Condenser-Evaporator Approach Temperatures and their Influences on Energy Performance of Water Cooled Chillers

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Abstract. This paper presents numerically and experimentally study of the effect of approach temperatures to temperature and energy performances of AC system type water-cooled chillers. Performance characteristics of the AC systems were analyzed at various approach temperatures and different refrigerants including refrigerant R-22, R-134A, R-407C and R-410A. Four numerical models have been developed in EES (Engineering Equations Solver) program to simulate the performances. The models were validated using data obtained from experimental investigation directly in hotel industries. The results showed that the increase of condenser and evaporator approach temperatures could cause the AC system to operate at a lower performance. The increase of condenser approach temperature by 1 K could reduce coefficient of performance (COP) of about 3.45%, 3.4%, 3.3% and 3.6% respectively for AC system with R-22, R-134A, R-407C and R-410A. This paper also presents the characteristic of condenser and evaporator approach temperatures that can provide indication the necessity of AC system maintenance in order to keep the best possible performance.

Introduction

In Indonesia, energy consumption of commercial sector includes office buildings, hospitals, hotels, trade centre (supermarkets and department stores) and airports is for about 3% of total national energy consumption. Although the percentage of this sector is quite small but development of this sector is continuously in progress. The growth of hotel industry in past three years for example could reach an average of 11.2% [1]. This would consequently increase the energy consumption. The commercial sector, however, has significant potential on energy saving and environmental impact reduction [2].

For hotel buildings, facilities with energy significant include air conditioning (AC) and hot water supply systems. Energy consumption of both systems can reach 70% of total energy use [3]. As the result, increase of energy use efficiency would accordingly contribute to reduction of energy consumption and greenhouse gas emissions to the environment. The reduction of energy use would be helpful for hotel industries due it could reduce operational cost and increase profit as well as hotel competitiveness. For the country, it could nationally reduce energy supply demand and environmental impact of the sector.

One factor that might constrain any efforts to achieve energy saving in AC system for commercial building was that shortness of knowledge of operators about critical-operation parameters of AC system especially central AC system with water cooled chillers. The parameters include evaporator and condenser approach temperatures. The increase of approach temperatures indicates that heat transfer in both condenser and evaporator has restricted. The chillers would operate at higher condensation temperature and lower evaporation temperature. These would cause temperature lift and energy consumption of chillers compressor high. The increase of approach temperatures also provides indications that the condenser and evaporator must be cleaned to maintain optimum temperature and energy performances as well as to prevent the condenser and evaporator from further damage.

Methods to detect fouling on the surface of condenser pipe were reported in [4]. It was demonstrated causes of damage in a chiller which included shortage of cooling water in condenser, insufficient chilled water in evaporator, low or over refrigerant charging and condenser fouling. It was found that condenser fouling had highest potential to instigate damage on a chiller system. Fouling could boost up approach temperature to become strong influence toward heat transfer capacity of a condenser and performance of a chiller system.

Approach temperature of a condenser has major influence to chiller system performance compared with evaporator approach temperature. A chiller system with high condenser approach temperature would require higher condensation temperature to reject heat to the cooling water. This would increase working pressure and energy consumption of a chiller. A study case showed that when approach temperature of a condenser was not tightly monitored, it could make condenser pipes crack and leak. Evaporator approach temperature, on the other hand, is not significantly influenced by fouling. It is usually used as an indicator how efficient a chiller system can perform. Evaporator approach temperature in combination with compressor discharge superheat can be used to determine the most efficient refrigerant charge [5].

In order to reduce effects of condenser approach temperature, cooling water temperature could be controlled and optimized. A control strategy which regularly reset temperature of the cooling water in such a way with the intention that the approach temperature would not influence condensation temperature was reported in [6]. Consequently, when the approach temperature increased the control strategy would increase the speed of cooling fan in the cooling tower to satisfy the requirement of cooling water for condenser. This meant energy consumption of the cooling tower would increase. The control strategy, however, was reported to provide energy saving up to 4% per annum.

It was reported that commercial building, such as hotels, consumed substantial amount of energy [7]. For that reason, it was recommended to continuously monitor performance of the AC system so as to detect early warning of performance reduction due to fouling in the condenser. A multivariable analysis involving chilled and cooled water temperatures showed that operational variables had to be tightly monitored to improve AC system performance with higher technical efficiency [8, 9].

A study on energy consumption of AC systems in hotel buildings was reported in [10]. It was found that ambient temperature which directly correlated to cooling water and approach temperatures showed significant influence on AC system. The system consumed the highest electrical energy among other hotels services. Similar study was also reported in [11].

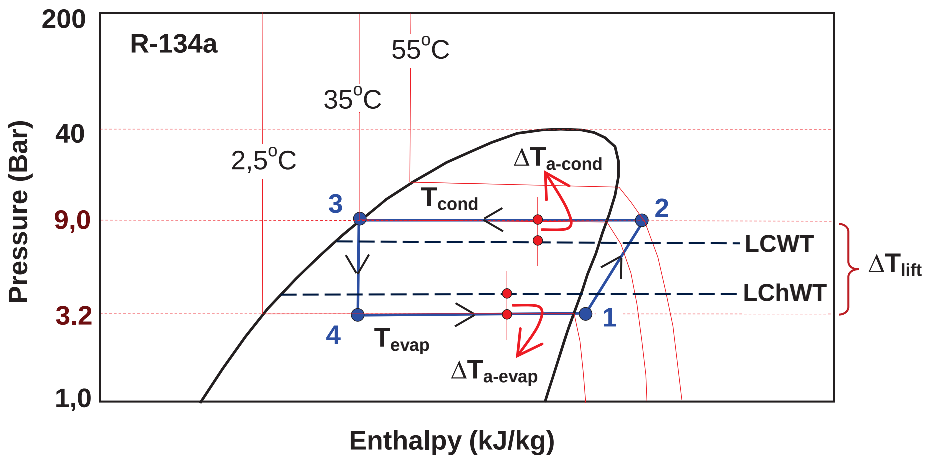
Preliminary observation results on commercial building in Indonesia conducted prior this research showed that most of chiller operators spent very little time on monitoring condenser and evaporator approach temperatures. A case study in a star hotel North Jakarta showed that the chiller systems operated at condenser approach temperature reaching 10^{o}C. Cooling capacity of the chiller system could not satisfy hotel load demand anymore. The AC system could not maintain room temperature at required comfort level especially during day time. Energy consumption of the chiller system also increased. Then the condensers of the chiller system were de-scaled. As the result the condenser could operate at approach temperature below 1^{o}C and the cooling capacity could be recovered as it was before. Other case was also found in a supermarket in Bali - Indonesia. Condenser pipes of a chiller in this supermarket were cracked and exploded. Investigation on the case showed that waterside surfaces of condenser pipes were totally covered by thick salt-scale. Another case which showing the importance of condenser temperature needed to be tightly monitored has also observed at terminal building of Ngurah Rai Airport Bali. In this building, the condenser approach temperature was regularly recorded and analyzed. In one year operation, the chillers were found to have a condenser approach temperature more than 5 K. This means the temperature has increased more than 4 K in one year. The condenser surface was obtained to be very dirty. The high increase rate of approach temperature indicated the quality of makeup water was below recommendation or blow down water rate of cooling tower need to be fine-tuned.

This paper presents results of theoretical and empirical investigation on effects of evaporator and condenser approach temperatures to energy performance of water cooled AC chillers. The investigation demonstrated variation of energy consumption and cooling capacity of chiller system at different evaporator and condenser approach temperatures. Four AC chillers with different refrigerants R-22, R-134A, R-407C and R-410A were included in the investigation.

Concept and Methodology

Evaporator approach temperature is a measure of temperature difference between chilled water temperature leaving the evaporator and evaporation temperature of refrigerant. Condenser approach temperature shows temperature difference between cooling water temperature leaving the condenser and refrigerant condensation temperature. Concept of approach temperatures of chiller system in a pressure-enthalpy diagram is shown in Fig. 1.

The increase of condenser and evaporator approach temperatures indicates that heat transfer in condenser and evaporator has decreased. Maintaining cooling capacity of a chiller system with high condenser and evaporator approach temperatures require higher condensation temperature and lower evaporation temperature. As the result, compressor temperature lift of the chiller system increases. This also increases system pressure ratio and energy required for compressor, consequently reduces chiller system performance.



$\Delta T_{a\text{-}cond}$ = Condenser approach temperature = T_{cond} - LCWT

$\Delta T_{a\text{-}evap}$ = Evaporator approach temperature = LChWT – T_{evap}

T_{cond} = Condensing temperature,
LCWT = Leaving Cooling Water Temperature

T_{evap} = Evaporating temperature
LChWT = Leaving Chilled Water Temperature

Fig. 1. Consept of approach temperatures in a chiller system with R-134A (Modofied from [12])

This research was based on numerical and experimental analyses of critical operation parameters for a central air conditioning system type water cooled chiller. The investigated chiller was for commercial building application, especially hotel building. The system comprises chillers, cooling water pump, chilled water pump, cooling tower and loading systems.

Variables to be investigated comprises dependant and independant variables. Dependant variables include energy consumption, cooling capacity and coefficient of performance (COP). Whilst independant variables consist of evaporator and condenser approach temperatures, evaporation and condensation temperatures of refrigerant respectively in evaporator and condenser, chilled and cooling water temperatures, ambient temperature, low and high system pressures, refrigerant flowrate, chilled and cooling water flow rate.

Instruments used for numerical and experimental investigations included EES (Engineering Equations Solver) program, thermocouples, pressure transducers, data logger, energy meter and flow meter. EES program was applied for numerical analysis and experimental investigation was conducted through on site testing. The data obtained was processed in a spread sheet program. The results of experimental testing were applied for validating numerical models established in EES program.

Results and Discussion

Numerical models of water cooled chillers have been established in this research. The models include chiller systems with refrigerant R-22, R-134A, R-407C and R-410A and have been validated by using data obtained from experimental testing. Models were subsequently used to simulate effects of evaporator and condenser approach temperatures to AC system performance.

Fig. 2(a) shows characteristic of COP (coefficient of performance) at different evaporator and condenser approach temperatures of water cooled chiller systems working with refrigerant R-134a. The COP generally decreases when the approach temperatures increase. At evaporator approach temperature of 0.5 K, the COP of chiller system drops down of 27.5% when condenser approach temperature increases from 0.5 K to 10 K. The reduction of COP would become worse when condenser approach temperature rises to above 10 K and evaporator approach temperature also increase to more than 0.5 K. Conversely, power consumption of chiller system increases when evaporator and condenser approach temperatures rises as shown in Fig. 2(b). Power consumptions presented in the figure were simulated in the model which has been validated using data from experiment at a water cooled chiller system of cooling capacity 650 TR (tons of refrigeration). The intensification of power consumption could reach 28% when condenser approach temperature rises up to 10 K. Other consequence, cooling capacity of the chiller system could drop by 7.4%.

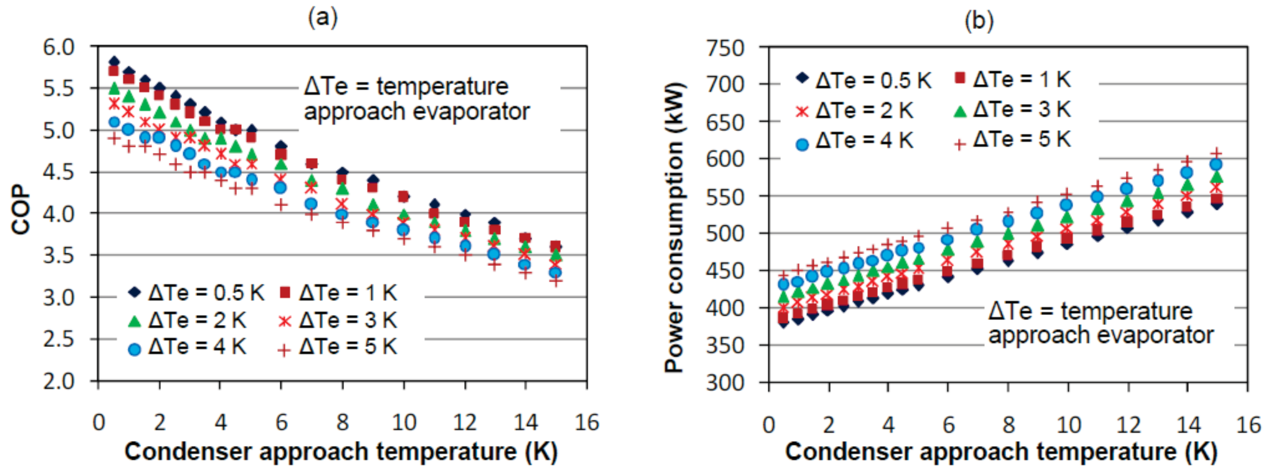


Fig. 2. (a) COP and (b) Power consumption of chiller system with refrigerant R-134A at different approach temperatures

The increase of power consumption and the decrease of cooling capacity result in significant reduction on the COP of a chiller system. Hence, maintaining evaporator and condenser approach temperatures as low as possible would be very essential to keep chiller system performance optimum.

Figs. 3(a) and (b) show COP characteristic and power consumption of chillers systems with different refrigerants. The results were investigated at evaporator approach temperature of 0.5 K. From the graphs, it can be seen that effects of the increase of condenser approach temperature to the reduction of system COP and intensification of power consumption quite significant on the chiller system with R-22 but reversely the effects are relatively low when the chiller system using R-134A or R-407C.

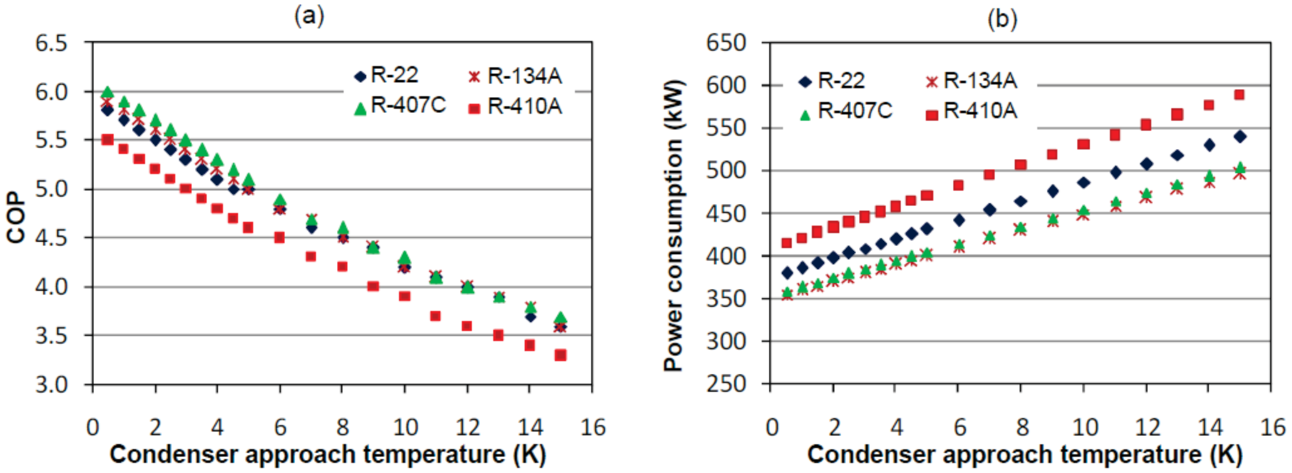


Fig. 3. (a) COP and (b) Power consumption of chillers systems with different refrigerants and various condenser approach temperatures (at evaporator approach temperature of 0.5 K)

With respect to the specific effects of condenser approach temperature to a chiller system, Fig. 4(a) illustrates that 1 K increment of condenser approach temperature causes power consumption to raise of about 3%, 2.9%, 2.9% and 3.0% respectively for chiller system with refrigerant R-22, R-134A, R-407C and R-410A. Fig. 5(b) shows the effects to cooling capacity (Q_{evap}) and COP of a chiller system. Cooling capacity seems to decline not more than 1% but COP may drop in the range of 3.3% and 3.6% per 1 K addition of condenser approach temperature.

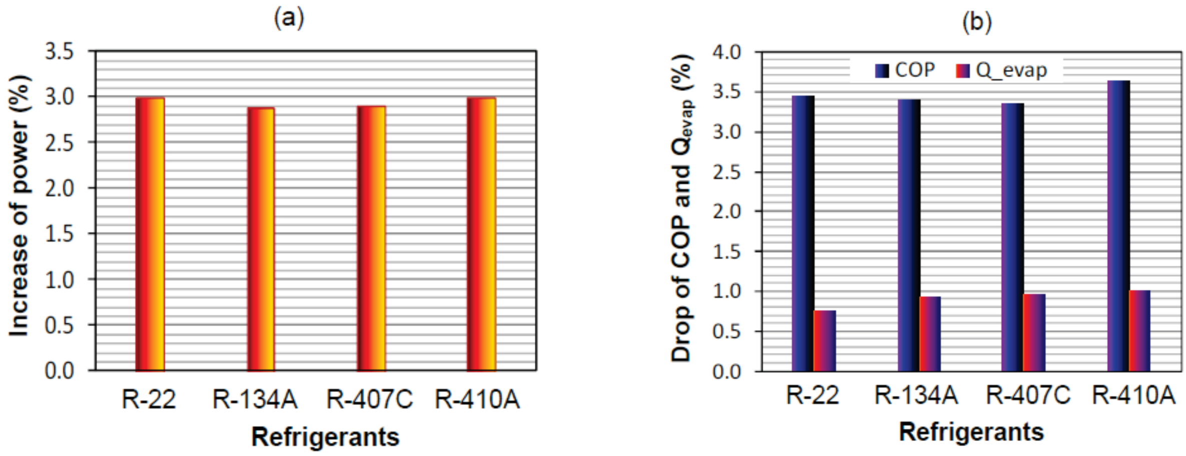


Fig. 4. (a) Increase of power consumption and (b) Reduction of COP and cooling capacity (Q_{evap}) of AC system at every 1 K increment of condenser approach temperature

From Figs. 3 and 4 can also be noticed that evaporator and condenser approach temperatures are very important operational parameters of a water cooled chiller system. The parameters can be used to monitor effectiveness of evaporator and condenser as well as temperature and energy performance of the chiller system. By regularly monitoring and recording both parameters as part of operational and maitenance programs, it can provide early warning that waterside surfaces of evaporator and condenser have been dirty and have occured heat transfer constraint in the components. Due to the importance of the two parameters, it was recommended to maintain evaporator and condenser approach temperatures lower than 2 K and the components must be immedietly cleaned when approach temperatures have reached 5 K [5].

Conclusion

Evaporator and condenser approach temperatures could provide significant impact on energy performance of a water cooled chiller system. The temperatures are also considered as critical operation parameters which are very functional for monitoring and evaluating performance of a chiller system. The increment of 1 K condenser and evaporator approach temperatures could cause an increase of power consumption of about 3% and reduction of cooling capacity by 1%.

The investigated chiller systems with various kinds of refrigerants R-22, R-134A, R-407C and R-410A were found to be subjected to a reduction of COP in the range between 3.3% and 3.6% per 1 K increment of condenser approach temperature.

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