Analysis Effect of Increasing Entering Condenser Water Temperature into the Chiller Performance

Mochammad Safi'i[1]; Agung Wahyudi Biantoro[2]

[1]Program Studi Teknik Mesin, Fakultas Teknik, Universitas Mercu Buana Jakarta

E-mail: mochammad.safii@yahoo.com; agung_wahyudi@mercubuana.ac.id

Abstrak-- *The use of electrical energy for the cooling system reaches 47% - 65% of the total electrical energy used in buildings. Therefore, in order to reduce energy use, it is necessary to evaluate and recommend in the process of increasing the energy efficiency used. The analysis aims to determine the impact caused by the entering condenser water temperature exceeding (ECWT) the standard chiller unit design by using energy audit equipment and Yorkwork's software. The results of the evaluation and optimization with the increasing ECWT by 3 °C or 10% of the unit chiller design; resulting in the decreasing of cooling capacity in the evaporator by 11-17% compared with the ECWT design 30 °C. Actual measurement capacity produced by the chiller is 1531 $kW_{cooling}$; as Yorkwork's software chiller capacity should be 1764 $kW_{cooling}$. Chiller COP decreased by 16-19%, with an average actual COP value 5.34 with an average COP as per chiller design is 6.49. Increasing of ECWT forces the compressor to work harder to produce the pressure and refrigerant saturation temperature exceeding ECWT temperature in order to rejected heat from the refrigerant to the condenser to change the refrigerant phase and influence to the subcooling temperature produced.*

Keywords: performance evaluation, optimization, chiller system.

1. INTRODUCTION

The results of studies conducted in several buildings in Jakarta show that the use of electrical energy for the cooling system reaches 47% - 65% of the total electricity consumption. Therefore, the energy conservation of the Heating, Ventilating and Air Conditioning (HVAC) system in a commercial building clearly has a significant influence on the use of electrical energy. [1]

The building management has begun to focus in Air Conditioning (AC) system energy, seeks to maintain and improve efficiency in the performance of the AC system, the parameter conducted by an energy audit. Energy audit on the AC system is an identification process that calculates the amount of electrical energy consumption (kW) used to produce an output process or cooling capacity output energy (kW Refrigeration or Btuh). When the measurement used same unit for cooling capacity and electrical energy input, the value of Energy Efficiency Ratio (EER) is the same as the value of the Coefficient of Performance [2]

M. Nuriyadi and Ade S. Margana who conducted research on optimizing the energy efficiency of the chiller system with the heat exchanger descaling process, namely cleaning the shell and tube condenser and evaporator pipes. Result after descaling process chiller efficiency improved to became better and more efficient than the previous condition [3].

Asep Rindika and Indra Saputra conducted research on the energy audit of the centrifugal water-cooled chiller unit and calculated the value of the global warming effect on CO2 emissions caused by the use of chiller electrical energy at Central Park Mall, West Jakarta [4].

Biantoro calculates the IKE value (Intensity of Electricity Consumption) and the payment costs that must be paid in 2 buildings, namely Building P in Tangerang district and Mercu Buana University with one of the calculations focusing on the AC system [5]. Yung-Chung Chang (2012) said that the evaluation and optimization with the increasing ECWT by 3 °C or 10% of the unit chiller design; resulting in the decreasing of cooling capacity in the evaporator by 11-17% compared with the ECWT design 30 °C. Actual measurement capacity produced by the chiller is 1531 kWcooling; as Yorkwork's software chiller capacity should be 1764 kWcooling [11].

Water chiller is a large capacity of refrigeration type machine and required large power consumption. Thus, it is highly recommended to operate the machine under optimum working conditions that provide minimum energy consumption. Water chiller type refrigeration machines generally use secondary refrigerant in the form of chilled water in the air conditioning system.

The important things to maintain the chiller performance as the unit design by maintain all of operating parameters operate in the normal range that have been determined by each of chiller brand. Abnormal reading of the parameters will be affected to the operating conditions of the chiller. In this study, we will discuss in more detail the impact caused by an increase in ECWT on the capacity and efficiency of the chiller unit.

Chilled water Refrigeration System

Like as usual of refrigeration system, water chiller system consists of 4 main components, namely compressor, condenser, expansion device and evaporator. Heat transfer process occurs in the evaporator and condenser and there is water that functions as a secondary refrigerant to release and absorb heat from the refrigerant in the refrigeration system. After going through the process of heat transfer in the refrigeration system, water temperature will be changed in the water side. In the evaporator, when the water releases heat to the refrigerant, the temperature of the water coming out of the evaporator becomes colder; but on the contrary in the condenser side when the water absorbs heat from the condenser, there is an increase in the temperature of the water after going through the condenser. As shown in Figure 1.

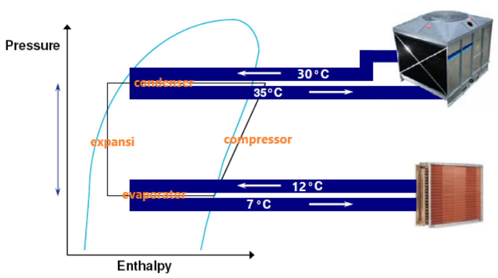

Figure 1. Water Chiller Circulation (Johnson Controls 2012)

Entering Condenser Water Temperature (ECWT)

ECWT means the water temperature that will be enter to the condenser to absorb heat from the refrigerant in the condenser, which is then discharged the heat to the cooling tower. This parameter is one of the main parameters that greatly influences the performance of the chiller unit on the condenser or high-pressure side, because it affects the process of changing the refrigerant phase in the condenser.

In the normal flowrate as per unit design, when there is an increase ECWT, will affect increasing of the leaving water temperature (LCWT). Refer to the Trane Application Engineering Manual inform that the effect of leaving-condenser-water temperature change on power consumption can be 1.0 to 2.2 percent per degree Fahrenheit [1.8 to 4.0 percent per degree Celsius]. Always consider the energy consumption of the entire system—not just the chiller. It is important to remember that although raising the leaving condenser-water temperature penalizes the chiller energy, it may reduce the energy used by the condenser pumps and cooling tower through the use of reduced flow rates and higher thermal driving-forces on the tower. [8]

Maintaining ECWT according to specifications is very important, because it greatly affects the consumption of electrical energy and cooling capacity.

AHRI and ASHRAE have clearly regulated the ECWT in the operation process and also the initial selection of chiller units. In accordance with AHRI STANDARD 550/590 (I-P)-2015, the loading conditions also affect the ECWT supply in the chiller unit [7]. As shown in Figure 2

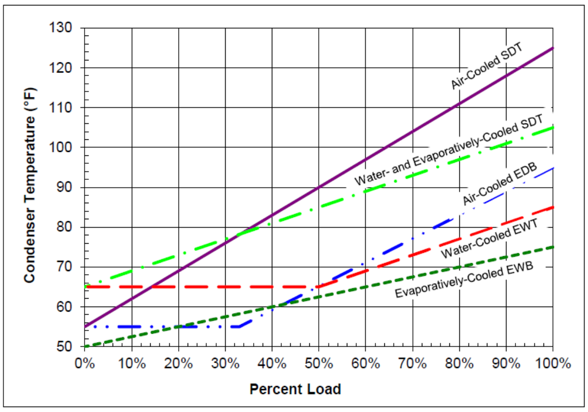

Figure 2. Part Load graph with various Load percentage and ECWT.

Chiller Performance

Chiller performance effectiveness could be determined by the reach the maximum capacity with the nominal energy consumption as the unit specification and reach the evaporator leaving setpoint temperature. Energy audit tools are required to calculate and determine the chiller performance.

Biantoro said energy management is defined as a systematic and integrated approach to implement the utilization of energy resources effectively, efficiently and rationally without reducing the quantity and quality of the main functions of the building. The first step in implementing energy management is an energy audit [9].

Chiller energy audit uses equipment that can detect water flow rate, delta temperature and measure electrical energy consumption, so that input and output energy calculations can be carried out directly. In the process of calculating chiller capacity using units of $kW_{cooling}$.

In general, the formula for calculating $kW_{cooling}$ is to use the calculation in international units as below [7]:

$$Q = M_w . C_p . dt \qquad (1)$$

M_w is the flow mass of the fluid that flowing in the shell. To determine of flow mass of fluid by multiply the volume and density of the fluid. So the formula as below:

$$h = C_p . \rho . q \ dt \qquad (2)$$

with the requirement data as below detail, so
h: heat load ($kW_{cooling}$)
C_p: specific heat, 4.187 (kJ/kg °C) for water
ρ: water density 1000 kg/m^3
q: water volume flowrate (l/s), due to the fluid flowing inside the shell, so that the fluid has velocity in the time.
dt: temperature difference (°C) between entering *and leaving water temperature*

$$h = \frac{4.187 \frac{kJ}{kg} °C . \left(1000 \frac{kg}{m^3}\right) . q . dt(°C)}{1000 \ (konversi \ m^3 \ to \ l)} \qquad (3)$$

$$h = 4.817 . q . \left(\frac{l}{s}\right) . dt(°C) \qquad (4)$$

formula for calculation incoming power supply as below:

$$kW = \frac{Voltage \ x \ Ampere \ x \cos\varphi \ x \sqrt{3}}{1000} \qquad (5)$$

Determine Coefficient of Performance (COP) for unit chiller by divide output energy that produce by unit chiller with input energy that consume by unit chiller.

$$COP = \frac{Cooling \ Capacity \ (kWr)}{Input \ Power \ (kW)}$$

2. RESEARCH METHODOLOGY

This section describes the stages carried out in the study. The complete stages can be seen in Figure 1.

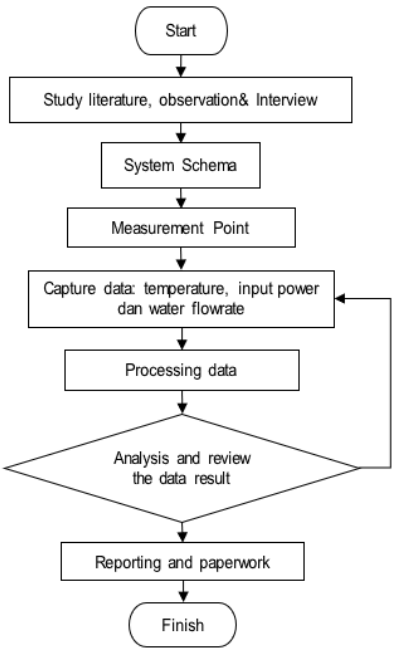

Figure 3. Research Stages

In Figure 3, that can be seen that the initial step to be taken for chiller performance analysis. this research will be collecting several data while the unit chiller operates and selection by Yorkwork's software, as below:

- Chilled water flowrate (l/s)
- Water temperature in and out evaporator (°C)
- Power Consumption while the chiller operates (kW)
- Selection in the Yorkwork's software based on the actual capacity measured

Equipment specification details as showed in the table 1

Table 1 Chiller Specification details

Unit Spesification	
Model	York, YKEEEGQ75EMH
Net Capacity (kW)	1814.24
Full Load (*COP*)	6.14
Input Power (kW)	295.7
Refrigerant Type	R-134a
Entering Evap Wtr Temp (ºC)	12.2
Leaving Evap Wtr Temp (ºC)	6.7
Water flowrate (l/s)	77.9
Entering Cond Wtr Temp (ºC)	30
Leaving Cond Wtr Temp (ºC)	35
Water flowrate (l/s)	100.5

As reference for the analysis, we print out the unit selection as the Table 2 [10].

Table 2. Unit Specifications

Unit Specifications			
Model	YKEEEGQ75EMH	*Gear Code*	XA
Rated Net Capacity (kW)	1814	*Specified Net Capacity (kW)*	1814
NPLV.IP (COP.R)	7.18	*Refrigerant type/charged*	R-134a/462
Full Load (COP.R)	6.136	*A. Weighted SPL (dBA)*	82
Input Power (kW)	295.7	*Max. Motor Load (kW)*	327
Voltage / Hz (Input)		*Oil Cooler*	*Refrig cir*
		Condenser Gas Inlet Type	*Baffle*
Job FLA (Amps)	520	*Optisound Control*	*Y*
		Isolation Valve	N
LRA (Amps)	3700	*Variable Orifice*	*Valve -2*
Min Circuit Ampacity	650	*Starter Type*	*Solid State – LV Unit Mounted*
Max Circuit Ampacity	1000	*Starter Model*	26LBK-50

Heat Rejection Capacity	2089	
Fluid	*Evaporator Water**	*Condenser Water**
Tube MTI No.	461	260 / 260
Passes	2*	2*
Fouling Factor ((m^{2-} °C)/kW)	0.01761*	0.04403*
Entering Fluid Temp (°C)	12.20*	30.00*
Leaving Fluid Temp (°C)	6.67*	35.00*
Fluid Flow (L/s)	78.21	100.5
Fluid Pressure Drop (kPa H_2O)	81.5	54.6

3. RESULTS AND DISCUSSION

Measurement method for calculating capacity and chiller efficiency using the comparison between the input energy and the chiller output energy. The parameters taken in this test method include:

- The temperature of the water entering and leaving the evaporator,
- The temperature of the water entering the condenser,
- The water flow rate that flows in the evaporator,
- Power (kW) used by the chiller unit,
- Refrigerant saturation pressure and temperature and compressor discharge temperature

Data retrieval is carried out at peak load, which is from 11:00 to 14:00 with an interval of 5 minutes.

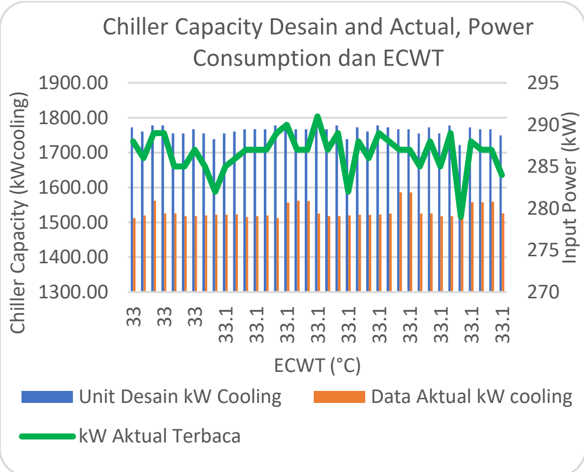

Figure 4. Comparation graph of chiller capacity, power consumption dan ECWT

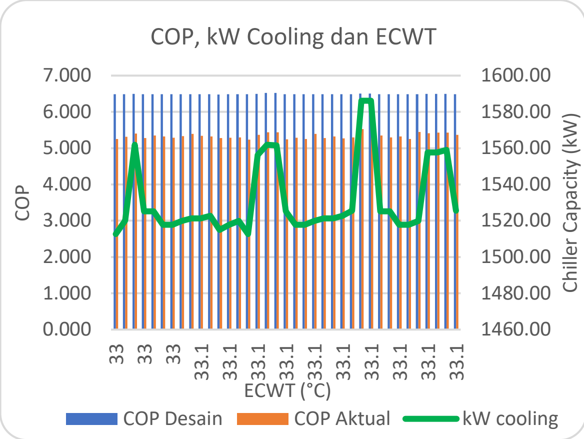

Figure 5. Comparation graph COP, kW cooling dan ECWT

Due to much of data that have been collected; for the chiller comparation performance taken from the average measurement data and Yorkwork software with the unit specification as showed in the Table 3.

Table 3. Comparation average measurement and Yorkwork software selection

Comparation data	Design Selection	Average operation data
Entering Fluid Temp Evaporator (ºC)	12.85	12.85
Leaving Fluid Temp Evaporator (ºC)	8.63	8.63
Water flowrate desain (l/s)	86.58	86.58
Entering Fluid Temp Condenser (ºC)	30.00	33.08
Leaving Fluid Temp Condenser (ºC)	35.00	39.59
Evaporator Sat temperature	7.8	7.26
Condenser Sat Temperature	36.1	40.57
Superheat	8.33	7.48
Subcooling	6.0	5.85
Unit Capacity (kW)	1531	1531.414
Input Power (kW)	239.5	286.68
COP	6.39	5.34

Table 2 showed the data parameter between selection design and average operation data in the same capacity but in the different ECWT. Showed that the chiller efficiency is worst than the unit desain. Based on the table 2 data, collected and calculated used software coolpack and the result of graph as showed in the Figure 7.

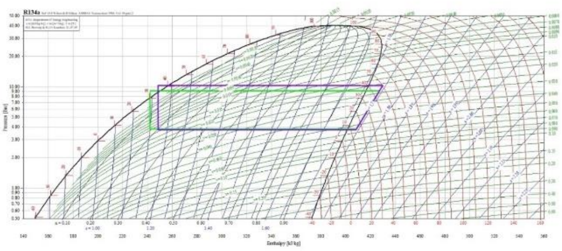

Figure 6. Graph Software Coolpack comparation refrigeration cycle between actual unit operation and software Yorkwork.

In the Figure 6, there are 2-line diagrams, each of which indicates the process of the refrigeration cycle. The refrigeration cycle with the green line represents the refrigeration cycle in accordance with the chiller unit design specifications, while the purple refrigeration cycle indicates the refrigeration cycle that is affected by the increase in ECWT. Based on the figure, it shows a significant difference, namely the capacity of the chiller unit and the electrical power used by the compressor in the process of achieving the same target temperature.

4. CONCLUSION

The chiller analysis has been carried out, and the results of the evaluation of the problem of increasing ECWT that occurred at the Mal Ambassador concluded as follows:

- Increasing ECWT by 3 °C or 10% of the chiller unit design results in a decrease in cooling capability or capacity in the evaporator by 11 – 17% compared to the initial selection design by Yorkwork software with operating ECWT 30 °C. During the 3 hours of observation, the average cooling capacity produced by the chiller was 1531 $kW_{cooling}$, below the value for the Yorkwork software selection, which is an average of 1764 $kW_{cooling}$ with the same nominal electricity consumption.

- This abnormal condition also affects the decrease in efficiency or COP value in the chiller, with a reduction rate of 16-19% when compared to the initial selection design of the unit with an ECWT value of 30 °C. The comparison of the actual COP value is 5.34 with the comparison of the design COP 6.49. An increase in ECWT forces the compressor to work harder to produce a pressure and saturation temperature exceeding the flowing medium temperature (ECWT). This increase in compressor performance makes the electricity consumption of the chiller motor increase, thus making the chiller more wasteful of electricity.

Recommendation

Based on the results of the observations, as well as observations on operational conditions that are not in accordance with operational design standards, the author conveys several suggestions that should be made regarding current conditions, and if you have plans to do a 'retrofit' or rejuvenation of the chiller machine.

- Repair or recalculate the capacity of the old cooling tower, if the calculations and conditions does not meet the specifications for the new chiller design, it is recommended to rejuvenate or replace it with a new cooling tower and ensure that the cooling tower is placed in a free condition and does not occur short cycle.

- Calculate the cooling capacity of the room to be cooled by the chiller. Changes in cooling load can occur in building operations. As with the conditions in 2021, with a tendency for warmer ambient air temperatures, of course it will be different from the cooling load conditions during the building construction in 2000.

- Repair, calculate and ensure pump capacity and piping installation accessories can still work optimally in supporting chiller operations. Sometimes the old pump capability or pump specifications do not meet the design specifications of the new chiller unit.

Reference

[1] DKI Jakarta, P. (2011). System pengendalian udara dan ventilasi udara (Vol. Vol 2). Jakarta, DKI Jakarta, Indonesia : Dinas penataan kota pemerintah provinsi Jakarta

[2] SNI-03-6390-2000. (2000). Konservasi energi sistem tata udara pada bangunan gedung.

[3] Nuriyadi, M. (2010). Perangkat RHVAC. Bandung: Politeknik negeri Bandung.

[4] Rindika, Asep; Indra, Saputra;. (2020). Analisa Performansi tipe water cooled centrifugal kapasitas 2000 TR pada gedung central park mall Jakarta Barat. ISBN.

[5] Biantoro, Agung Wahyudi. (2017). Analisis perbandingan efisiensi energi pada gedung P

kabupaten Tangerang dan gedung tower UMB Jakarta. Jurnal Teknik Mesin (JTM), 10.

https://publikasi.mercubuana.ac.id/index.php/jtm/article/view/1966

[6] Johnson Controls. (2012). Retrieved from Training material chilled water system

[7] AHRI Standard, 5. (2016). Performance rating of water-chilling and heat pump water-heating packages using the vapor compression cycle. Arlington, VA 22201 USA: AHRI.

[8] Trane (2011, November). Applications Engineering Manual Chiller System Design and Control

[9] Biantoro, A. W., & Permana, D. S. (2017). Analisis audit energi untuk pencapaian efisiensi energi di gedung AB, kabupaten Tangerang, Banten. Jurnal Teknik Mesin (JTM): Vol. 06, No. 2, Maret 2017. https://scholar.google.com/citations?user=uxBYmnsAAAAJ&hl=en

[10] Johnson Controls. (2019, August 12). Yorkwork software. Retrieved from www.johnsoncontrols.com: https://be-ebusiness.eu.johnsoncontrols.com/

[11] Yung-Chung Chang, Chao-Yuan Chen, Jyun-Ting Lu, Jin-Kwei Lee, Tian-Shuen Jan, Ching-Liang Chen. (2012). Verification of Chiller Performance Promotion and Energy Saving. National Taipei University of Technology, Taipei, Taiwan.