ANALYSIS ON THE IMPACT OF DELTA T TO THE PERFORMANCE OF CHILLER

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ABSTRACT

Chiller systems had become commonly used for large residential or commercial buildings. However, the energy consumption of the chiller system also occupied a large portion of the total energy consumption of the building. Therefore, it is very important to ensure the chiller system is able to work in the most energy efficient condition to reduce the electricity bill of the building. The reduction in the electricity bill is not only able to reduce the operating cost of the building, it also would be able to decrease the impact of the chiller system to the environment. Therefore, in order to achieve this objective, many research has been done to find out the energy saving measures to increase the energy efficiency of the chiller system. According to the research, increase temperature difference of chilled water is able to increase the energy efficiency of chiller system. However, many of the studies only concentrate on electricity saving. The trade-off that came together with these savings did not take into account. Thus, this research aims to develop a model to evaluate the energy saving capability of increase ΔT of chilled water to the chiller system and the impact of ΔT of chilled water to the performance of the system. The research methodology includes: (1) Modeling of energy consumption of the chiller system (2) Validate model with case study (3) Manipulate the ΔT of chilled water and (4) Results analysis.

At the end of this research, the increase of ΔT of chilled water is found to be able to reduce the energy consumption of the chilled water pump, which would increase the energy efficiency of the chiller system. For example, by increasing the ΔT of chilled water from 5°C to 8°C, the user would be able to save 6.41% of total energy consumption of the chiller system. In other word, the user could be able to reduce up to 6.33% of their electricity utility bill and greenhouse gases released per year. However, the increase of ΔT of chilled water would also increase the size required for cooling coil of AHU. Therefore, when implementing these improvement measures, the user would have to check whether the performance of AHU that connected to the chiller system is still able to be maintained at an acceptable level.

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LIST OF ABBREVIATIONS

GA	-	Genetic Algorithm
UTM	-	Universiti Teknologi Malaysia
IEA	-	International Energy Agency
COP	-	Coefficient of Performance
AHU	-	Air Handling Unit

LIST OF SYMBOLS

Q_{cl}	-	Cooling capacity (kW)
T_{chwr}	-	Temperature of return chilled water (°C)
T_{chws}	-	Temperature of supply chilled water (°C)
T_{ev}	-	Evaporating temperature (°C)
E_T	-	Energy consumption of chiller system (kW)
$E_{CHILLER}$	-	Energy consumption of chiller (kW)
E_{EVP}	-	Energy consumption of pump at evaporator side (kW)
E_{CDP}	-	Energy consumption of pump at condenser side (kW)
E_{CT}	-	Energy consumption of the cooling tower (kw)
Q_{EV}	-	Cooling capacity of evaporator (kW)
m_W	-	mass flow rate of chilled water (kgs^{-1})
C_{PW}	-	specific heat capacity of water (kJ $kg^{-1}°C^{-1}$)
COP	-	Coefficient of Performance of chiller
η_{pump}	-	Efficiency of pump
η_{motor}	-	Efficiency of motor
m_{cd}	-	mass flow rate of cooling water (kgs^{-1})
H_D	-	Discharge head in meter (m)
EFF	-	Efficiency of the pump (%)
p	-	Density of fluid (kg/m^3)
g	-	Gravitational Acceleration (m/s^2)
Q_{CD}	-	Heat rejection (kW)
M_{cdw}	-	Mass flow rate of water entering cooling tower (kgs^{-1})
T_{cdwl}	-	Condenser water leaving temperature (°C)
T_{cdwe}	-	Condenser water entering temperature (°C)
ε_a	-	Airside heat transfer effectiveness of cooling tower
m_a	-	Mass flow rate of air entering cooling tower (kgs^{-1})
h_{alct}	-	Specific enthalpy of saturation air leaving the cooling tower (kJ kg^{-1})
h_{aect}	-	Specific enthalpy of air entering the cooling tower (kJ kg^{-1})
E_{CTR}	-	Rated Energy Consumption of cooling tower (kW)

m_{ar}	-	Nominal mass flow rate of air entering cooling tower (kgs^{-1})
E_{CT}	-	Energy consumption of the cooling tower fans (kW)
T_{ctwe}	-	Cooling water entering temperature (°C)
T_{ctwl}	-	Cooling water leaving temperature (°C)
C_{paf}	-	Fictitious specific heat capacity of saturation air ($kJ\ kg^{-1}°C^{-1}$)
Au_{ct}	-	Overall heat transfer coefficient ($kW°C^{-1}$)
C_{pa}	-	Specific heat capacity of air ($kJ\ kg^{-1}°C^{-1}$)
$LMTD_{ct}$	-	Log mean temperature difference (°C)
Ntu	-	Number of transfer units of the cooling tower
T_{awb}	-	Outdoor Wet-bulb temperature (°C)

CHAPTER 1

INTRODUCTION

1.1 Problem Background

The usage of the chiller system to cool large residential or commercial buildings has become common as it is more practical for the user to centralize the air conditioning equipment in one location rather than install several pieces of individual equipment at various locations (Pérez-Lombard, Ortiz and Pout, 2008). Chiller is a refrigeration machine that produces chilled water, which is used to provide air conditioning in buildings. There are two types of chiller based on the heat rejection method, which is air-cooled chiller and water-cooled chiller as shown in Figure 1.1. Air-cooled chillers blow the air across their condenser while water-cooled chillers will use cooling towers to dissipate the heat into the atmosphere (Chillers – What are they? HVAC,2017).

Figure 1.1 Air-cooled chiller and water-cooled chiller (How a Chiller, Cooling Tower and Air Handling Unit work together - The Engineering Mindset, 2021)

However, research shows that the chiller system typically consumes more than 40% of the total electricity used in a building (Technical report Building energy data book, 2009). Based on research, chillers and pumps could occupy around 21% of the total operating cost of the semiconductor industry as shown in Figure 1.2 (Yogesh Mukesh, 2004). In other words, the increase in energy efficiency of the chiller system will have a significant effect on the energy performance of the building.

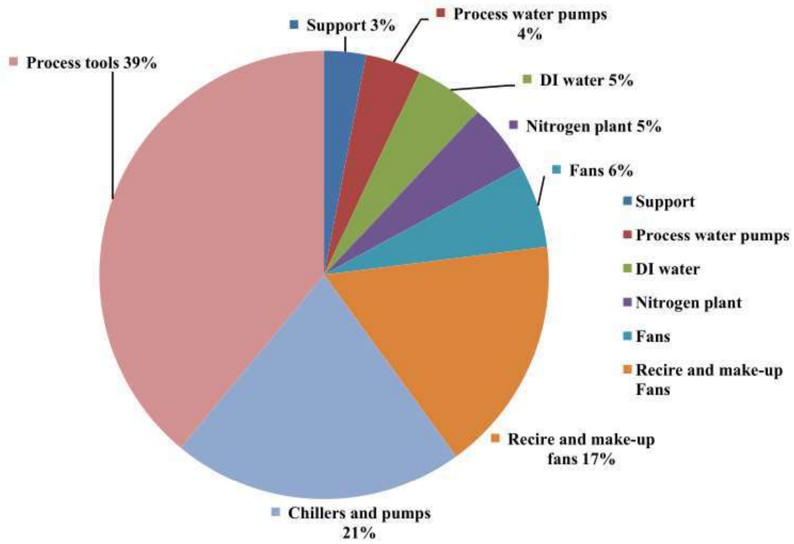

Figure 1.2 Magnitude of operating cost in a semiconductor industry (Yogesh Mukesh, 2004)

Therefore, the improvement measures to improve the energy efficiency of the chiller system is an important topic for both the developing and developed country. The high economic growth of these countries has resulted in a significant increase in the energy consumption. This is because the people in these countries will tend to reach a higher standard of living, which will also come with the increase in energy consumption. Based on a research done for the energy consumption of Malaysia, the electricity consumption of Malaysia rises by 1.5% for every 1% increase in GDP (Saidur, 2009).

1.2 Energy Consumption in Malaysia

According to the IEA, Malaysia is one of the countries with the highest cooling degree days among the Southeast Asian countries as shown in Figure 1.3 (IEA, 2019). This is due to Malaysia being located close to the equator. Therefore, Malaysia experiences hot and sunny weather throughout the years. Study shows that Malaysia is able to receive a monthly average of daily solar radiation of 4000–5000 Wh/m2 and about 2200 hours of sunshine a year, which is around 6 hour of daily sunshine (Mohammad, Al-Kayiem, Aurybi, et al., 2020). In 2018, the highest temperature that was recorded in Malaysia was 37.5 Celsius (Azis, 2021).

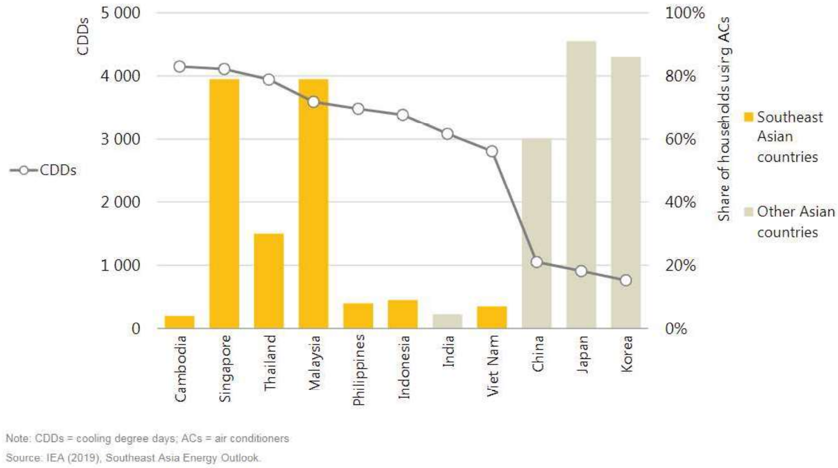

Figure 1.3 Cooling degree days of Southeast Asian Countries (IEA, 2019)

Because of the high cooling demands required in Malaysia, the large commercial building and industry sector often use chillers to provide cooling. Figure 1.4 shows the electricity consumption by sector in 2018,which shows the commercial sector and industry sector had contributed 29.0% and 49.8% of the total electricity consumption in 2018 (Suruhanjaya Tenaga, 2018). In another word, the improvement in the energy efficiency of the chiller system would be able to effectively reduce the total electricity consumption of the country. Besides that, from the report of the energy audit on Research and Development (R&D) building at Universiti Malaya, it shows that the cooling services contributes 34% of the total energy consumption of the building,which occupied the largest portion on the total energy consumption of the building (Birkha Mohd Ali, Hasanuzzaman, Rahim, Mamun & Obaidellah, 2021) . This further justified that the efficiency of the chiller is significant in energy consumption reduction.

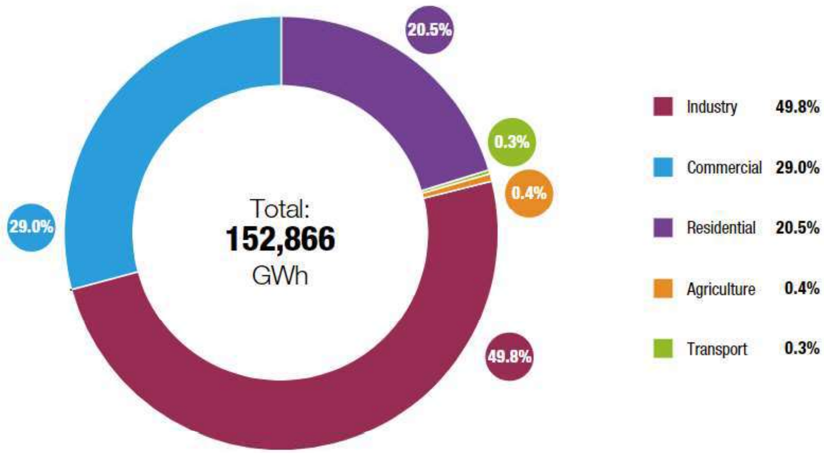

Figure 1.4 Electricity consumption by sector in 2018(Suruhanjaya Tenaga, 2018)

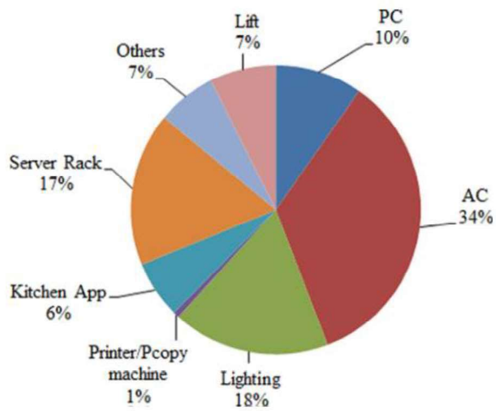

Figure 1.5 Electricity consumption by selected category of R&D building (Birkha Mohd Ali, Hasanuzzaman, Rahim, Mamun & Obaidellah, 2021)

1.3 Problem Statement

Based on research, the chiller system typically consumes more than 40% of the total electricity used in a building (Technical report Building energy data book, 2009). Therefore, it is very important to have effective energy management for the chiller system in order to save energy consumption. The saving on the energy consumption is not only able to reduce the operating cost for the user, it is also able to reduce the impact of the chiller system to the environment. In other words, the strategy that are able to improve the energy efficiency of the chiller system is very important since it is able to reduce the operating cost for the consumer and protect the environment at the same time.

In order to identify the improvement measures to increase the energy efficiency of the chiller system, various methods and strategies were proposed by researchers. According to the research, the increase of the ΔT of chilled water will be able to reduce the energy consumption of the chiller system (Using Data Loggers to Improve Chilled Water Plant Efficiency, 2022). However, many of the studies only concentrate on electricity saving. The impact of the improvement method to the performance of the chiller system was not considered. Therefore, a model that is able to calculate the energy consumption of the chiller system and evaluate the impact of ΔT of chilled water to the performance of the system is required by the market.

1.4 Objective

The objective of this research is to develop a model to evaluate the impact of ΔT of chilled water and calculate the energy consumption of the chiller system. The sub-objective of this study is to evaluate the impact of increase the temperature difference of chilled water to the performance of the other component inside the chiller system.

1.5 Research Scope

The scope of this study focuses on the following elements in order to ensure the fulfilment of the research objectives:

1. State-of-the-art review on the working process of the chiller system, modelling of water-cooled chiller system and PH diagram of refrigeration cycle.

2. Developing a model to evaluate the impact of ΔT of chilled water to the performance of chiller system.

    a) The model from the existing study is reviewed for their methodology and limitations.
    b) Evaluate the performance of the chiller system after the temperature difference of chilled water increased

3. Developing an energy consumption model to calculate the energy consumption of chiller system

    a) The energy consumption model from the existing study is reviewed for their methodology and limitations.
    b) Develop an energy consumption model that able to quantify the energy consumption yield from the manipulation of the control parameter of energy saving strategy proposed

4. Applying the energy consumption models on case studies from journal paper to reflect the accuracy of proposed models in energy consumption calculation

5. Propose increase temperature difference of chilled water as strategy to improve the energy efficiency of chiller system

1.6 Significant of Study

The model that evaluates the impact of ΔT of chilled water is very important since increase the ΔT of chilled water is able to improve the efficiency of the chiller system. There are many advantages associated with the increase in the energy efficiency of the chiller system. For example, the chiller system would be able to consume less energy if they are able to work in high efficiency. In other words, the energy planner would be able to reduce the operating cost of the owner of the chiller system by reducing the electricity bill they pay. Besides that, the chiller is also able to reduce the emission of greenhouse gas by operating with higher efficiency. The reduction in the greenhouse gas emitted by the chiller system would be able to reduce the impact of the chiller system to the environment.

Besides the improvement in the energy efficiency, the energy planner would also be able to quantify the energy saving occurred from increasing the ΔT of chilled water and evaluate the trade-off that comes together with the improvement measures to the chiller system. They would be able to know what would be sacrificed in terms of the performance of the chiller system in order to get the saving in energy consumption of the chiller system. This would help them to evaluate the execution of the improvement method proposed to increase the energy efficiency of the chiller system.

Additionally, this research is also able to correspond with the National Energy Efficiency Action Plan of Malaysia. This plan aims to promote energy efficiency and minimize the waste of energy to contribute to the sustainable development of Malaysia (Kementerian Tenaga Teknologi Hijau dan Air, 2015). The energy consumption model is able to evaluate the energy efficiency improvement measures for the chiller system. It would be able to assist energy users to improve the energy efficiency significantly since chiller systems typically consume more than 40% of the total energy consumption of a building(Technical report Building energy data book, 2009).

In summary, the model that able to calculate the energy consumption of the chiller system and evaluate the effect of ΔT of chilled water to the chiller system is aims to serve as a convenient tool for the energy planner to improve the energy efficiency of the chiller system. The relevant parties such as end users would also benefit from this research since they are able to save their electricity bill they pay for the chiller system.

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