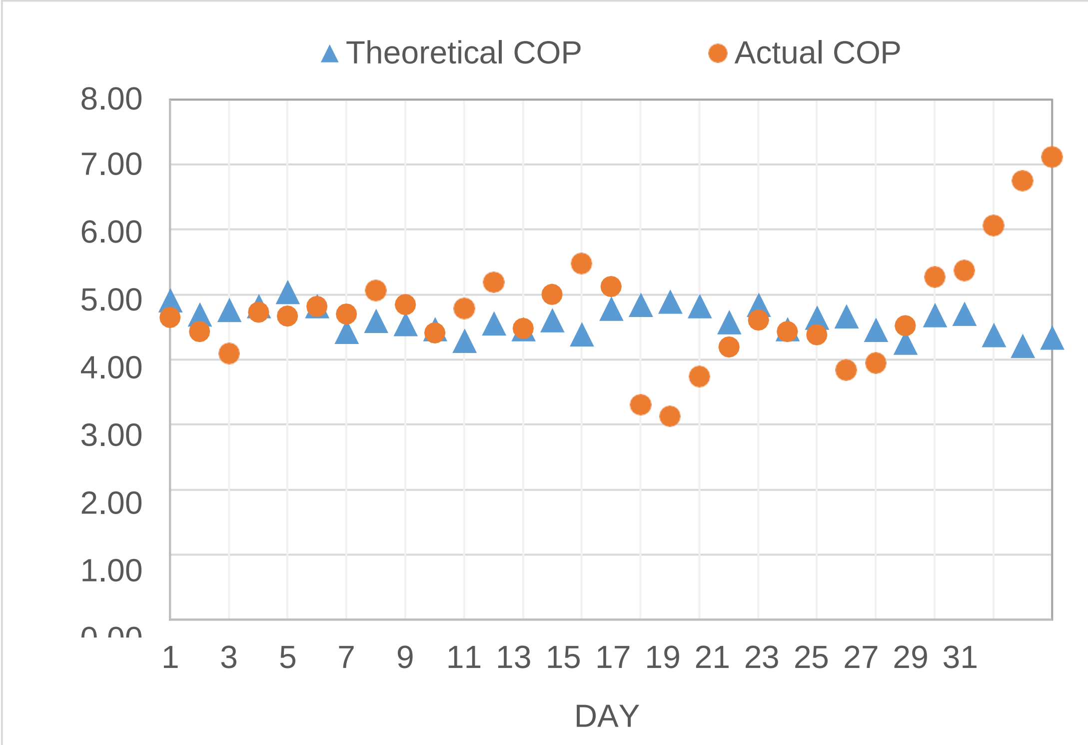
COP $= \frac{Q_2}{W_c}$

$= \frac{845.30}{207.87}$

$= 4.07$

Where refrigeration is the amount of chilled water produced per hour (RT), electricity is the amount of electricity consumed per hour by the electric chiller (kW), and 0.2844 is a conversion unit that converts kW value to RT.

Theoretical COP is represented by blue colour while the actual COP is represented by orange colour. It was observed that the actual COP exhibit an irregular trends compared to the theoretical COP. The COP range under actual operating condition is 3.12 to 7.11 while the COP range under theoretical operating condition is 3.90 to 5.42. The normal range of electric chiller COP is between 4.20 to 6.10 [20]. At certain days, it was observed that EC-0121A COP either exceeds or falls behind the normal COP range.



In theory, electric chiller electricity consumption should be in positive correlation with amount of chilled water produced; the more the production of chilled water, the higher the electricity consumption by the electric chiller. But it was observed that these correlation does not fully applies for EC-0121A during its actual operation. After the design capacity (325 RT), the electricity consumption decreased with every increase in production of chilled water. At certain days, EC-0121A produced chilled water more than its design capacity; which can reach up to 350 RT. This contributes to high actual COP values (COP > 5.70).

But sometimes, the electricity consumption of EC-0121A does not necessarily follow the trend. At any given chilled water production amount, the electricity consumption can either be higher or lower than the indicated trend. They might be caused by sensor error in the measurement of the data or there are other factors that affect the irregular electricity consumption by the electric chiller. This inconsistency caused the COP values to either exceed or falls behind the normal COP range for an electric chiller. Further study is required in order to study the parameters that affects the irregular electricity consumption of EC-0121A.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study evaluated the coefficient of performance (COP) of both EC-0121A under theoretical and actual condition from January 2020. For electric chiller A (EC-0121A), the evaluated COP ranged from 3.12 to 7.11. Normal COP range for electric chiller is between 4.2 to 6.1. It was observed that the EC-0121A COP have an irregular trends throughout the month. The significant variation in COP value might be contributed by irregular electricity consumption of EC-0121A during its actual operations. The irregularity of the result may also be affected by the weather. This is because it is observed that January is a month with lots of rainfalls thus effecting the temperature in and out of the chiller. Further study might need to be conducted in order to understand the parameter that affect the electricity consumption of EC-0121A.

5.2 Recommendations

For the electric chiller, condenser saturation temperature can be determined more accurately if the ambient air temperature entering and leaving the condenser is recorded. Also the data would be more accurate if we were to look into the result by hourly rather than using the average of 24 hours, the effect of ambient air temperature to the electric chiller performance can also be investigated. It is also better to assume that the condition are not isentropic which will include losses. A recommendation to do the analysis during a much stable weather condition are also included. This is because January is seen as a weathery month due to lots of rainfalls thus the temperature are one degree less than the usual temperature.

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APPENDIX

Timestamp	Chilled Water Volume Per Hour	Chilled Water Return Temperature	Chilled Water Supply Temperature	Chilled Water Mass Flow Rate	Refrigeration Effect (Q2)	Refrigeration Effect (Q2)	E ev	Evaporator Saturation Temperature (T1/T4)	Condenser Saturation Temperature (T3)	Condenser Saturation Temperature	ECC-0122A
Hour	(m3/hour)	(℃)	(℃)	(kg/s)	(kW)	(RT)	(Ɛ)	(℃)	(℃)		
0:00	131.02	12.25	7.16	36.39	776.56	220.08	0.90	6.58	26.22	27.40	748.99
1:00	130.98	12.21	7.12	36.38	776.32	220.01	0.90	6.54	26.22	27.56	752.98
2:00	131.02	12.25	7.16	36.39	776.56	220.08	0.90	6.58	26.22	27.56	749.30
3:00	130.98	12.21	7.12	36.38	776.32	220.01	0.90	6.54	26.22	27.54	741.33
4:00	131.00	12.16	7.07	36.39	776.44	220.04	0.90	6.49	26.22	26.60	516.32

5:00	130.99	12.10	7.00	36.39	777.91	220.46	0.90	6.42	26.22	25.49	215.20
6:00	130.99	12.02	6.93	36.39	776.38	220.03	0.90	6.35	26.22	25.42	0.16
7:00	131.02	11.85	6.79	36.39	771.98	218.78	0.90	6.21	26.22	25.43	0.00
8:00	130.97	10.33	6.79	36.38	539.88	153.00	0.90	6.39	26.22	25.42	0.00
9:00	131.01	11.85	5.45	36.39	976.34	276.70	0.90	4.72	26.22	25.42	0.00
10:00	123.40	12.44	6.76	34.28	816.17	231.30	0.90	6.11	26.22	25.44	0.00
11:00	0.00	13.43	7.86	0.00	0.00	0.00	0.90	0.00	30.02	25.56	0.00
12:00	0.58	11.85	13.01	0.16	0.00	0.00	0.90	11.85	30.02	25.71	0.00
13:00	0.58	10.33	0.00	0.16	0.00	0.00	0.90	10.33	30.02	25.99	0.00
14:00	0.58	11.85	0.00	0.16	0.00	0.00	0.90	11.85	30.02	26.30	0.00
15:00	0.58	12.44	0.00	0.16	0.00	0.00	0.90	12.44	27.68	26.59	0.00

16:00	0.58	9.74	0.00	0.16	0.00	0.00	0.90	9.74	28.24	26.93	0.00
17:00	0.58	9.97	0.00	0.16	0.00	0.00	0.90	9.97	28.75	27.20	0.00
18:00	0.58	10.22	0.00	0.16	0.00	0.00	0.90	10.22	29.04	27.35	0.00
19:00	0.58	10.45	0.00	0.16	0.00	0.00	0.90	10.45	29.19	27.47	0.00
20:00	0.58	10.67	0.00	0.16	0.00	0.00	0.90	10.67	29.26	27.55	0.00
21:00	0.58	10.89	0.00	0.16	0.00	0.00	0.90	10.89	29.22	27.56	0.00
22:00	0.58	11.11	0.00	0.16	0.00	0.00	0.90	11.11	29.12	27.53	0.00
23:00	0.58	11.31	0.00	0.16	0.00	0.00	0.90	11.31	28.97	27.50	0.00
0:00	286.86	12.53	0.00	79.68	4185.08	1186.05	0.90	-1.43	31.64	28.08	273.57
1:00	530.00	13.47	0.00	147.22	8312.50	2355.76	0.90	-1.53	35.45	29.06	790.67
2:00	530.00	13.41	0.00	147.22	8274.77	2345.07	0.90	-1.53	35.37	29.00	790.49

3:00	184.81		0.00	51.34	0.00	0.00	0.90	0.00	30.90	28.56	333.34