THE STUDY OF THE DRYING APPLICATION DISTANCES FROM THE CONDENSING UNIT EFFECTING ON THE AIR CONDITIONING EFFICIENCY AND DRYING RATE

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ABSTRACT

This work was focused on the study of the drying application distances, or the heated air-obstacle distance, from the condensing unit of the 24000 BTU/hr air conditioning systems (A/C) which effected on the A/C efficiency and the drying rate the application. The drying application utilized exhausted heat from the condensing unit and performed as the fabric dryer. The application or the experimental setup was investigated for the A/C efficiency and the drying rate in 4 different weather conditions; the normal and rainy daytime and nighttime. The fan, which was driven by electric from battery charged by a solar cell panel, was installed on the application to enhance heat convection inside the application. The application; which can be considered as an obstacle of exhausted air from the condensing unit, was placed behind the condensing unit at two different distances; 0.5 and 0.7 m, respectively, to investigate their effects on the A/C power consumption of the obstacle distances which directed the heated air into different heated-air-flow patterns. The velocities of inlet and outlet air through condensing unit, humidity ratios and temperatures of ambient air, sunlight intensity, fabric weights before and after drying and A/C power consumptions were measured. From the results, when the application was placed at 0.5 m behind the condensing unit, the A/C efficiency was better than it was at 0.7 m in all four weather conditions. Since the closer distance between the application and the condensing unit could enhance more convective and evaporative heat transfer of the heated-air flow behind the condensing unit, we found that the evaporative cooling and convective heat transfer played their important roles in the drying process of the application and in the heat rejection of the A/C system. We also confirmed that the A/C system cleanness plays an important role on the power consumption indicators.

INTRODUCTION

Air conditioners (A/C) take parts as the refrigerating systems which adjust air to proper conditions for people who occupy those spaces. The A/C can consume electrical energy more than 50% of the total energy in typical buildings [1]. The A/C with less coefficient of performance (COP) or energy efficiency rating (EER) wastes more energy than the higher performance ones. Two of main processes in the refrigeration are 1) collecting heat from the refrigerating space and 2) discharging the collected heat out to environments. These 2 processes are occurred in 2 pressure levels; the low pressure in a fan coil unit and the high pressure in a condensing unit. Regularly, the condensing unit combines of a compressor and a condenser. The former compresses refrigerant to the designed pressure level and the latter rejected the heat to the environment causing hot air which flow out of the condenser, so called heated air or exhausted air [2].

Theoretically, when ambient temperatures surrounding the condensing unit are raised, the EERs will be dropped because the compressor has to work harder and consumes more power. The high condensing temperature can be caused by blocking the heated air flow or global warming crisis that affected ambient temperatures everywhere around the world. Normally, the condensing unit is installed to ease the heated air flow and the heated air is released without any utilization because of increasing the heated-air temperature decreasing the A/C EER. Therefore, if placing something behind the condensing unit to obstruct the heated air flow but this arrangement does not affect the A/C EER; which means EER is constant or increased, this placement can be considered as an indirect A/C utilization.

Thai people traditionally dry their cloths naturally by natural convection and radiation, while the weather in Thailand is hot and humid. Thailand rainy season usually takes 3 to 4 months, starting from May to August, so the humid weather causes problems in drying products such as any residential and agricultural products. One common problem in the residential level is drying cloths in the rainy season and no sunshine because the clothes can be smelly or, even, undried cloths. The cloth dryers have become more popular in Thailand but their prices are expensive, hence, developing a simple and affordable dryer can reduce the cost problem [2].

There were local works [3, 4] trying to apply the exhausted air from the condensing units to dry variety of products. As well as, there are many commercial dryers [5–7] available in markets. Duangthongsuk and Chaiyawongsa [8] experimentally studied and compared COPs, EERs and total power inputs of split-type A/C systems with an air-cooled condenser (ACC) and air-evaporative-cooled condensers (AECC) which combined of an air-water-cooled condenser (AWCC) and an air-cooled packaged condenser (ACPC). They applied the 12000 BTU/hr air conditioning system using new refrigerant; R-410A, refrigerating space temperatures between 23 to 26 degrees Celsius and ambient temperature at 36 degree Celsius. They found that COP, EER and total power input of the A/C system with the normal air-cooled condenser were 3.66, 10.45 BTU/hr-W and 1109 W, respectively. The COP, EER and total power input of the A/C system with the air-water-cooled condenser were 4.30, 11.57 BTU/hr-W and 1070 W, respectively. The COP, EER and total power input of the A/C system with the air-cooled packaged condenser were 4.68, 12.31 BTU/hr-W and 1056 W, respectively. They concluded that the A/C system with the air-cooled packaged condenser provided the highest EER; 27.87% higher than the A/C system with the normal air-cooled condenser and 8.84% higher than the A/C system with the air-water-cooled condenser. One may notice that the EER of the A/C system with the air-water-cooled condenser were 17.49% higher than the A/C system with the traditional air-cooled condenser.

Phatidamrongkul [9] experimentally investigated the split-type A/C system with an evaporative condenser which worked 24-hr period to find COPs, (EERs) and total power costs. She indicated that the field performance of the evaporative condenser was lower that that of the laboratory test; the refrigerating-space cooling load played an important role, but the evaporative condenser could enhance the performance of the A/C system. She also found that the COPs of the tested A/C system were varied with accumulative heat inside the refrigeration space before the A/C system was turned on, and ambient relative humidity as the lower relative humidity the higher COP. She claimed that her conclusion could lead to suggestions in using the evaporative condenser with the split-type A/C system in the household level because the power consumptions during the daytime and the nighttime were reduced from those of the A/C system without the evaporative condenser by 14.98% and 9.49%, respectively. They strongly recommended that the evaporative condenser could be used with the split-type A/C system during the daytime. The evaporative condenser should not be used with the 24-hr operated A/C system because it did not help reducing the power consumption of this system.

Suntivarakorn and Satmarong [10] presented their study results of drying clothes using waste heat from split-type air conditioner, the drying room was made from canvas at the volume size of 0.5x0.5x1.0 m3 and wrapped with the insulator inside the room for minimizing heat loss. The drying room was connected to the heating coil of a 12647.94-BTU/hr air conditioner. The cotton clothes with 54.8 % of moisture and 2.09 kg in weight were used in the drying experiment, then, the moisture of the clothes was reduced to 4.63 % due to hot air blowing. Their result showed that the cloth drying rate using waste heat from split – type air conditioner was at 2.26 kg/h, this rate was better than the conventional drying method with commercial electrical dryer, at 1.9 kg/h and drying rate in shade at 0.17 kg/h. They also presented their results from the mathematical model for clothes drying using waste heat from split – type air conditioner and the calculated drying rate was 2.3 kg/h, they claimed that it was quite close to that of the experiment. Additionally, they found that the air temperature, humidity and velocity at the exit of the heating coil were the major impact factors for the clothes drying rate, increasing in the hot-air temperature and velocity increased the drying rate and increasing the hot air humidity decreased the drying rate.

Pramuanjaroenkij et al. [2] introduced the fourth-year-student project on applying the heated air from the condenser to help drying products; fabrics, with less COP effects and studying relationships between the heated air flow patterns of the exhausted air and COP values. The condensing unit of a 24000 BTU/hr air-conditioning system was tested to find effects of the heated air flow patterns. The experimental setup consisted of an aluminium frame and a plastic cover which could be opened in 4 sides to arrange 5 patterns of air flow; (1) opened back and top sides or free-end flow, (2) opened left and right sides or tee-way flow, (3) opened top and right or left sides or right-up flow, (4) opened back and right or left sides or right-direct flow and (5) all sides was closed or collected flow, in 4 weather conditions; normal and rainy daytime and nighttime. The fabric drying application by using the heated air was chosen as the residential application and was simulated as the barriers surrounding the condenser in its installation. Moreover, the effects of the system cleanness and the heat convection were also observed by putting a fan driven by electricity from the solar cell on the setup. The inlet and outlet air velocity of the condensing unit, relative humidity and temperatures of air inside and outside the application, solar intensity, electrical power consumed by the A/C system and the drying product weights before and after the experiments were measured and used to calculate SMER or Specific Moisture Extraction Rate and EER or Energy Efficiency Ratio. In the first experiment, the A/C was just cleaned, the results obtained from 5 flow patterns in 4 weather conditions showed that the best EER were from the 2nd, 3rd, 4th and 2nd patterns in normal and rainy daytime and nighttime. The best SMERs as 0.3175 (2nd), 0.1067 (3rd), 0.3428 (5th) and 0.2865 (2nd) kg/kW-hr, according to the above weathers respectively. The 1st pattern provided the least EER almost in all 4 weathers. One year later with the same A/C without cleaning, the patterns providing the first-three best SMERs from the first experiment were tested again by coupling the setup with the fan and simulating the heavier rain condition to find the effects of the system cleanness and the heat convection enhancement. The second sets of the results showed that the 5th pattern could provide the best SMERs with the following EER at 0.593 kg/kW-hr and 12.414, at 0.247 kg/kW-hr and 11.613, at 0.530 kg/kW-hr and 11.25 and at 0.17 kg/kW-hr and 12.414 with respect to the above weathers. The 5th pattern provided the best EER almost in all 4 weathers. The cleanness was found to affect the A/C efficiency in the nighttime because the EERs were reduced. The cleanness was confirmed its effect on the EERs, it also implied that the air flow patterns and the barriers affected the efficiency of the clean A/C more than that of the unclean A/C. For the heated air utilization in the drying application, the convection was reconfirmed to enhance the SMERs in the drying process and the EERs.

This current work was aimed to study the effects of the heated air-obstacle distances; the obstacle was the household fabric drying application, on the A/C efficiency and the drying rate the application. The application was placed behind the condensing unit of the 24000 BTU/hr air conditioning systems in two different distances as 0.5 and 0.7 m, respectively, to investigate their effects on the A/C power consumption with different heated-air-flow patterns. The application utilized the exhausted heat from the condensing unit and performed as the fabric dryer in 4 different weather conditions; the normal and rainy daytime and nighttime. A fan was installed on the application to enhance convective heat transfer inside the application and the fan was powered by a battery from the solar cell charger. The velocities of inlet and outlet air through condensing unit, humidity ratios and temperatures of ambient air, sunlight intensity, fabric weights before and after drying and A/C power consumptions were measured. The power consumption, evaporated water rate, Energy Efficiency Ratio (EER), power consumption per evaporated water rate and specific moisture extraction rate were discussed.

THEORETICAL STUDY

Air conditioning systems play an important role in industrial and residential applications. To evaluate the A/C performance, Energy Efficiency Ratio (EER) is one of important parameters indicating the performance in the refrigeration and EER can be determined as [2, 11]

$$EER = \frac{Useful\ \ refrigerating\ \ capacity}{Total\ \ power\ \ input} \tag{1}$$

Where the useful refrigerating capacity is in BTU/hr and the total power input is in Watts. Moreover, another parameter is COP which generally indicates the refrigerating efficiency as [2, 12]

$$COP = \frac{EER}{3.14188} \tag{2}$$

Since water vaporization is the most significant process in drying applications, it can be expressed by using an indicator to indicate the drying performance. One common indicator is Specific Moisture Extraction Rate; SMER, which is an amount of water evaporated per unit power [2, 13] or

$$SMER = \frac{\dot{m}_w}{\dot{W}_{total}} \tag{3}$$

where $\dot{W}_{total}$ is the total power input in kilowatts and $\dot{m}_w$ is the water evaporating rate in kilogram per hour or

$$\dot{m}_w = \frac{\left(Initial\ weight - Final\ weight\right)}{Drying\ time} \tag{4}$$

Where the drying time is in hours and the initial and final weights are the product weights before and after the drying process, respectively [2].

EXPERIMENTAL STUDY

Figure 1 showed the experimental setup or the drying application which consisted of the modified clothes line and the application plastic cover. The fan was installed on the application to enhance the convective heat transfer inside the application. Figure 2 showed the experimental arrangements which was placed behind the condensing unit. The application cover could be opened and arranged the heated air flow into two patterns; (1) opened left and right sides or tee-way flow and (2) all sides was closed or collected flow, in 4 weather conditions; normal and rainy daytime and nighttime. The experimental setup; which can be considered as an obstacle of exhausted air from the condensing unit, was placed behind the condensing unit at two different distances; 0.5 and 0.7 m, respectively, to investigate their effects on the A/C power consumption of the obstacle distances which directed the heated air into two different heated-air-flow patterns. In each setup distance, the setup was connected with an electric fan powered by electric from battery charged by a solar cell panel. The experiments were carried three times in each weather condition, each experiment took 30 minutes. The A/C was turned on 1 hour to allow the cooling load to become stable before we started measurements; the initial and final fabric weights, power consumption units, temperatures inside and outside the setup and relative humidity of the ambient air. We used the digital weight scale to monitor the fabric weights, the residential electric watt hour meter to monitor the power consumption units, the thermo-hygrometer to monitor the temperatures and relative humidity inside and outside (ambient) the setup. The same water sprinkle was used to spray water on the setup in both rainy daytime and nighttime conditions

Figure 1 The experimental setup.

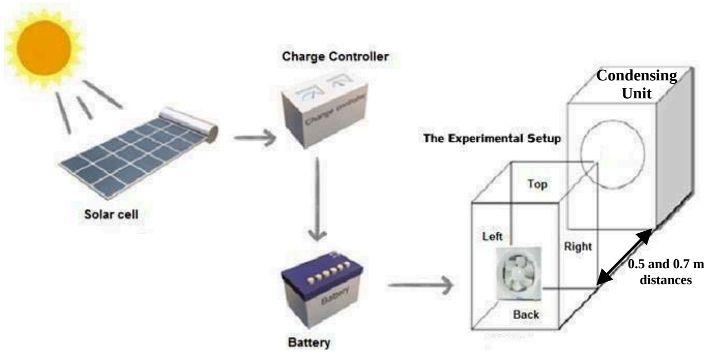

Figure 2 The experimental setup schematic.

RESULTS

The experimental setup can be opened to arrange several patterns of the heated-air flow. Two patterns of the heated-air flow; (1) opened left and right sides or tee-way flow as the flow from the unit installed on the balcony with a wall on the edge or inside the spaces between two large buildings and (2) all sides was closed or collected flow, from our previous works [2], were selected as good flow patterns for the heated-air flow to investigated the effects of the drying application distances, or the heated air-obstacle distance, from the condensing unit of the 24000 BTU/hr air conditioning system on the A/C efficiency and the drying rate the application. The experimental setup was investigated in 4 different weather conditions; the normal and rainy daytime and nighttime. The experimental setup can be compared the arrangements with how we set the surroundings for the condensing unit such as placing the condensing unit on narrow enclosed balcony or installing it inside spaces between two big walls [2] and, especially, it could also be considered as the small evaporative air cooler behind the condenser which can yield the better heat exchanging between the heated air and ambient air as mentioned in the literature [8].

Table 1 concluded the results for all two flow patterns from all four weather conditions in the experiment. If we considered only the water evaporating indicator as evaporated water rate ($\dot{m}_w$), the second arrangement or collected flow indicated the best evaporated water rate in all four weather conditions in each setup distance. But when we considered the power consumption indicators; power consumption rate and EER, the second arrangement or collected flow indicated the best power consumption indicators only in the daytime conditions; normal and rainy, in each setup distance while the first arrangement or tee-way flow indicated the best power consumption indicators only in the nighttime conditions; normal and rainy, in each setup distance. The evaporated water rate results of the second arrangement or collected flow concurred with the results obtained from the literature [10] since the collected flow arrangement was similar to the drying room of the literature. From the power consumption indicators, we noted that the nighttime results agreed well with the literature [9] that the water evaporation did not reduce the power consumption indicators. On the other hand, the small evaporative air cooler or the drying application could not enhance the A/C performance during the nighttime.

To investigate the effects of the obstacle distances which directed the heated air into different heated-air-flow patterns on the A/C power consumption, we considered only the results obtained from the second arrangement or collected flow in two distances since it could enhance the evaporated water rate and reduce the power consumption indicators in all four weather conditions. When we placed the small evaporative air cooler or the drying application at the distance of 0.5 m, we found that the small evaporative air cooler could enhance the heat exchanging between the heated air and ambient air because the power consumption indicators provided from the setup placed at 0.5 m were lower than those from the setup placed at 0.7 m in all four weather conditions. We also discovered that another water evaporating indicator as Specific Moisture Extraction (SMER) could be enhanced by the small evaporative air cooler since SMERs taken from the setup placed at 0.5 m were lower than those taken from the setup placed at 0.7 m in all four weather conditions. Remarkably, the evaporative air cooler or the drying application could enhance the A/C EER and the SMER when we placed the setup 0.5 m, the closer the evaporative air cooler, the better EER and SMER in all four weather conditions.

Table 1 The concluded results for two heated-air flow patterns at two different distances; 0.5 and 0.7 m, from four weather conditions.

Heated-air flow and Arrange.	Power Consumption (Watts)	Evaporated water rate (kg/hr) $\dot{m}_w$	EER	Power Consumption per $\dot{m}_w$ (kWh/kg water)	SMER
The normal daytime					
(1) at 0.5 m	1400	0.372	17.14	3.763	0.266
(2) at 0.5 m	532	0.680	45.11	0.782	1.278
(1) at 0.7 m	1400	0.236	17.14	5.932	0.169
(2) at 0.7 m	600	0.500	40.00	1.200	0.833
The normal night time					
(1) at 0.5 m	600	0.176	40.00	3.409	0.293
(2) at 0.5 m	532	0.250	45.11	2.128	0.470
(1) at 0.7 m	932	0.244	25.75	3.820	0.261
(2) at 0.7 m	666	0.198	36.04	3.364	0.297
The rainy daytime					
(1) at 0.5 m	800	0.344	30.00	2.326	0.430
(2) at 0.5 m	866	0.350	27.71	2.474	0.404
(1) at 0.7 m	932	0.214	25.75	4.355	0.229
(2) at 0.7 m	1066	0.310	22.51	3.439	0.290
The rainy night time					
(1) at 0.5 m	532	0.0566	45.11	9.399	0.106
(2) at 0.5 m	866	0.28	27.71	3.093	0.323
(1) at 0.7 m	532	0.0434	45.11	12.258	0.082
(2) at 0.7 m	1000	0.1414	24.00	7.072	0.141

As we emphasized in our previous work [2], the A/C system cleanness plays an important role on the power consumption indicators, we recalled that the same A/C was tested for 1st and 2nd periods as 1 year apart without cleaning; average increased power consumption was 97% and the setup was connected with the fan causing convective heat transfer enhancement; the average increase of water vaporizing rate was 170%. Tables 2 concluded the SMERs and EERs obtained from our previous work [2], the setup placed at 1 m, and current work to compare results of the collected flow pattern with and without the setup and at 3 different setup distances from all weather conditions. We could confirmed that the evaporative air cooler or the drying application could enhance the A/C EER and the SMER when we placed the setup 0.5 m during the daytime, the closer the evaporative air cooler, the better EER and SMER. We also noted that the evaporative air cooler could yield the better A/C EER because the EERs taken from the A/C with placing the setup were higher than those taken from the A/C without the setup during the daytime; normal and rainy. Since the A/C system in our current work was the same system as in our previous work [2] and it was cleaned before we started our experiment, one can observe the effects of the A/C system cleanness during the daytime. From Table 2, we would like to point out one concern that if one turns on the A/C system only the rainy nighttime, one may not notice the effect of the A/C system cleanness.

Table 2 Comparisons among the results of the collected flow pattern with and without the setup and at 3 different setup distances from four weather conditions.

Heated-air flow and Arrange.	Power Consumption (Watts)	Evaporated water rate (kg/hr) $\dot{m}_w$	EER	Power Consumption per $\dot{m}_w$ (kWh/kg water)	SMER
the normal daytime					
No test section	866	N/A	27.71	N/A	N/A
(2) at 0.5 m	532	0.680	45.11	0.782	1.278
(2) at 0.7 m	600	0.500	40.00	1.200	0.833
(2) at 1 m [2]	2200	0.5326	10.91	4.13	0.24
the normal nighttime					
No test section	666	N/A	36.04	N/A	N/A
(2) at 0.5 m	532	0.250	45.11	2.13	0.47
(2) at 0.7 m	666	0.198	36.04	3.35	0.30
(2) at 1 m [2]	1200	0.4114	20.00	2.92	0.34
the rainy daytime					
No test section	932	N/A	25.75	N/A	N/A
(2) at 0.5 m	866	0.350	27.71	2.47	0.40
(2) at 0.7 m	1066	0.310	22.51	3.44	0.29
(2) at 1 m [2]	2400	0.1866	10.00	12.86	0.08
the rainy nighttime					
No test section	732	N/A	32.79	N/A	N/A
(2) at 0.5 m	866	0.28	27.71	3.09	0.32
(2) at 0.7 m	1000	0.1414	24.00	7.07	0.14
(2) at 1 m [2]	1000	0.1540	24.00	6.49	0.15

Conclusion

Two heated air patterns represented two different exhausted air flows out of the condensing unit where the flows was obstructed or directed by different environments surrounding the condensing unit. The drying application could be considered as the small evaporative air cooler behind the condenser which can yield the better heat exchanging between the heated air and ambient air. The fan could enhance the convective heat transfer and the convection could help the A/C consumed less power during the daytime, the collected flow could reduce the A/C power consumption. When the ambient temperature was not high as in the nighttime, the small evaporative air cooler might not affect the A/C power consumption in our current work. Therefore, utilizing the exhausted air or arranging the exhausted air patterns should be considered together with weather conditions. When the application was placed at 0.5 m behind the condensing unit, the A/C efficiency was better than it was at 0.7 m in all four weather conditions. Since the closer distance between the application and the condensing unit could enhance more convective and evaporative heat transfer of the heated-air flow behind the condensing unit, we found that the evaporative cooling and convective heat transfer played their important roles in the drying process of the application and in the heat rejection of the A/C system. We also confirmed that the A/C system cleanness plays an important role on the power consumption indicators.

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