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CLOTHES DRYING FROM ROOM AIR CONDITIONING WASTE HEAT: THERMODYNAMICS INVESTIGATION

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الخلاصـة:

تُقدّم هذه الورقة البحثيّة مناقشة لِدراسةٍ عمليّةٍ حول الاستفادة من الحرارة المُتبدّدة من مُكيف غُرفٍ هوائيّ ذي جزءين (سبليت) ، وذلك لتجفيف الملابس. وتقوم هذه الدراسة بمقارنة فعاليّة هذا النظام للتجفيف مع نظام تجفيف تقليديّ ، وذلك باعتبار المدّة الزمانيّة المطلوبة لتجفيف الملابس واستهلاك الطاقة. ويهدِفُ هذا البحث إلى دراسة وتحليل أداء مُكيف الغُرف الهوائيّ كمُجفّف ملابس ، وإلى تقييم فعاليّة حرارته المُتبدّدة في نظام التجفيف. وقد تمّ إجراء تجارب التجفيف تحت ثلاثة أوضاع ، هي: تجفيف خارجيّ طبيعيّ في وسط النهار، وتجفيف داخليّ طبيعيّ، وتجفيف بوساطة حرارة المُكيف الهوائيّ المُتبدّدة. وقد توصّلت الدراسة إلى أنّ استعمال حرارة مُكيف الغُرف الهوائيّ المُتبدّدة في تجفيف الملابس جديرٌ بالاعتماد وبخاصة في الأماكن السكنيّة ذات الأبنية العالية المُكتظّة ، حيث لا يوجد تكلِفةٌ كهربائية إضافيّة.

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ABSTRACT

This paper discusses an experimental study for using heat wasted from a split-type room air conditioner for clothes drying. The study compares the effectiveness of this drying system to a conventional one in terms of duration required to dry the clothes and energy consumption. The objectives of the study are to analyze performance of a room air-conditioner as clothes dryer and to evaluate the effectiveness of its heat waste for a drying system. The experiment is conducted for three drying conditions, namely, outdoor natural drying at midday, indoor natural drying, and drying using air-conditioner waste heat. The study found that using room air-conditioner waste heat for clothes drying is very reliable, especially in congested high-rise residential areas, without additional electricity cost.

Key words: clothes dryer, drying, room air conditioner, waste heat

Nomenclature

A	room area, m^2
COP_c	coefficient of performance of cooling
Cp_{air}	constant pressure specific heat, kJ/kg.K
DR	drying rate, kg/h
DT	drying time, h
E	Volt
I	Amps
$\dot{m}_{air}$	mass of the air, kg/s
P_c	power input to the compressor, kW
PF	power factor
Q_{out}	cooling capacity of a room air conditioner, kJ
RACD	room air-conditioner dryer
RH	relative humidity, %
SEC	ratio of the energy consumed per kg of moisture removed, kWh/kg
$SMER$	the moisture removed per unit of energy consumption, kg/kWh
T_{in}	air temperature entering the evaporator, °C
T_{out}	air temperature leaving the evaporator, °C
υ	air flow velocity, m/s
W_{in}	power consumption, kWh
X/g	moisture removed, kg
ρ	air density, kg/m^3

CLOTHES DRYING FROM ROOM AIR CONDITIONING WASTE HEAT: THERMODYNAMICS INVESTIGATION

1. INTRODUCTION

Decreasing energy losses and heat recovery are important research topics, nowadays. Many thermal system processes have waste energy. Some of this waste can be utilized for other useful applications. Many types of devices have been developed to re-use some of this heat waste [1]. Significant energy savings can be achieved by reusing this waste. Several researchers have conducted research related to waste heat recovery in many applications and sources such as heat recovery from engine [2], domestic water-cooled air conditioner [3], textile drying [4], and paper machine by means of simulation [5]. However, it has been found that heat wasted from an air-conditioning unit still has not been fully utilized. This study attempts to utilize this waste heat for a useful purpose. An experiment has been constructed to analyze the room air-conditioner dryer (RACD). Since the air-conditioning units are designed to remove heat from interior space and reject it to the ambient (outside) air, this hot air or waste heat can be utilized for drying purposes. Furthermore, from an energy conservation point of view, heat recovery and utilizing waste heat to replace a clothes dryer will reduce electricity bills [6]. Energy efficiency analysis of air cycle heat pump dryers was discussed extensively in [7].

In addition, the need to introduce RACD for households in Malaysia is supported by the following reasons:

(i) Limited sunlight (cloudy days) and restricted air flow for house types such as high rise condominiums and apartments.

(ii) Natural drying is prohibited in some housing areas for aesthetic reasons.

(iii) Conventional domestic electric dryers are too expensive and inefficient.

For these reasons, the purpose of this experiment is to offer a low cost solution that complies with the global concern for energy conservation.

2. METHODOLOGY

2.1. Theoretical Background

A room air conditioner (RAC) is designed to remove heat from an interior space and reject it to the ambient air. The air flow from the condenser, the so-called waste heat, can be utilized for drying purposes. The RACD system consists of a split room air-conditioner unit and a drying chamber that is attached separately to a condenser. This combination allows the additional process of drying clothes by using the RAC heat rejection without increasing the energy consumption as compared to using a separate clothes dryer. It was designed and used for the waste heat recovery at the exhaust of a condenser air stream and then utilizes this hot air stream for drying purposes.

In this study, the possibility of using the vapor compression refrigeration cycle for both space cooling and drying clothes is considered, and therefore, the system is called a room air-conditioner dryer [6]. A p-h diagram of the refrigerant circuit (1-2-3-4) is shown in Figure 1, which shows that the theoretical energy available for heating or drying is (h_2-h_3), for space cooling is (h_4-h_1), and the work energy input to the compressor is (h_2-h_1). Using this diagram, the amount of energy available for space cooling and drying as a function of the power input to the compressor P_c (kW) and the coefficient of performance of cooling (COP_c) can be defined [8]:

Refrigerating effect available for space cooling (kW) is calculated by the following equation:

$$R_e = (COP_c)\, P_c \tag{1}$$

Heating effect available for drying (kW) is calculated by the following equation:

$$H_e = (COP_c + 1)\, P_c \tag{2}$$

The performance of a room air conditioner is by the ratio of cooling capacity and power consumption and is referred to as coefficient of performance (COP_c), which can be calculated by the following equation:

$$COP_c = \frac{Cooling\ Capacity}{Power\ Consumption} = \frac{Q_{out}}{W_{in}} \tag{3}$$

The cooling capacity of a room air conditioner can be calculated using the following equation:

$$\dot{Q}_{out} = \dot{m}\ \mathrm{Cp_{air}}\ (T_{out} - T_{in}) \tag{4}$$

In addition, the mass flow rate of air is calculated by following formula:

$$\dot{m}_{air} = A\, \rho\, \upsilon \qquad (5)$$

The electricity consumption is measured using a power meter and calculated by the following formula:

$$W_{in} = E\, I\, PF \qquad (6)$$

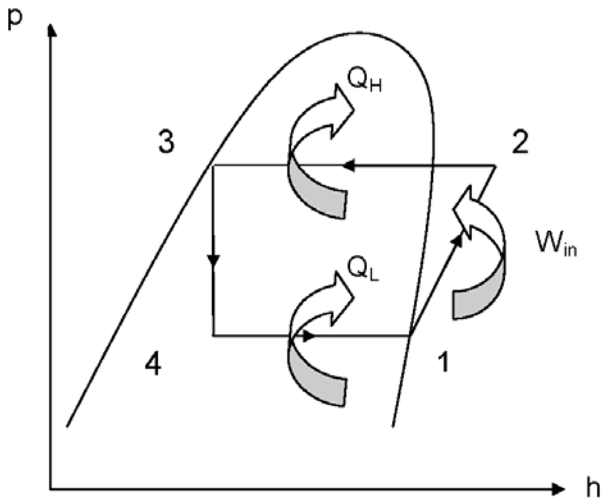

Figure 1. Pressure vs enthalpy diagram for refrigerant circuit °C

The most important criteria for the performance of a RACD are (i) SEC rate in (kWh/kg), defined as the ratio of the energy consumption (kWh) per kg of moisture removed, and (ii) *SMER* (kg/kWh), defined as the moisture removed per unit energy consumption (kWh). It should be noted that *SMER* is the inverse of *SEC*, and the drying efficiency is highest when *SMER* is maximum [6]. In this study, the waste heat was used, and therefore, it's considered as free energy.

2. 2. Experimental Set-Up

Systems that consist of a drying chamber and a moveable unit of split-type air conditioner have been constructed. The split unit is attached to a frame that was specifically designed for this experiment. The condenser is connected to the drying chamber with an air duct made from zinc and tube steel. The schematic diagram for RACD is presented in Figure 2.

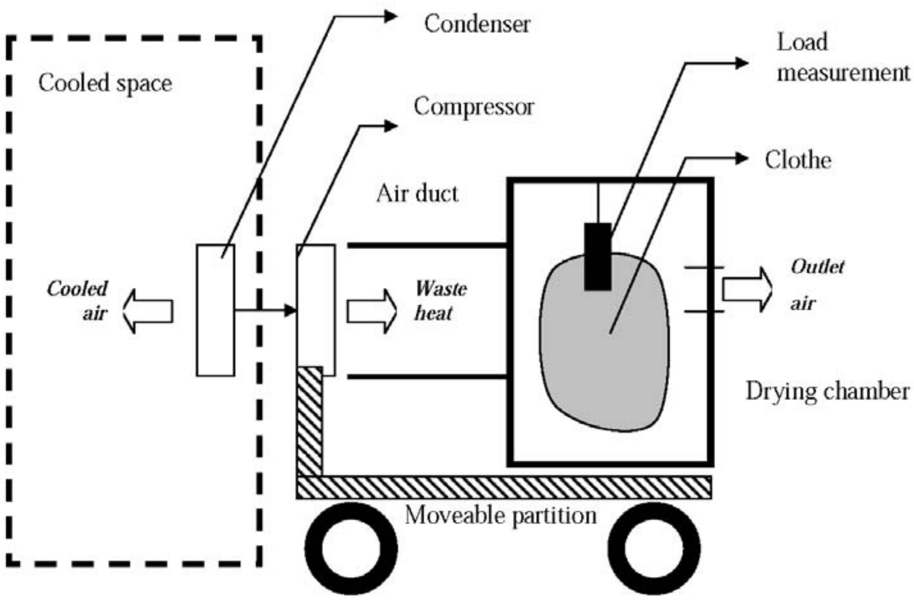

Figure 2. Schematic diagram for room air-conditioner dryer

The equipment and instrument used in this experiment are as follows:

(i) Load measurement instrument-load spring
(ii) Drying chamber and moveable partition
(iii) Thermocouples
(iv) Room air conditioners
(v) Data acquisition system
(vi) Digital power meter
(vii) Anemometer
(viii) Relative humidity sensor

The main characteristics of the split air conditioner used in this study are shown in Table 1.

Table 1. Main Characteristics of Split-Type Room Air Conditioner

Characteristics	Technical Description
Type	Split unit
Volt/Ph/Hz	220-240/1/50
Cooling Capacity	10000 Btu/hr
Condenser Power Requirement	1400 W
Refrigerant	R-22
Fan Power Input	25 W
Rated Capacity	2.931 kW
Nominal Ampere	6.0 A
Outdoor Condenser Power (Watt)	881 W
Excessive Permissible Pressure	4000 kPa

The air flow rate over the evaporator as a function of air velocity is measured using an anemometer. The area of air flow is measured using a micrometer and a measurement tape. Meanwhile, the density of the air depends on temperature and was taken from the thermodynamics table in [8]. Based on these data the mass air flow rate over the evaporator can be calculated using Equation (5). A washing-machine is also used for clothes wetting and spin drying, with nominal power input of 1.4 kW, and the drying time is approximately 7 minutes for 2.5 kg of various types of clothes. A power meter was used to record the actual electricity consumption during the drying process. The schematic diagram of the experimental set-up is given in Figure 3.

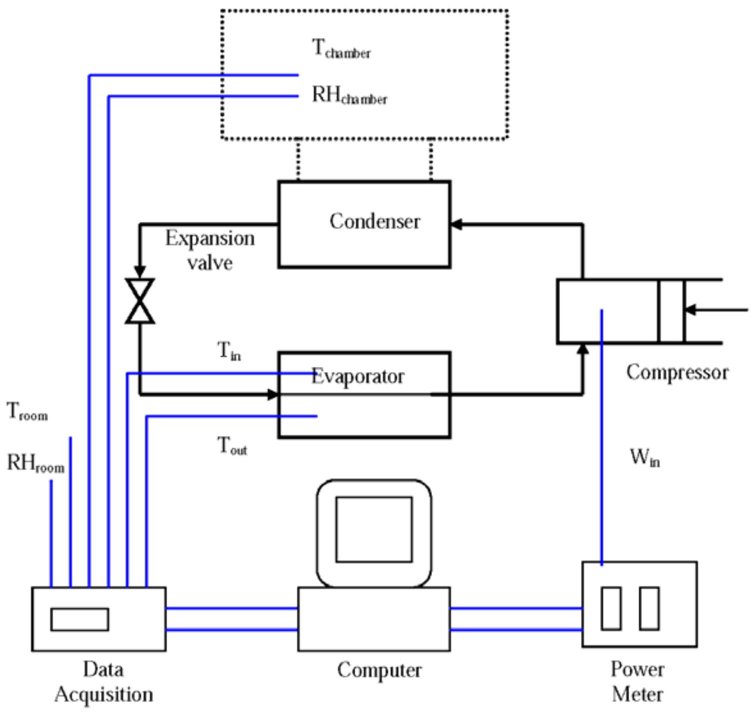

Figure 3. Schematic diagram of the experimental setup

The drying chamber is mounted on a moveable partition and left open at the back to allow hot air to flow through. A spring-type load measurement was placed on top of the drying chamber for continuous measurement of the drying rate of the clothes. The thermocouples are placed in four positions: two at the evaporator, one for room temperature, and another one placed inside the drying chamber. All the data was read and recorded by Benchlink Data Logger II software.

The experiment is started by setting the room air conditioner at 25°C and leaving it for 15 minutes to reach steady state condition. Then the power measurement test for the room air conditioner is conducted for 1 hour. Simultaneously, the data logger records the following data:

(i) Air temperature entering the evaporator, T_{in}

(ii) Air temperature leaving the evaporator, T_{out}

(iii) Room temperature

(iv) Room relative humidity

(v) Air temperature of drying chamber

The experiment above is carried out for three cases of drying:

(i) indoor natural drying

(ii) outdoor natural drying at midday

(iii) drying clothes using air-conditioner waste heat

Four types of clothes (polyester, silk, cotton, and jeans) are mixed and wetted then spin-dried by a washing machine. For every case of drying, the drying sample is weighed before being wetted and spin-dried by a washing machine. This weight was used as a reference to determine the drying time. Soon after the weight of the drying sample is similar to the reference weight, the drying process is complete [9].

2.3. Waste Heat Characteristic

After all the experiments are completed, the test attributes (performance criteria) such as moisture removed (*X*), drying time, *SEC*, *SMER,* and drying rate were calculated. These calculations are adapted from [6]. The moisture removed can be calculated from the weight differences of clothes before and after drying. The performance measurement of RACD is evaluated by its specific moisture extraction (*SMER*), which is defined as the moisture removed per unit energy consumption. *SMER* is a characteristic to indicate the effectiveness of energy use in the drying process. *SMER* is calculated by the following equation:

$$SMER = \frac{X}{[\dot{m}_{air} \times Cp \times (T_{out} - T_{in}) + W_{in}]} \tag{7}$$

The specific energy consumption (*SEC*) is calculated by the following equation:

$$SEC = \frac{[\dot{m}_{air} \times Cp \times (T_{out} - T_{in}) + W_{in}]}{X} \tag{8}$$

The drying rate for each dying case is calculated by the following equation:

$$DR = \frac{X}{DT} \tag{9}$$

3. RESULTS AND DISCUSSIONS

3.1. Data Assessment

During the experiments, the ambient temperature was between 26.9°C and 27.5°C and the relative humidity ranged between 51.7% and 52.2%. The temperature of the air at the condenser was 30°C to 40°C. The tests for the first and second case of drying were considered as the benchmarks from which the drying performance of the RACD was to be evaluated. The experimental data is presented in Table 2. The drying rate, *DR* (kg/h), and *SMER* (kg/kWh) were calculated based on the data from this table. The results for the three cases of drying are tabulated in Table 3.

Table 2. Test Parameters for Experiments Under Case 1, 2, and 3

Test Case	Ambient Condition	Initial Weight of Dry Cloths (g)	Weight of Spin Dried Cloths (g)	Final Weight (g)	Moisture Removed (g)	Drying time (min)
Case1 (Indoor drying)	27.21 °C RH=51.93%	1875	2800	1875	925	420
Case 2 (Outdoor drying)	33.10 °C RH=83.57%	1675	2400	1675	725	240
Case 3 (Drying clothes using condenser waste heat at 17°C room air conditioner)	27 °C RH=32.42%	1600	2350	1600	850	80
Case 3 (Drying clothes using condenser waste heat at 19°C room air conditioner)	27 °C RH=31.74%	1612	2425	1612	812	80
Case 3 (Drying clothes using condenser waste heat at 21°C room air conditioner)	27 °C RH=32.47%	1625	2425	1625	800	70
Case 3 (Drying clothes using condenser waste heat at 23°C room air conditioner)	27 °C RH=31.80%	1600	2437	1600	837	90
Case 3 (Drying clothes using condenser waste heat at 25°C room air conditioner)	27 °C RH=33.22%	1625	2500	1625	875	70

Table 3. The Results of Three Cases

Drying Configuration	Moisture Removed (g)[a]	Drying Time (min)[b]	Drying Rate (kg/h)	Air Conditioner Power Consumption With Dryer (Watt)	Mass of Air (kg/s)	Cooling Capacity (kJ/s)	SMER (kg/kWh)
Case 1 (Indoor drying)	925	420	0.1312	-	-	-	-
Case 2 (Outdoor drying)	725	240	0.1813	-	-	-	-
Case 3 (Drying clothes using condenser waste heat at 17°C room air conditioner)	850	85	0.5985	810	290.5	3627	0.1916
Case 3 (Drying clothes using condenser waste heat at 19°C room air conditioner)	812.5	80	0.6095	833	290.5	3023	0.213
Case 3 (Drying clothes using condenser waste heat at 21°C room air conditioner)	800	70	0.6857	828	290.5	2799	0.2205
Case 3 (Drying clothes using condenser waste heat at 23°C room air conditioner)	837.5	85	0.589	855	290.5	3051	0.2144
Case 3 (Drying clothes using condenser waste heat at 25°C room air conditioner)	875	70	0.75	843	290.5	3993	0.1809

[a, b] Average results of experiment repeated three times

Figures 4 and 5 show the moisture removal *vs* drying time for indoor and outdoor conventional drying processes.. The results show that the indoor drying takes a longer time than outdoor drying. The experiment was repeated for every temperature setting and is shown in Figures 6–10. These figures show that the drying time of RACD is much shorter than conventional drying. Table 3 shows the RACD drying rate at a temperature setting of 17°C was 4.6 times higher than indoor drying and 3.3 times higher than outdoor drying. The drying rate for RACD at 21°C was

5.2 times higher than indoor drying and 3.8 times higher than outdoor drying. Meanwhile, the drying rate for RACD at 25°C was 5.7 times higher than indoor drying and 4.1 times higher than outdoor drying.

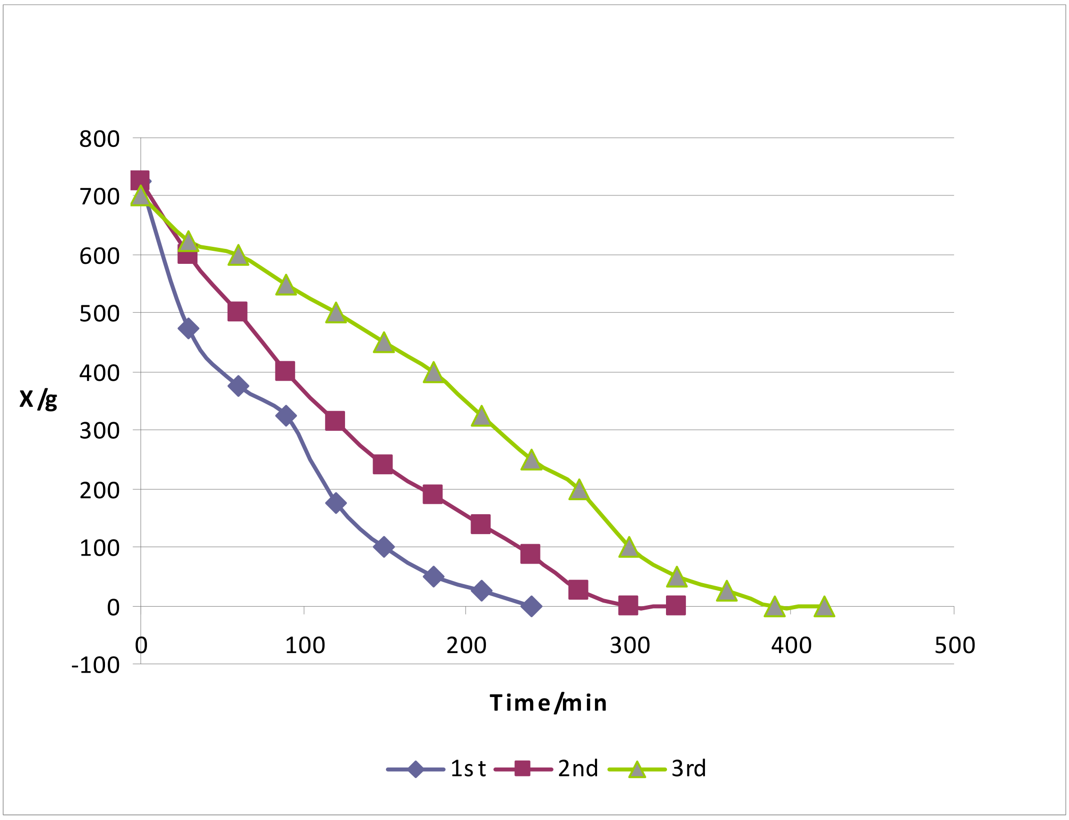

Figure 4. Moisture removal vs drying time for outdoor case of drying

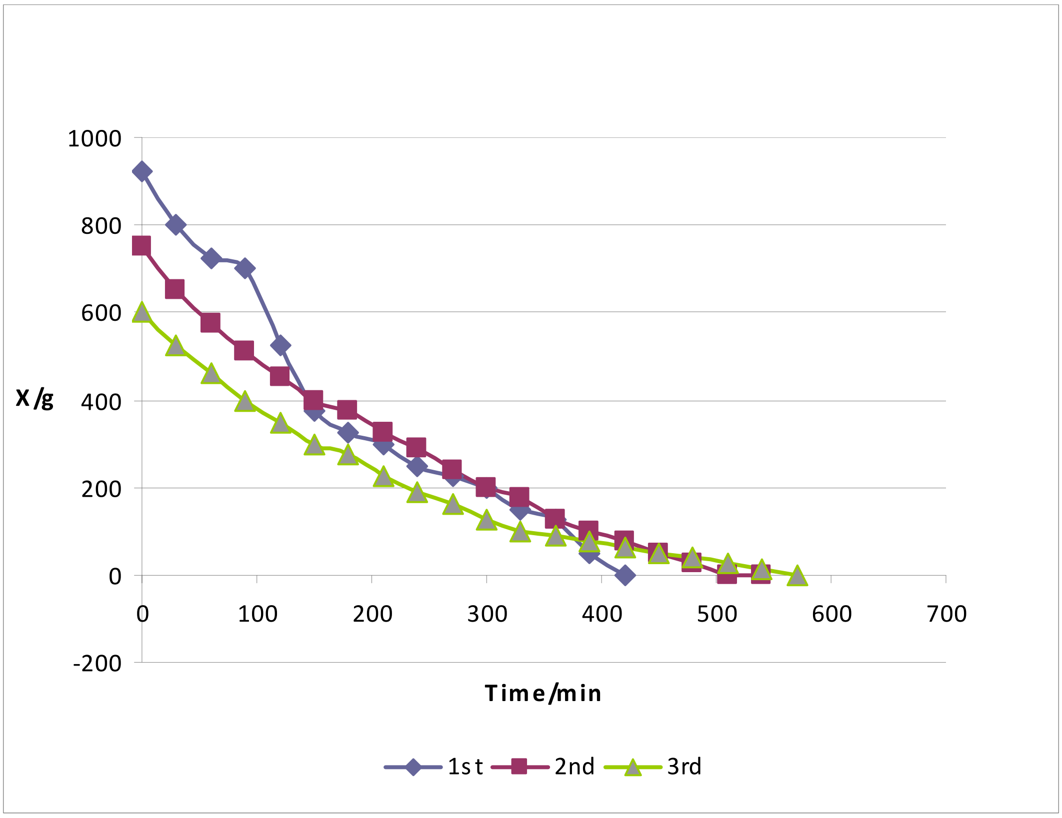

Figure 5. Moisture removal vs drying time for indoor case of drying

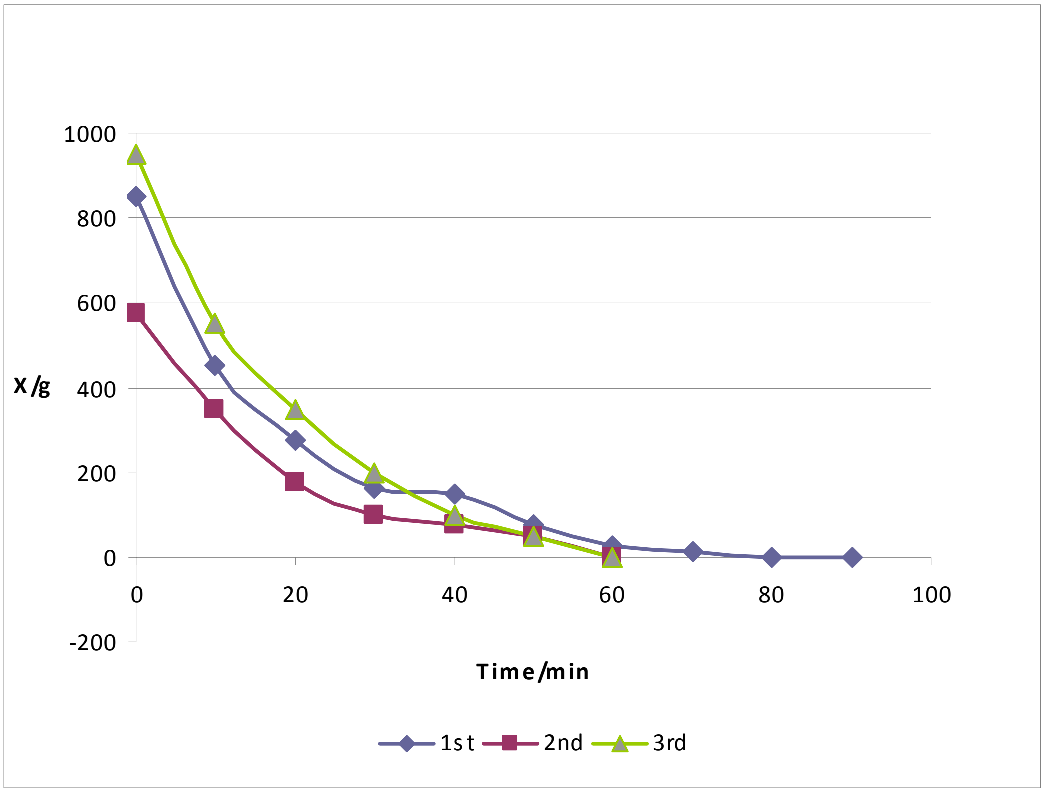

Figure 6. Moisture removal vs drying time for RACD at 17°C

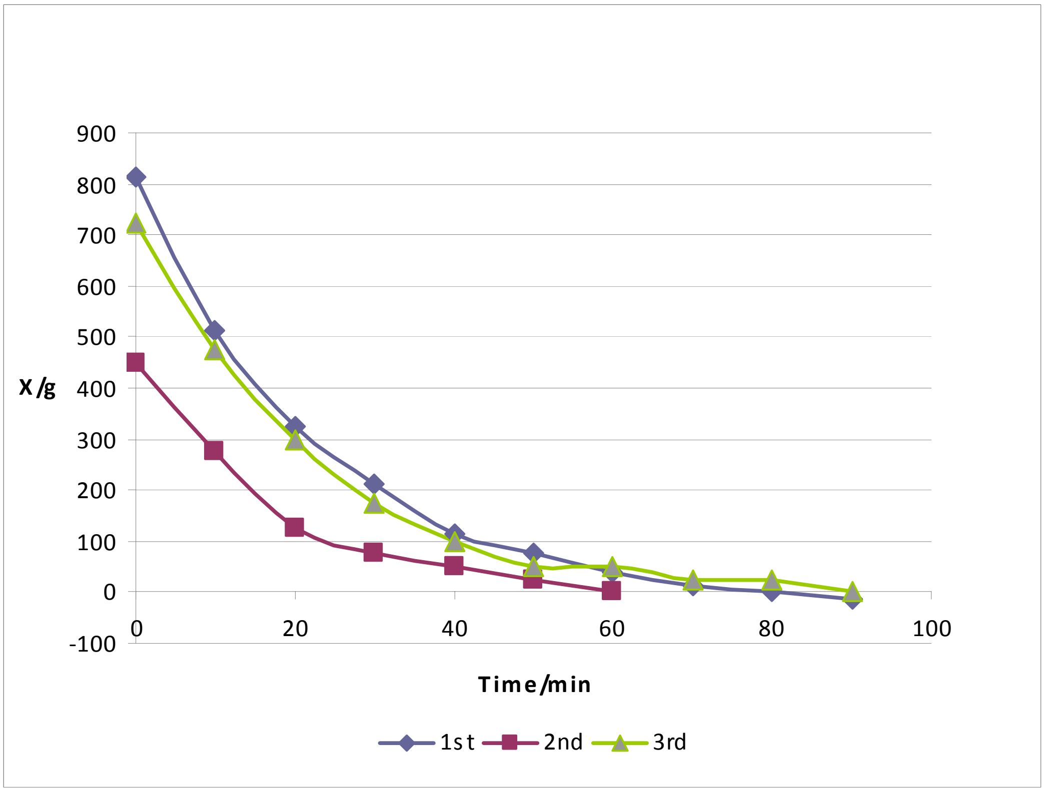

Figure 7. Moisture removal vs drying time for RACD at 19°C

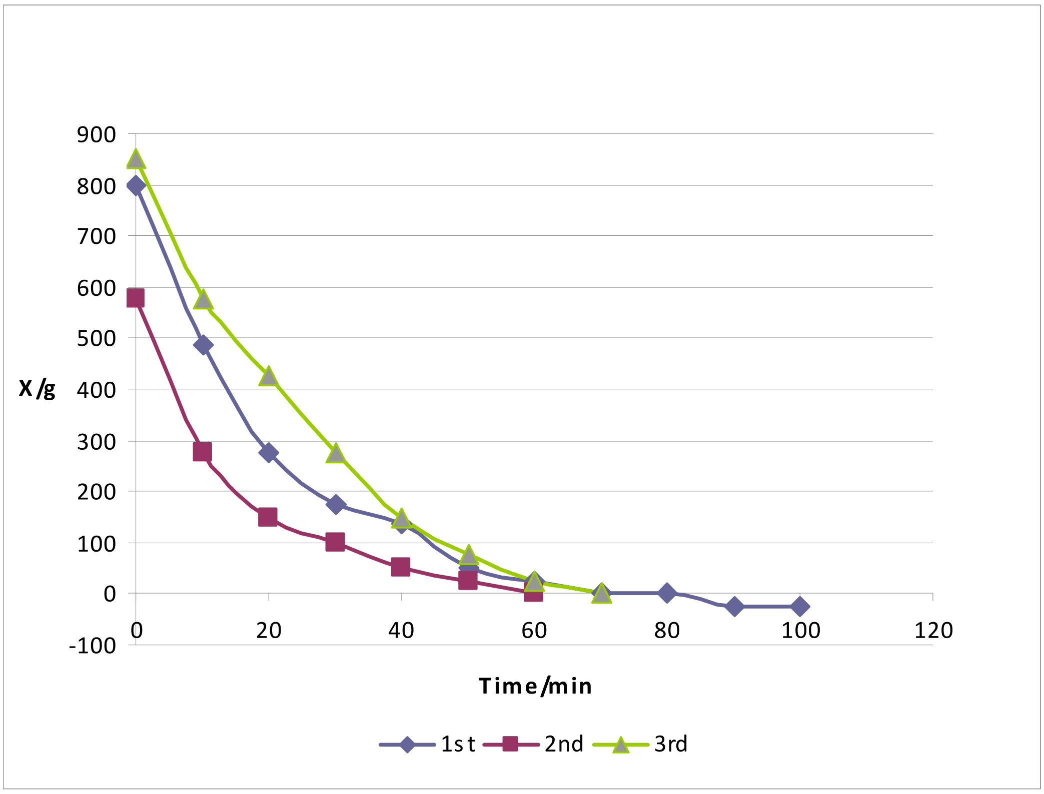

Figure 8. Moisture removal vs drying time for RACD at 21°C

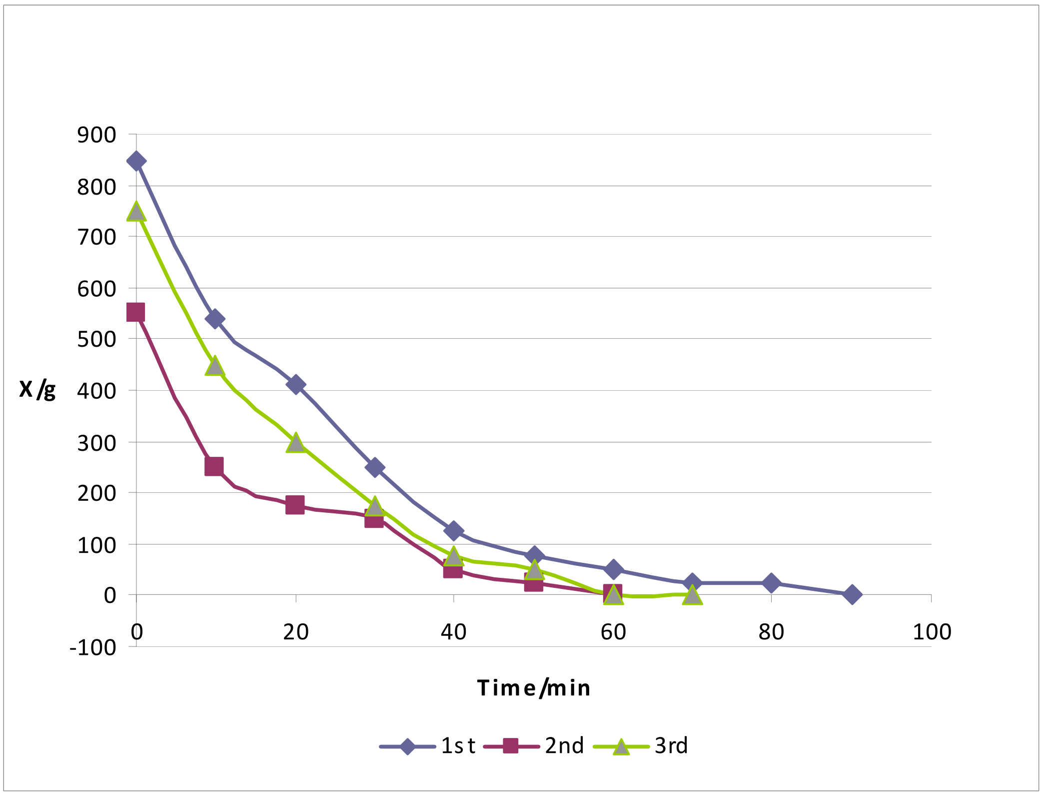

Figure 9. Moisture removal vs drying time for RACD at 23 °C

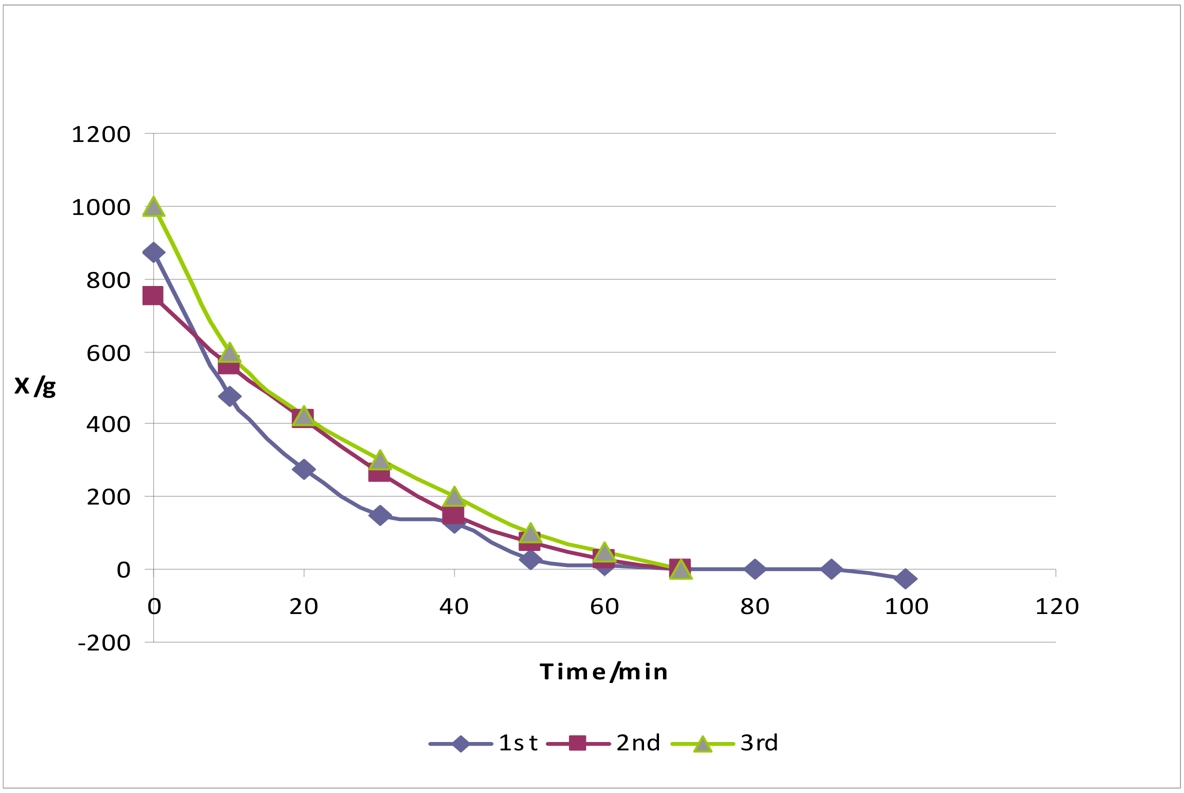

Figure 10. Moisture removal vs drying time for RACD at 25°C

The SMER for both indoor drying and outdoor drying is zero, whereas it was 0.197 kg/kWh for RACD at 17°C, 0.213 kg/kWh for RACD at 19°C, 0.221 kg/kWh for RACD at 21°C, 0.214 kg/kWh for RACD at 23°C, and 0.1801 kg/kWh for RACD at 25°C. The RACD drying times at a temperature setting of 17°C were only 19.05% and 33.33% of time use for indoor and outdoor drying, respectively. At 21°C, drying times with RACD were 16.67% and 29.17% of time spent for indoor and outdoor drying, respectively. Meanwhile, at 25°C, the drying times were 16.67% and 29.17% of time spent for indoor and outdoor drying, respectively.

This study also found that the air temperature at the exit of the chamber fell significantly when the sample was placed inside the chamber. This was due to heat and mass transfer process taking place between the drying air stream and the drying sample. As the drying time passed by, the drying sample became completely dry. As a result, less heat was transferred and less moisture was carried away by the air system. The negative values indicate that the initial weight of the clothes before the experiment was because of a slightly higher moisture content compared to the weight after drying.

The average energy consumption of the split air conditioner without dryer is about 0.807 kWh for 85 minutes running time at a temperature of 17°C. This is slightly lower than with the dryer at the same temperature setting. This is expected because of the increase in fan resistances due to the wet clothes in the drying chamber. The energy consumption for RACD is between 0.810 kWh to 0.855 kWh per cycle. Meanwhile, the most efficient commercial type of clothes dryer consumes 898 KWh/year [10]. This shows that RACD consumes less energy than a commercial clothes dryer. However, the energy used by RACD is waste heat from an air-conditioner condenser that is purposely used for cooling. The savings relative to a regular clothes dryer can be calculated with the assumption that the energy consumption for standard clothes dryers is 898 kWh per year and the price of electricity in Malaysia is RM 0.235/kWh. Therefore, the bill savings is about RM 211/year (US$ 1 = RM 3.50).

3.2. Effectiveness of RACD

Significant electricity savings in the residential sector could be achieved with RACD compared to other types of drying processes on the condition that the air-conditioning unit is operated for at least two hours daily. Taking into consideration the hot and humid climate in this region, this target is certainly achievable. Furthermore, by using RACD, the problem of drying clothes in congested areas where the average size of high-rise apartments is relatively small can be solved.

4. CONCLUSION

Experimental investigation of the effectiveness of using heat rejected from a split-type room air conditioner for clothes drying was carried out. The results of the study indicate that clothes drying by RACD is viable. The experiment proves that RACD performance is more effective then other drying methods. The analysis shows that the drying rate for the test ranged from 0.56 kg/hr to 0.75 kg/hr with RACD for temperatures ranging from 17°C to 25°C compared to 0.13 kg/hr for indoor drying and 0.18 kg/hr for outdoor drying. Meanwhile, the energy consumptions for drying clothes are from 0.810kWh to 0.855 kWh per cycle. The time required for moisture removal with RACD is around 17% to 21% and 29% to 37% of time spent for indoor and outdoor drying, respectively. This shows that the RACD is a more efficient way to dry clothes and proves that clothes can be dried in a controlled environment in a shorter time. However, the increase of fan capacity due to air resistance of the wet clothes in the drying chamber was not taken into account in this study. Therefore, the fan power input was assumed to be constant. Since most people in the cities of Malaysia and in the big cities all over the world today tend to live in apartments, condominiums, and flats, the idea could spread. Most of the apartments, condominiums, and flats in Malaysia have a small multipurpose store room. This room can be used to place the condenser and drying camber. However, it is difficult to implement this drying system for buildings with district cooling, because it needs more space than flats or apartments. However, since this system is to be used in high-rise flats or apartments with a split room air conditioner, which are widely found in the cities of Malaysia, this drying system can be directly implemented.

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REFERENCES

[1] "Industrial Heat-Recovery Strategies", *PG&E Energy Efficiency Information*, 2003. Available from: www.pge.com

[2] H. L. Talom and A. Beyene, "Heat Recovery from Automotive Engine", *Applied Thermal Engineering*, **29**(2009), pp. 439–444.

[3] Y. Xiaowen and W. L. Lee, "The Use of Helical Heat Exchanger for Heat Recovery Domestic Water-Cooled Air-Conditioners", *Energy Conv. Management*, **50**(2009), pp. 240–246.

[4] R. T. Ogulata, "Utilization of Waste-Heat Recovery in Textile Drying", *Applied Energy,* **79**(2004), pp. 41–49.

[5] L. Sivill, P. Ahtila, and M. Taimisto, "Thermodynamic Simulation of Dryer Section Heat Recovery in Paper Machines", *Applied Thermal Engineering,* **25**(2005), pp. 1273–1292.

[6] A. Ameen and S. Bari, "Investigation into the Effectiveness of Heat Pump Assisted Clothes Dryer for Humid Tropics", *Energy Conv. Manage*., **45(9–10)**(2004), pp. 1397–1405.

[7] J. E. Braun, P. K. Bansal, and E. A. Groll, "Energy Efficiency Analysis of Air Cycle Heat Pump Dryers", *International Journal of Refrigeration*, **25(7)**(2002), pp. 954–965.

[8] Y. A. Cengel and M. A. Boles, *An Engineering Approach—Thermodynamics, 6th Edition*. New York: McGraw-Hill.

[9] S. Deng and H. Han, "An Experimental Study on Clothes Drying Using Rejected Heat (CDURH) With Split-Type Residential Air Conditioners, *Applied Thermal Engineering*, **24(17–18)**(2004), pp. 2789–2800.

[10] Natural Resources Canada. "Major Household Appliances Shipped in Canada", *EcoEnergy-Natural Resources Canada's Office of Energy Efficiency Report*, December 2007, pp. 64–69