Performance of a residential air conditioning unit under constant outdoor air temperature and varied relative humidity

A Setyawan* and A Badarudin
Department of Refrigeration and Air Conditioning Engineering, Politeknik Negeri Bandung, Bandung 40012, Indonesia

*andriyanto@polban.ac.id

Abstract. An experiment on the effect of the relative humidity variations of outdoor air on the performance of an air conditioning system under constant dry-bulb temperature has been performed. In this experiment, the outdoor air temperature was maintained at 35°C while the relative humidity was varied from 40% to 70%. As a result, the operating conditions were slightly changed. In general, the suction temperature decreases with the increase of relative humidity. On the other hand, the condensing temperature slightly increases with the increase of relative humidity. Other findings for the experiment are almost constant of cooling capacity, with a variation of only 1.2%. An important evidence is that the condenser capacity increases by 15.2% for the relative humidity variation from 40% to 70%.

1. Introduction
In a room air conditioning system, two main parts are well-acknowledged: the indoor unit and outdoor unit. The indoor unit consists of evaporator and its circulating fan. Meanwhile, the compressor and condenser are installed at the outdoor. The performance of the condenser depends on the ambient air condition. In the hot tropical climate, the air conditioning machine usually consumes more energy due to the higher discharge and condensing temperature. This condition increases the compression ratio and compressor work and reduces the system efficiency. In this condition, the COP (coefficient of performance) decreases in the range of 2.2 to 2.4 [1]. Each increase of ambient temperature by 1°C reduces the cooling capacity as well as COP by 2% [2]. In tropical area, the cooling load generally increases due to the higher temperature difference between the outdoor and indoor. It results in the increase of compressor’s operating time to cool the air within the predetermined setting. Consequently, it consumes more energy [3].

On the other hand, decreasing the ambient temperature could improve the cooling performance. It was reported that the use of cooling pad in the condenser [4] could improve the COP by 1.8%. Decreasing condensing temperature by using the evaporative cooling could reduce the compressor power consumption [5,6]. It also reduces the total power consumption up to 6% [7]. The reduction of power consumption is highly desired as the air conditioning system could absorb 30 – 45% of electricity used in residential and commercial buildings [8,9]. In addition, alternative energy for AC system is very important for reducing the use of fuel energy [10].

The effect of the ambient temperature on the cooling performance of an air conditioning system has been widely studied. In this paper, the effect of constant ambient temperature but varied relative...
humidity (RH) will be presented. Discussion concerning to the operating condition, cooling capacity, energy consumption, and energy efficiency will be elaborated.

2. Methodology

In this research, a 2-hp air conditioning unit with a nominal cooling capacity of 5275 W was employed. The indoor unit of the machine was installed in a room maintained at 27°C dry bulb temperature and 19°C wet bulb temperature. Meanwhile, the outdoor unit was installed in the adjacent room where its temperature is maintained at 35°C, while the relative humidity was varied to 40%, 50%, 60%, and 70%. The variation of RH was carried out by using an electric heater and water spray. Whenever the relative humidity is lower and the temperature is higher than that of the predetermined value, the water spray works to cool the air and increase the moisture content and its RH. On the other hand, when the RH is higher and the temperature is lower than its setpoint, the heater works to lower the RH of the condenser air.

During the first experiment with 40% of RH, the wet-bulb temperature was found to be 24°C and the moisture content was at 15.61 grams of water vapor per kilogram of dry air. In the second experiment of 50% RH, the water spray added the moisture content of the condenser air to 19.64 g/kg. In the third experiment (60% RH), the moisture content was added to 23.71 g/kg. Finally, in the last experiment with 70% RH, the moisture content of the condenser air was increased to 27.84 g of water vapor per kg of dry air. The diagram of the experiment is presented in Figure 1.

![Figure 1. The diagram of the experimental setup.](image)

3. Results and discussions

This section discusses the results of the experiment concerning to the operating conditions and the performance of the air conditioning system. The discussed operating conditions are discharge and condensing temperature. Meanwhile, the performance consists of cooling capacity, energy consumption, and energy efficiency.

3.1. Discharge temperature

Discharge temperature is measured at the compressor’s outlet. It expresses the temperature of refrigerant after being compressed by the compressor. The experiment with 4 different RH of outdoor air showed that the average discharge temperature is in the range of 78.8°C to 79.0°C. As shown in Figure 2, the discharge temperature for the experiment with the lower relative humidity is somewhat
lower than that of the higher RH. However, it could be noted that the difference of the temperature is not significant, only in the order of 0.1°C in average. In other words, the effect of RH on the discharge temperature is insignificant. In addition, there is no specific trend in discharge temperature due to the change of RH.

3.2. Condensing temperature
Condensing temperature is the refrigerant temperature measured at the condenser outlet. From the experiment, it ranges from 49.4°C to 49.7°C. The profile of condensing temperature shows that there is no significant effect of the change of RH on the condensing temperature. If 50% RH is taken as the reference, the highest difference of the average condensing temperature is only 0.3°C. As shown in Figure 3, the condensing temperature for the 4 test conditions are relatively same. However, detail observation reveals that there is a somewhat lower condensing temperature for the experiment with outdoor RH of 40%.

3.3. Cooling capacity
The term cooling capacity expresses the ability of the air conditioning machine to remove heat from the conditioned space. From the experiment, again, it is obvious that the relative humidity of outdoor air has no significant effect on the cooling capacity. As could be seen in Figure 4, there is no specific trend for the cooling capacity. The cooling capacity is in the range of 5128 Watt to 5135 Watt. Seen from the average values of 7 runs of the experiment, the maximum difference of the cooling capacity
is only 0.2%. Therefore, it can be stated that the relative humidity of the outdoor air has no effect on the cooling capacity as long as the dry bulb temperature is constant.

3.4. Power consumption

This term expresses the power drawn by the cooling unit, including the compressor, fans, and control devices. From the experiment, the power absorbed by the machine is in the range of 1670 Watt to 1674 Watt. The difference of the required power for the experiment with different outdoor RH is only in the range of 0.23%. It indicates that the power consumption is constant for all experimental conditions. A slightly higher power consumption is found at the experiment with 70% outdoor RH. The profile of the power consumption for this experiment is depicted in Figure 5.

3.5. Energy efficiency

The energy efficiency ratio (EER) depicts the ratio of the cooling capacity of the cooling unit and its power consumption. From this definition and discussion of Section 3.3 and 3.4, it can be expected that the outdoor relative humidity has no substantial effect on the energy efficiency. Calculation of EER results in the range of EER from 3.069 to 3.074. The spread of the EER values is only 0.15%, implying that it is not affected by the outdoor RH on condition that the dry-bulb temperature is constant. The profile of EER for this experiment is presented in Figure 6.
4. Conclusion
The performance of an air conditioning unit has been tested under constant 35ºC dry-bulb temperature and varied relative humidity from 40% to 70%. In general, there is no substantial effect of the varied RH on the operating condition and performance of the cooling unit. The discharge temperature only changed by the order of 0.1ºC in average, while the condensing temperature only changed by 0.3ºC. The similar trends are also found for the performance of the cooling unit. The cooling capacity variation during the experiment is only 0.2%. Meanwhile, the variation of the power consumed by the cooling unit is only 0.23%. It results in the almost constant energy efficiency ratio. In this study, the EER is only varied by the factor of 0.15%. Therefore, it could be concluded that the variation of the outdoor effect has no considerable effect on the performance of an air conditioning unit.

References
[1] Lam J C 2000 Residential sector air-conditioning loads and electricity use in Hong Kong. Energy Convers Manag 41 1757–68
[2] Yau Y H and Pean H L 2014 The performance study of a split type air conditioning system in the tropics, as affected by weather, Energy Build. 72 1–7
[3] Sharma N K and Singh J 2014 Int. J. Emerg. Technol. Adv. Eng. 4 513-518
[4] Martinez P, Ruiz J, Cutillas C G, Martinez P J, Kaiser A S and Lucas M 2016 Experimental study on energy performance of a split air-conditioner by using variable thickness evaporative cooling pads coupled to the condenser Appl. Therm. Eng. 105 1041-50
[5] Kabeel A E, Bassuoni M M and Abdelgaied M 2017 Experimental study of a novel integrated system of indirect evaporative cooler with internal baffles and evaporative condenser Energ. Convers. Manage. 138 518–525
[6] Junior I C A and Smith-Schneider P 2016 Consolidated experimental heat and mass transfer data base for a reduced scale evaporative condenser Int. J. Refrig. 66 21-31
[7] Ibrahim N I, Al-Farayedhi A A and Gandhidasan P 2017 Experimental investigation of a vapor compression system with condenser air pre-cooling by condensate Appl. Therm. Eng. 110 1255–63
[8] Jahangeer K A, Andrew A O and Raisul M 2011 Numerical investigation of transfer coefficients of an evaporatively cooled condenser Appl Therm Eng 31 1655-63
[9] Kalkan N, Young E A and Celiktas A 2012 Solar thermal air conditioning technology reducing the footprint of solar thermal air conditioning Renew Sustain Energy Rev 16(8) 6352–63
[10] Fong K F, Lee C K, Chow T T, Lin Z, and Chan L S 2010 Solar hybrid airconditioning system for high temperature cooling in subtropical city Renewable Energy 35 2439–51