

An Experimental Study on Clothes Drying Using Waste Heat from Split Type Air Conditioner

P. Suntivarakorn, S. Satmarong, C. Benjapiyaporn, and S. Theerakulpisut

Abstract—This paper was to study the clothes dryer using waste heat from a split type air conditioner with a capacity of 12,648 btu/h. The drying chamber had a minimum cross section area with the size of 0.5 x 1.0 m². The chamber was constructed by sailcloth and was inside folded with aluminium foil. Then, it was connected to the condensing unit of an air conditioner. The experiment was carried out in two aspects which were the clothes drying with and without auxiliary fan unit. The results showed that the drying rate of clothes in the chamber installed with and without auxiliary fan unit were 2.26 and 1.1 kg/h, respectively. In case of the chamber installed with a auxiliary fan unit, the additional power of 0.011 kWh was consumed and the drying rate was higher than that of clothes drying without auxiliary fan unit. Without auxiliary fan unit installation, no energy was required but there was a portion of hot air leaks away through the punctured holes at the wall of the drying chamber, hence the drying rate was dropped below. The drying rate of clothes drying using waste heat was higher than natural indoor drying and commercial dryer which their drying rate were 0.17 and 1.9 kg/h, respectively. It was noted that the COP of the air conditioner did not change during the operating of clothes drying.

Keywords—Drying Rate, Clothes Dryer, COP, Air Conditioner.

I. INTRODUCTION

FORMERLY, drying clothes usually use natural way by using the energy from the sunlight and the wind, but nowadays the technology is plentifully developed upward and the clothes dryers that use the electric energy or other energy come to use extensively, especially in the urban area where people live in the tall buildings. Then, people who live in the building have the limitation in the area in drying clothes from the sunlight. However, they can dry their clothes in the balcony. In order to maintain an acceptable appearance of building façade, clothes drying using natural means by

Prapat Suntivarakorn is an assistance professor of the Mechanical Engineering Department, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand (phone: +66-81-989-1983; fax: +66-43-347-879; e-mail: sprapat@kku.ac.th).

Somchai Satmarong is a graduate student of the Mechanical Engineering Department, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand (e-mail: somch_s@hotmail.com).

Chatchai Benjapiyaporn is an assistance professor of the Mechanical Engineering Department, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand (e-mail: chaben@kku.ac.th).

Somnuk Theerakulpisut is an associate professor of the Mechanical Engineering Department, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand (e-mail: somthe@kku.ac.th).

hanging clothes in the balcony may not be allowed. Increasingly, clothes drying has become confined to indoors which take time for drying clothes, especially drying clothes in the period that the air humidity is high such as in the raining season. Clothes drying indoors by natural ventilation can take a long time and still yield unsatisfactory results. In addition, drying clothes indoors by natural ventilation impacts indoor thermal environment, as the moisture contained in wet clothes is transferred to indoor air during drying, by evaporation and diffusion. This additional indoor moisture load must be dealt with either mechanical or natural ventilation means. If clothes drying as achieved by either electricity or gas-powered dryer, the drying process may be completed within hours with the expense of additional energy use and pollution.

On the other hand, for residential buildings in subtropical regions, because of its subtropical climates, annually, air conditioning is normally necessary for 7-8 months when it is either hot or humid, or both. From a survey of user behavior in the residential buildings, it was indicated that most people use split-type air conditioner. For split-type air conditioner, air is used to carry away heat rejected from its air-cooled condenser and is therefore heated so that its temperature may increase by up to 10 °C [1]. This presents an opportunity to re-use the heated air exiting from an air-cooled split-type air conditioner for clothes drying in residential building located in regions where air-conditioning is required for a long period, thus improving energy use efficiency for residential clothes drying and reducing heat pollution to the environment. Thus, many researchers utilized the waste heat from air conditioner for clothes drying. The clothes drying chamber was designed and installed to the condensing unit of air conditioner and its experiment was examined. It was proved that using waste heat from air conditioner was functional and realistic for clothes drying [2-5]. However, installation the clothes drying chamber in the condensing unit may effect to the performance of air conditioner due to the decreasing of air flow from the exit of condenser. To protect the reduction of the air conditioner efficiency, an auxiliary fan unit was installed at the exit of clothes drying chamber. However, it was found that the previous design of clothes drying chamber had a limitation for utilizing due to its big structure and unsuitable installation area, including there was a few of the study about re-using waste heat from split type air conditioner. Therefore, to collect more data about clothes drying using waste heat from

air conditioner, a study on clothes drying was studied in this work. An experiment for reduction the energy of fan unit installed at the end of clothes drying chamber was also carried out to find a suitable way to utilize the waste heat from air conditioner for clothes drying.

II. PRINCIPLE OF SPLIT-TYPE AIR CONDITIONER

Split type air conditioner works by vapor compression refrigeration cycle as showed in Fig. 1. It consists of four major processes namely: (1) Isentropic compression in a compressor, (2) Constant-pressure heat rejection in a condenser, (3) Throttling in an expansion device and (4) Constant-pressure heat absorption in an evaporator. In vapor compression refrigeration cycle, the refrigerant enters the compressor at state 1 as saturated vapor and is compressed isentropically to the condenser pressure. The temperature of the refrigerant increases well above the temperature of the surrounding medium during this compression process. The refrigerant then enters the condenser as superheated vapor at state 2 and leaves as saturated liquid at state 3 as a result of heat rejection to the surroundings. The temperature of the refrigerant at this state is still above the temperature of the surroundings. The saturated liquid refrigerant at state 3 is throttled to the evaporator pressure by passing it through an expansion valve or capillary tube. The temperature of the refrigerant drops below the temperature of the refrigerated space during this process. The refrigerant enters the evaporator at state 4 as a low quality saturated mixture, and it completely evaporates by absorbing heat from the refrigerated space. The refrigerant leaves the evaporator as saturated vapor and reenters the compressor, completing the cycle. The performance of this refrigeration cycle is expressed in terms of the coefficient of performance (COP), which was defined as [6]

$$COP = \frac{Q}{W} \quad (1)$$

where Q represents the heat transferred to evaporator and W represents the work supplied to the system. In this paper, the heat transferred to the evaporator was defined as

$$Q = \dot{m}(h_{a1} - h_{a2}) \quad (2)$$

where \dot{m} represents the mass flow rate of air that flows into the evaporator and h_{a1} and h_{a2} represent respectively the enthalpy of air at the inlet and outlet of evaporator.

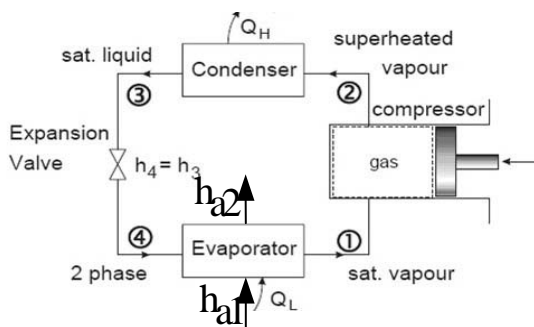


Fig. 1 Vapor compression refrigeration cycle

III. DRYING THEORETICAL CONSIDERATION

When the material, which has moisture inside, is contacted to the hot air, the heat transfer will occur at the surface of the material. The temperature of the material will be increased and the moisture inside the material will evaporate to the surrounding. The process of drying is related to the mass transfer from moisture inside the material to the surrounding. Reduction of moisture in the material will be divided in 3 periods as shown as a typical drying curve in Fig. 2. A typical drying curve, where the drying rate (kg/s) is plotted against moisture content, has an initial heating stage (A-B), unhindered or constant drying rate period (B-C) and hinder drying or falling rate drying period (C-D-E). At point C, the drying rate starts to decrease and this point is called the critical humidity point. The drying rate continuously decreases and stops at point E when the moisture in material is in the equilibrium state with surrounding. One of the important criteria with respect to the performance of dryer is drying rate in kg/h. The drying rate (\dot{m}_d) is defined as:

$$\dot{m}_d = \frac{W_0 - W_f}{t} \quad (3)$$

where W_0 and W_f represent the weight of material before and after drying, respectively, and t represents the time for drying.

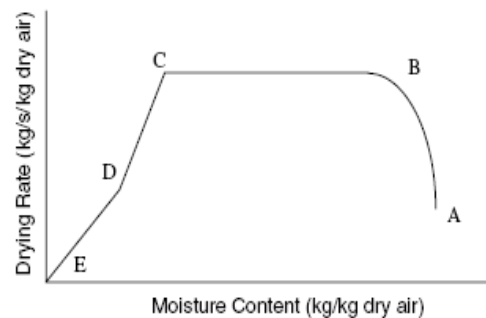


Fig. 2 Typical drying rate curve [2]

IV. EXPERIMENTATION

Split type air conditioner with capacity of 12,648 btu/h was used to examine the clothes drying using heat rejected from condensing unit. Clothes drying chamber was designed with the capacity of $0.5 \times 0.5 \times 1.0 \text{ m}^3$. The chamber consists of 3 parts namely: (1) the expansion area, (2) the constant area and (3) the contraction area as shown in Fig. 3. The chamber was constructed by sailcloth with an aluminum steel structure and aluminum foil was folded inside the chamber in order to protect heat loss. The drying chamber with 180 watts of auxiliary fan unit was installed to the condenser. The clothes used in the experiment were 100% of cotton and were one meter high.

Before installation the drying chamber to the condenser, the velocity, temperature and humidity of air at the entrance and exit of condenser were measured for calculating the COP. The room temperature, while the experiment was conducted, was set at 25°C . After that, the drying chamber was installed to

the exit of condenser. The experiment was started with weight measurement of the clothes, then hanging the clothes in parallel with the flow direction of hot air from condenser. During the examination, the weight of clothes, humidity and the temperature of hot air were collected every two minutes. The COP of the air conditioner was again calculated from the experimental data. The experiment will be finished when the clothes were dried after the weight of clothes was not changed. In this study, clothes drying with and without the auxiliary fan unit were conducted to compare the drying rate and the suitable way to utilize the waste heat from air conditioner. The comparison of the drying rate between drying with waste heat from air conditioner, commercial dryer and natural drying indoors were also conducted.



Fig. 3 Clothes drying chamber installed to the condensing unit

V. RESULTS AND DISCUSSION

A. Coefficient of Performance of the Experimental Air Conditioner

The COP of the air conditioner was varied to the temperature outside the room. Therefore, the data for calculation the COP were collected in two weeks. From the calculation, the results were shown that the COP was decreased with the increasing of the temperature outside the room as shown in Fig. 4. The value of COP was varied between 2.5 to 3.5 while the outdoor temperature was varied between 32 to 40 °C. The relation between the COP and the temperature was expressed as

$$COP = 6.19317 - 0.09121 \times (T_{outdoor}) \quad (4)$$

where $T_{outdoor}$ represents the temperature outside the room. Moreover, it was found the temperature at the exit of condenser was increased by up to 10 °C. This is because that the air is used to carry away heat rejected from its air-cooled condenser. From Fig. 5, it was shown that the air temperature at the exit of condenser was increased with the increasing of the temperature outside the room, and its relation can be expressed as:

$$T_{indoor} = -10.41752 + 1.58185 \times (T_{outdoor}) \quad (5)$$

where T_{indoor} represents the temperature at the exit of the condenser or the temperature inside the drying chamber.

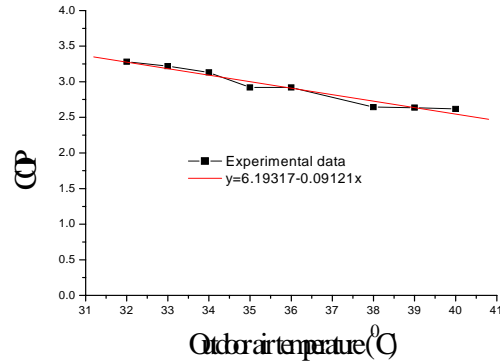


Fig. 4 The relation between the COP and the outdoor temperature

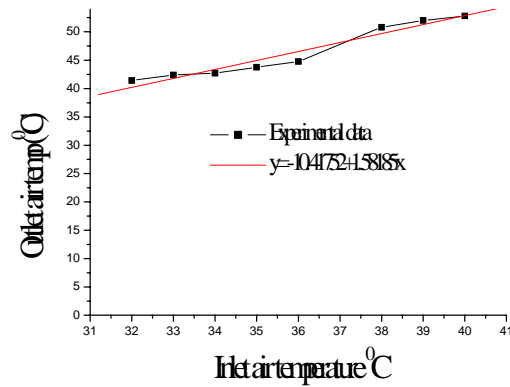


Fig. 5 The relation between the temperature at the entrance and exit of condenser

TABLE I
DRYING RATE OF THE CLOTHES IN CASE OF 4-10 PIECES

Number of clothes	Temperature (°C)	Humidity (%)	Distance between 2 pieces of clothes (m)	Drying rate from experiment (kg/h)	Drying rate from theoretical calculation (kg/h)
4	42.6	45	0.0840	1.44	0.72
6	41.5	46	0.0543	1.77	1.42
8	41.9	45	0.0378	2.26	2.38
10	42.2	44	0.0273	1.58	3.65

B. Clothes Drying with Auxiliary Fan Unit

During the operation of the air conditioner, if there was an obstruction in front of the condensing unit, the COP will be decreased due to the inadequate heat transfer. Consequently, the auxiliary fan unit was installed at the exit of drying chamber for solving that problem. The 120 watts of fan unit with vary speed control was used in the experiment. By adjusting the speed of fan, the air flow rate at the exit of drying chamber was controlled to be equal to flow rate of the hot air from the exit of the condenser. The experiment was

begun from drying four pieces of clothes, and then adding the number of clothes to be 6, 8, and 10 respectively. From collecting the experimental data, the drying rate from the experiment was examined and compared with that of the theoretical calculation as shown in Table I and Fig. 6.

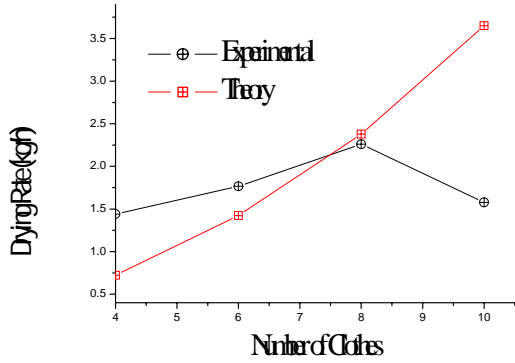


Fig. 6 The drying rate from the experiment compared with that of the theoretical calculation

From Table I and Fig. 6, the drying rate of 8 pieces of clothes had maximum drying rate of 2.26 kg/h, which was close to that of theoretical (2.38 kg/h). In case of theoretical calculation, the drying rate was increased when the number of clothes was increased. This was contrasted with the experimental results. Due to the limitation of the size of the drying chamber, which its wideness was only 0.5 meter, the drying rate was decreased in case of drying 10 pieces of clothes. The distance between 2 pieces of clothes was only 0.0273 meter and was very close to each other, then the hot air can not flow through the clothes in the chamber and the heat exchanging was not occurred. This caused the hot air changing its direction to the top and bottom in the chamber as shown in Fig. 7. The results were shown that the suitable number of clothes in this chamber was eight pieces.

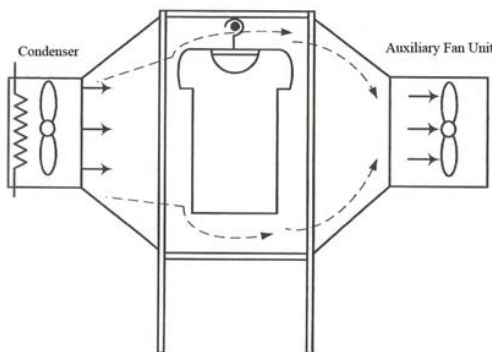


Fig. 7 The direction of hot air to the top and bottom of the chamber



Fig. 8 Hanging 8 pieces of clothes in the chamber

TABLE II
AIR FLOW RATE AND THE COP RECEIVED FROM THE EXPERIMENT IN CASE OF CLOTHES DRYING WITHOUT FAN UNIT AND PUNCTURING THE HOLES AT THE WALL OF THE CHAMBER

Number of holes	Air flow rate at the exit of the chamber (m ³ /h)	COP in case with clothes drying	COP in case without drying chamber	The difference of percentage
3	0.208	2.66	3.24	17.82
6	0.212	2.48	3.21	22.41
9	0.217	2.49	3.33	25.21
12	0.221	3.24	3.34	3.02
15	0.222	3.36	3.46	2.94
18	0.226	3.38	3.41	0.42
21	0.230	3.45	3.45	0.00



Fig. 9 The drying chamber without auxiliary fan unit

C. Clothes Drying without Auxiliary Fan Unit

The disadvantage of clothes drying with auxiliary fan unit was the electrical energy consumption. Therefore, the experiment on clothes drying without auxiliary fan unit was examined in order to reduce the energy consumption. The auxiliary fan was removed. The experiment was set up to dry

8 pieces of clothes in the chamber. It was found that the flow rate at the exit of the chamber was $0.203 \text{ m}^3/\text{h}$ which was less than the flow rate of $0.23 \text{ m}^3/\text{h}$ from the exit of the condenser. This indicated that the COP of the air conditioner was decreased. Hence, the difference of the flow rate, which was $0.03 \text{ m}^3/\text{h}$, was used to calculate the area for puncture at the wall of the drying chamber in order to balance the flow rate of the hot air. From the calculation, the suitable area of 0.0363 m^2 was obtained. Three holes with the size of $0.11 \times 0.11 \text{ m}^2$ were punctured at the bottom and the sides of the chamber in order to allow the ventilation of hot air over the drying chamber. The experiment of clothes drying without auxiliary fan unit and puncturing three holes at the wall, the COP was examined and compared with that of the case without the drying chamber. The results were revealed that the COP in case of clothes drying without fan unit was 17.82 % less than that of the case without drying chamber. It means that the hot air from condenser was accumulated within the chamber and the ventilation of hot air was still inadequate. Then, the addition of holes was done by gradually puncturing every three holes. The experimental data was still continuously collected and finished until the wall was punctured up to 21 holes (See Fig. 9). The COP and air flow rate for each step were shown in Table II.

From Table II, the results showed that the air flow rate was increased with the addition of the holes. In case those 21 holes were punctured at the wall of the chamber, the air flow was $0.23 \text{ m}^3/\text{h}$ and equal to the flow rate in case without drying chamber. This means that the clothes drying were conducted without any effect to the COP of the air conditioner. The drying rate in case of clothes drying without auxiliary fan unit was 1.1 kg/h and less than the drying rate in case of clothes drying with auxiliary fan unit.

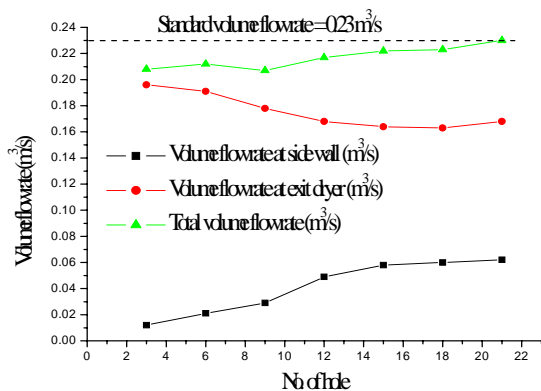


Fig. 10 The air flow rate at the exit and the side wall of the chamber

D. Comparison of the Drying Rate in Various Type of Clothes Drying

Besides, clothes drying using waste heat from split type air conditioner were carried out, clothes drying by using commercial clothes dryer (2,000 watts heater) and natural clothes drying indoors were also examined. The comparison of the drying rate in each type of clothes drying was shown in Table 3. It was found that the maximum drying rate was 2.26

kg/h in case that the clothes drying chamber with auxiliary fan unit was conducted by using waste heat from air conditioner. This drying rate was higher than that of clothes drying using commercial dryer and clothes drying indoor which their drying rate were 1.9 kg/h and 0.17 kg/h , respectively. For the clothes drying chamber without auxiliary fan unit, the drying rate was 1.1 kg/h and less than that of clothes drying with commercial dryer and clothes drying chamber with auxiliary fan unit, but more than that of indoor drying. However, when consider the energy consumption, it was indicated that the energy was not consumed in case of using clothes drying without auxiliary fan unit, while clothes drying with auxiliary fan unit consumed 0.011 kWh of electrical energy or 1.5% of the energy consumption in commercial dryer.

TABLE III
COMPARISON OF THE DRYING RATE IN VARIOUS TYPES OF CLOTHES DRYING

Type of clothes drying	Time (h)	Initial weight (kg)	Final weight (kg)	Energy consumption (kWh)	Drying rate (kg/h)
Clothes drying with fan unit	0.3	2.09	1.41	0.011	2.26
Clothes drying without fan unit	0.6	2.1	1.41	-	1.1
Clothes Drying indoor	4	2.09	1.4	-	0.17
Commercial clothes dryer	0.33	2.05	1.42	0.66	1.9

VI. CONCLUSION

An experiment study on the effectiveness of clothes drying using waste heat from condensing unit has been carried out and reported. Results from the study indicated that clothes drying using waste heat from condensing unit in residential building can be effective, for its reasonably short drying duration and high energy efficiency during air conditioning seasons. The suitable size of clothes drying chamber is $0.5 \times 0.5 \times 1.0 \text{ m}^3$ and is suitable for 8 pieces of clothes drying. The drying rate of clothes drying using waste heat from air conditioner is between $1.1\text{--}2.26 \text{ kg/h}$. This is better than that of clothes drying with commercial dryer and natural indoor drying which their drying rate are 1.9 and 0.17 kg/h , respectively. Moreover, the result is also revealed that the drying chamber without auxiliary fan unit is workable and can help achieve energy saving, even its drying rate is lower than that of clothes drying chamber with fan unit.

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P. Suntivarakorn was born in Loei, Thailand in 1973 and is a lecture from Department of Mechanical Engineering. He received his Bachelor degree in Mechanical Engineering from Khon Kaen University, Thailand. In 2000 and 2003, he has got Master of Engineering (M.E) and Doctor of Philosophy (Ph.D) in Mechanical Engineering, respectively. His main field is Alternative Energy and Energy Conservation.