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An Experimental Evaluation of Energy Saving in a Split-type Air Conditioner with Evaporative Cooling Systems

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ABSTRACT

This research aims to experimentally evaluate the energy saving in a split-type air conditioner, which is using various types of evaporative cooling systems. The condensing unit is retrofitted with a cellulose corrugated pad, water sprayers, a water source and a pump. The power consumption and refrigeration capacity obtained from various cooling types are monitored and compared. The results show that the electrical consumption and coefficient of performance (COP_R) significantly depend on the ambient conditions. Due to effects of condensing pressure, when the ambient temperature rises, the electrical consumption becomes higher, while the COP_R becomes lower. Utilizing the indirect evaporative cooling system decreases the temperature of air entering the condensing unit, and this causes the system performance to be enhanced considerably. Among the investigated cases, the maximum energy saving occurs when the water spray cooperates with cellulose cooling pad. By using the evaporative cooling systems, COP_R is improved by around 6-48%, and electrical consumption is approximately reduced by 4-15%.

1. Introduction

With impact of energy crisis and global warming, many researches have paid much attention on strategies for saving energy. In the tropical climate countries such Thailand, more than 50%

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of total electrical consumption in residential and commercial buildings comes from air conditioning systems. Due to simplicity and flexibility, the conventional split-type air conditioner is widely used in small and medium size buildings, e.g. residences, offices, and schools. Condensers used in this air conditioner are mainly air-cooled. In addition, their performances depend on the heat transfer between coils and the ambient airflow. Chow et al. (2002) reported that if the on-coil temperature of a condensing unit were raised by $1^{O}C$, the coefficient of performance (COP_R) of the air conditioner would drop by around 3%. In addition, if this temperature remained above $45^{O}C$ for an extended period, the air conditioner would trip because of the excessive condenser working pressure. Effect of hot air recirculation on condensing temperature was studied by Avara and Daneshgar (2008). It was found from their numerical results that the distance between walls (L), where a condensing unit was installed, affected the on-coil temperature. If L was less than 1.5 m, the air flow should be parallel to the walls. In addition, if L = 1.5 m, optimal distance of condenser from the supporting wall (D) was 35 cm. Selecting a greater D led to more hot air circulation and consequently increased the on-coil temperature.

Hu and Huang (2005) improved the system performance of a water-cooled air conditioner by utilizing the cellulose pad, which was in cellulose bound cardboard structure. Instead of plastic packing in a cooling tower, this cellulose pad depressed the effect of surface tension on the plastic surface. This caused the contact area between air and water to be increased, resulting in enhancement of heat transfer. To improve the COP_R and save energy in refrigeration and air conditioning systems, Vrachopoulos et al. (2007) developed an incorporated evaporative condenser, which was installed with a cooling water sprinkle network in the front. In this method, water was directly sprayed into air-stream. The results showed that COP_R was improved up to 211% and energy saving was up to 58%. However, since the air filled with water droplets was directly induced to the condensing unit, corrosion problem possibly occurred on equipment. In order to reduce the condensing temperature in a window-type air conditioner, Hajidavallo (2007) installed two cooling pads in both sides of the air conditioner and injected water on them. With the cooling pads, the water droplets, which were exchanged the heat with hot-air flow, were trapped and dropped to the bottom. Hajidavallo (2007) reported that with evaporative cooling pad, the energy consumption decreased by about 16%, and the COP_R increased by about 55%.

In this study, the energy saving in a residential-sized split-type air conditioner is performed by retrofitting condensing unit with various types of indirect evaporative cooling systems. Air-stream entering condensing unit is cooled down at two positions, i.e. in the front of and within cellulose corrugated pad. Moreover, injecting water into the air is divided into two types: water curtain and water spray. Comparison on system performances obtained from each case is reported.

2. Experimental study and instrumentation

From the name plate given by manufacturer, cooling capacity of the split-type air conditioner is 30,165.49 Btu/hr (8.84 kW), and condenser fan is 174 W (full load amp = 1.79 / 220 volts). The condensing coil is rectangular and is placed outside the building. Distance between condensing unit and wall is 0.3 m. The ambient air flows in and out from the condensing unit in the horizontal direction.

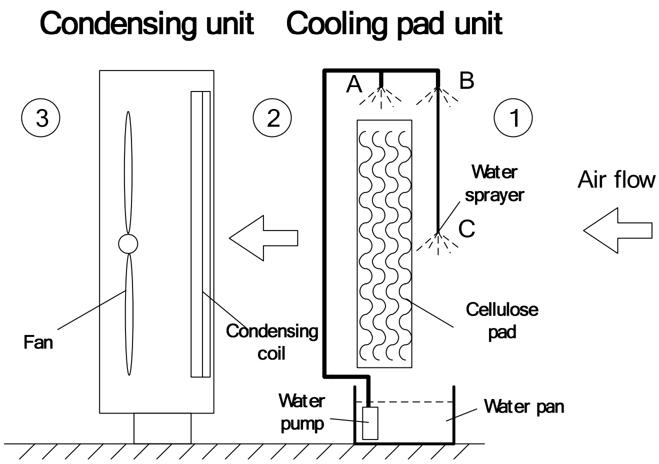

Figure 1: Schematic diagram of evaporative cooling system.

The evaporative cooling pad unit of 0.15 m thick is placed in the upstream flow of air entering the condensing unit. As shown in Fig.1, the unit comprises of cellulose pad, water pipe networks, which are located on the upper and in the front of cellulose pad (at position A, and B), and a water pan at the bottom. In addition, a 100–W pump with the maximum flow rate of 0.07 m^3/min is used for circulating water in the system. Gap between the cooling pad and condensing unit is 0.05 m. In the cases using water curtain, water pipe at position B is bored with 1-mm holes

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and spacing between bores is 0.01 m. While in the cases using water spray, at positions B and C, the pipe network is replaced with spray bars. Along the spray bars, pipes are bored and installed with spray heads, where spacing between them is 0.185 m. In order to produce water mist by a low–power water pump, spray heads are installed normal to the direction of air-stream entering the condensing unit.

A power meter (CHAUVIN ARNOUX SERIES C.A.8310) is used to monitor the total power consumption including compressor, evaporator fan and condenser fan. Temperature and humidity of outdoor air conditions (position 1, 2, and 3 shown in Fig.1) and indoor air conditions (upstream and downstream of the evaporative coil) are measured by TESTO 400. Average flow rate of air-stream entering the condensing unit is 1,171.74 cfm (0.9 m/s). Indoor air condition is controlled by thermostat at 25^{O}C, and airflow rate exiting from evaporator is 186.22 cfm (0.93 m/s). Testing conditions are divided into 6 cases as shown in Table 1.

Table 1: Testing conditions.

Case	Condition
1	Without cooling system
2	With cellulose cooling pad
3	With water curtain
4	With water curtain and cellulose cooling pad
5	With water spray
6	With water spray and cellulose cooling pad

3. Results and discussions

In order to evaluate improvement of the system performance, the air conditioning system with the evaporative cooling systems is first monitored. In all experiments, air properties and total electric power consumption are measured and recorded for 24 hours.

3.1 Total power consumption

The results from Fig. 2 show that in the afternoon, the power consumption is higher than the other periods. Particularly, the maximum power consumption is in the period of 13.00 - 17.00. This indicates that outdoor temperature has much affected the power consumption of air conditioner. Discontinuity shown in the Fig. 2 is the effect of the cycling machines (starting and stopping the fan motor and compressor). In fact, when temperature of air conditioning room reaches a set point, then electrical machines in condensing unit will stop running.

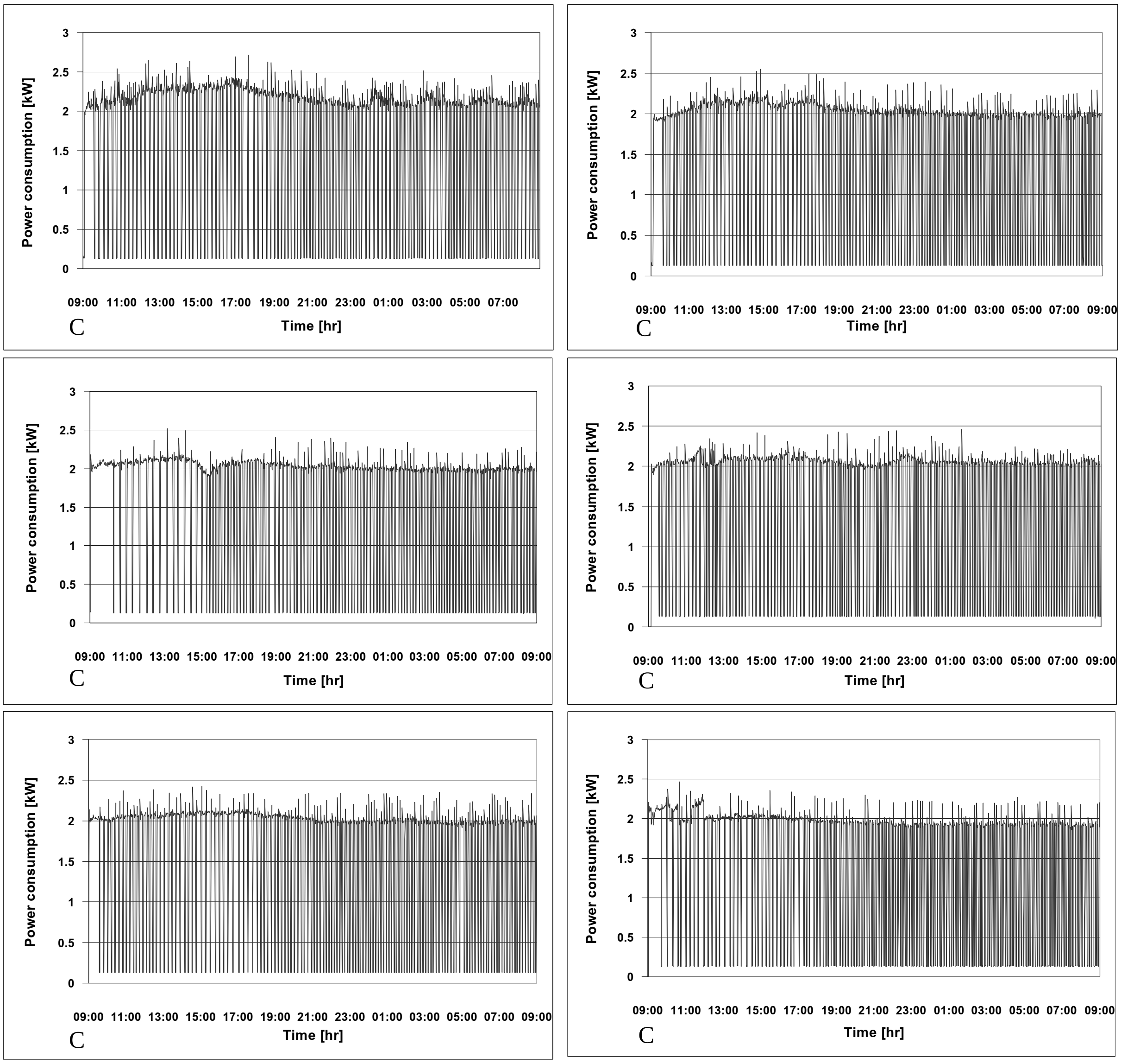

Figure 2: Total power consumption in various cases.

By comparing with case 1 (without evaporative cooling systems), it seems that the frequency of the cycling machines in the air conditioner retrofitted with evaporative cooling systems is more often. This is evident that decreasing temperature of air entering condensing unit also

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influences the refrigeration capacity in evaporator. The average power saving values in case 2 to case 6 approximately are 3.8, 7.8, 9.7, 10, and 15%, respectively.

3.2 System performance

In this study, coefficient of performance in refrigeration (COP_R) is defined as the ratio of refrigeration capacity to total power consumption measured by power meter. In addition, refrigeration capacity is computed through the amount of energy transfer between air and refrigerant, and it can be written as

$$Refrigeration\ capacity = \dot{m}_a \left(h_{ra} - h_{sa} \right) \quad (1),$$

Where $\dot{m}_a$ is mass flow rate of air exiting from the supply air grille, h_{ra} and h_{sa} are enthalpy of supply and return air, respectively.

The average system performances are shown in Fig. 3 in which ambient air conditions are presented by temperature (^{O}C) and relative humidity (% RH). The results show that temperature affects the system performances more than relative humidity. When ambient air temperature becomes lower, the system obtains higher COP_R. Due to outdoor air effect, COP_R during night time is higher than that during day time. As the day progressed, the ambient temperature is higher. This causes condenser pressure head to be increased, resulting in a lower performance. In other words, higher condenser pressure results in an increase of power consumption by the compressor. On the other hand, the performance of the system increases when the ambient air temperature drops. By using curve fitting, it is found that electrical power consumption increases by around 4% when temperature is raised by 1^{O}C.

With indirect evaporative cooling system, ambient air transfers heat to water. This causes temperature of air entering condensing unit to become lower. In addition, heat transfer between refrigerant flowing through condensing unit and the entering air more increases. Consequently, COP_R of the system is improved.

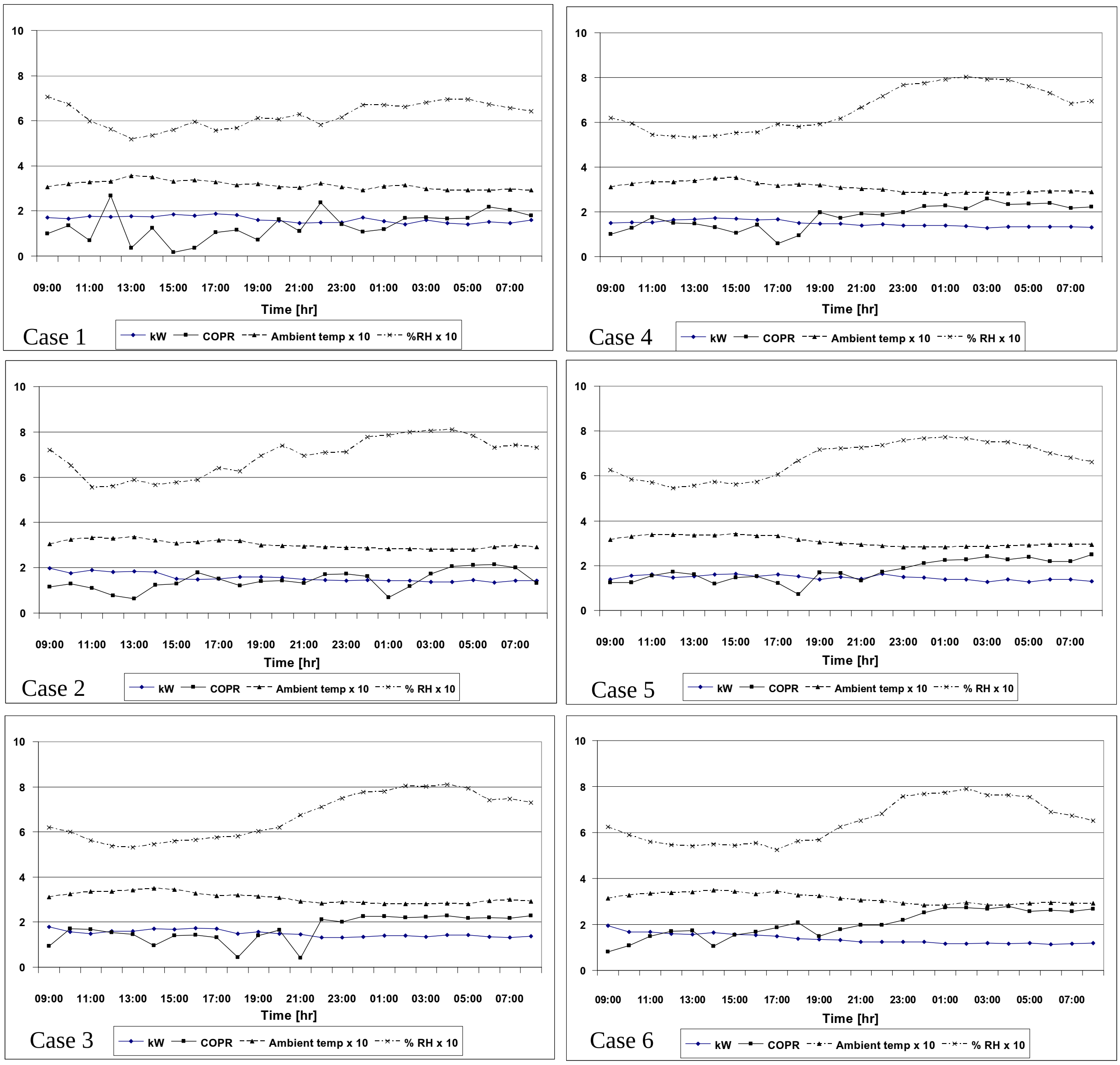

Figure 3: System performance in various cases.

3.3 Comparison on power consumption

The outdoor and indoor air conditions are shown in Table 2. With indirect evaporative cooling systems, temperature of air entering condenser can approximately reduce by 3^{O}C in maximum, and relative humidity is 85% in maximum. Moreover, the indirect evaporative cooling influences power consumption and refrigerating effect (Δ*h* in room) of air conditioning system, resulting in improvement of COP_R.

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Table 2: Outdoor and indoor air conditions.

Case	Condition	Ambient condition		After passing cooling device		After passing condensing unit		kW	Δ*h* in room	COP_R
		T_1 [C]	RH_1 [%]	T_2 [C]	RH_2 [%]	T_3 [C]	RH_3 [%]			
1	Without water cooling system	31.06	63.29	31.06	63.29	38.64	48.66	1.63	20.26	1.35
2	With cooling pad	29.79	74.63	27.59	84.85	34.16	58.80	1.56	20.73	1.43
3	With water curtain	30.48	68.47	30.02	71.44	34.99	58.32	1.50	23.51	1.69
4	With water curtain and cooling pad	30.66	67.36	26.97	81.85	34.18	59.50	1.47	24.12	1.77
5	With water spray	30.33	72.73	29.31	81.28	35.28	59.05	1.46	24.12	1.76
6	With water spray and cooling pad	30.88	69.79	27.01	85.38	34.84	58.37	1.38	25.15	2.01

Figure 4 shows the comparison on average power consumption per ton of refrigeration among various cases. Air conditioner with water spray and cooling pad (case 6) provides the minimum value of kW/ton. This is because air-stream entering the condensing unit has more contact with cooling water. Hence, heat can much transfers from refrigerant to air-stream, and then condenser pressure head is lower. By comparing the case without the cooling water system (case 1), it is found that the electrical power saving values in case 2 to 6 are around 4, 7.7, 9.6, 10.1, and 15.3%, and system performances are improved around 6.4, 25.6, 31.7, 31.1, and 49.5%, respectively. Even though the evaporative cooling system reduces the power consumption, influence of corrosion due to high humidity on equipment should be considered.

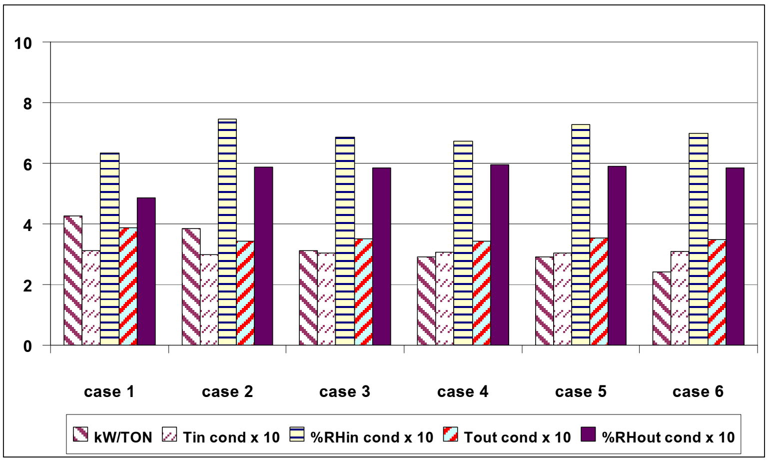

Figure 4: Comparison on power consumption among various cases.

4. Conclusions

Improvement of system performance in a split-type air conditioner with various types of indirect evaporative cooling systems is evaluated in this study. The following paragraph summarizes the conclusions of this study:

1. Based on the experimental results, it reveals that ambient temperature has much influenced the power consumption of compressor and COP_R. When temperature is raised by $1^{O}C$, electrical power consumption increases by around 4%.

2. With evaporative cooling systems, the air entering condensing unit is cooled to a lower temperature. This causes the power consumption by compressor to lower, and the refrigeration capacity to be higher, resulting in enhancement of COP_R. In addition, evaporating cooling systems are effective in day time more than in night time.

3. Due to high contact surface between water and air-stream, the evaporative cooling system using spray water cooperating with cellulose cooling pad can decrease the power consumption by around 15%, and can increase COP_R up to 45%.

5. Acknowledgements

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