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DESIGN A FEASIBLE CLOTH DRIER UTILIZING DOMESTIC WASTE-HEAT
FOR HOUSEHOLD APPLICATION

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This thesis is submitted to the faculty of mechanical engineering in partial fulfillment
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“I verify that this report is my own work except for the citation and quotation that the source has been clarified for each one of them”

Signature:.....

Author:.....

Date:.....

To my beloved family for their encouragement and support especially, and for their understanding in the way I am.

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ABSTRACT

This paper is about an experimental study on the effectiveness of using heat emitted from a split-type residential air conditioner (RAC) for clothes drying in residential buildings. This work will focus on utilizing waste-heat from air condition to dry the clothes. In this work a new cabinet for the clothes dryer had been designed and some of the important formula for drying process had been included. This experiment was done by referring to drying clothes activity and with this project it is hoped that the drying activity can be done at anytime without any problem. The experiment was done by an actual prototype that was built with some properties like acrylic, aluminum and polyvinyl chloride (PVC). The material was selected because the properties are suitable for this process. 5 pairs of jeans trouser had been used as the specimen to shown the capability of the drying process with heat emitted from the air conditioning despite of its high level of moisture content after washing process. With all the precautions and preparation, an efficient dryer cabinet was fabricated and proposed for domestic use. It is hoped that with this innovation, clothes drying will be easier and economical no matter what the weather or conditions are.

ABSTRAK

Kertas kerja ini membincangkan satu kajian terhadap keberkesanan penggunaan haba yang dibebaskan dari penghawa dingin untuk proses pengeringan pakaian bagi kegunaan domestik. Kerja akan tertumpu kepada penggunaan semula haba dari penghawa dingin untuk mengeringkan pakaian. Dalam kertas kerja ini satu reka bentuk bagi almari untuk mengeringkan pakaian direka dan sebahagian dari rumus yang diperlukan akan diletakan bersama dalam kertas kerja ini agar kajian yang dijalankan akan berjaya. Kajian ini dilakukan dengan mengambil kira aktiviti pengeringan pakaian yang boleh dilaksanakan pada bila-masa tanpa bermasalah. Kajian ini dilakukan dengan menghasilkan satu almari pakaian dengan bahan seperti acrylic, aluminum and polyvinyl chloride (PVC). Bahan-bahan ini dipilih disebabkan sifat bahan tersebut bersesuaian dengan proses dalam kajian ini. 5 helai seluar 'jeans' telah dijadikan sebagai rujukan untuk menunjukkan proses pengeringan dengan menggunakan haba yang terbebas melalui penghawa dingin dapat mengeringkan pakaian yang mempunyai kelembapan yang tinggi apabila dibasuh. Dengan kajian yang telah dilaksanakan satu almari pengeringan pakaian dapat dihasilkan untuk kegunaan domestik. Dengan inovasi ini, diharap pengeringan pakaian dapat dijalankan dengan lebih mudah disamping menjimatkan dan dapat dilaksanakan tanpa mengira cuaca dan masa.

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NOMENCLATURE

C_p	specific heat capacity (kJ/kg K)
E_s	energy-saving rate (%)
k	drying rate (%)
m_a	rate of process air (kg/h)
m_e	rate of evaporated water (kg/h)
m_{pi}	rate of product-input to dryer (kg)
m_{po}	rate of product-out from dryer (kg)
Q	actual heat-transfer (kJ)
Q_H	heater capacity (kJ/h)
Q_{max}	maximum possible heat-transfer (kJ)
Q_R	heat of recuperator (kJ/h)
Q_T	total heat rate (kJ/h)
t	drying time (h)
T_a	ambient-air temperature ($^{\circ}\text{C}$)
T_{di}	dryer-inlet air temperature ($^{\circ}\text{C}$)
T_{do}	dryer-outlet air temperature ($^{\circ}\text{C}$)
T_e	exhaust-air temperature ($^{\circ}\text{C}$)
T_{fi}	recuperator-inlet air (fresh-air) temperature ($^{\circ}\text{C}$)
T_{fo}	recuperator-outlet air (fresh-air) temperature ($^{\circ}\text{C}$)
X_1	dryer-inlet air_s moisture-content (kg _w /kg _a)
X_2	dryer-outlet air_s moisture-content (kg _w /kg _a)
ΔX	difference of dryer inlet–outlet moisture content (kg _w /kg _a)
ΔT	difference between Tdo and Te ($^{\circ}\text{C}$)
ε	effectiveness of heat recuperator (%)
ϕ	ambient-air_s relative humidity (%)
C_p	specific heat (kJ/kg K)

m_a	mass flow-rate of dry air (kg/s)
M_{BD}	bone-dry mass of clothes (kg)
Q	heat-flow rate (kW)
T_m	mean temperature of the clothes ($^{\circ}C$)
X	moisture content of clothes
ω	specific humidity

Subscripts

a	air
cold	cold fluid
hot	hot fluid
max	maximum
min	minimum
w	water
a	air
BD	bone-dry mass
cl	clothes
D	drum
evap	evaporation
0	ambient
w	water

CHAPTER 1

INTRODUCTION

Clothes drying, done for ages by the Sun and wind, has become in industrialized societies an important consumer of electrical or other types of energy through the use of tumbler dryers. In large densely populated cities, residential buildings are usually high-rise blocks. In order to maintain an acceptable appearance of building façade, clothes drying using natural means by hanging clothes outside windows or a balcony may not be allowed. Increasingly, a clothes drying has become confined to indoors, either at the expense of consuming energy through the use of clothes dryers or by natural ventilation. Clothes drying indoors using natural ventilation, versus by an electrical or a gas clothes dryer, can take days, depending on textile type, weather conditions, and the location of a residential flat in a high-rise residential block (e.g., prevailing flat orientation and floor level). In places where air humidity is high (e.g., during wet seasons in end of the year, or during rainy days), clothes drying indoors by natural ventilation can take a long time and still yield unsatisfactory results.

In addition, drying clothes indoors by natural ventilation has an effect on the indoor thermal environment, as the moisture contained in wet clothes is transferred to internal ventilation during drying, by evaporation and diffusion. This additional excess moisture must be dealt with through either mechanical or natural ventilation means.

Now days in developed countries, the application of residential air conditioning (RAC) has increased and without recycling the consumption of heat from the RAC it can be wasted and to take the advantage of it an innovation had been made to use the recycle heat to make something useful for our daily life. One of the solutions is to prove that the emission of heat is useful in clothes drying process. Eventually there's an alternative method in the drying process using RAC besides the natural dependence on weather.

The concept of the RAC system for clothes drying had been patented by Shiming Deng in 2004 with the wooden prototype but in this study focuses on an experimental study on the effectiveness of clothes drying using rejected heat (CDURH) with a split-type RAC which will make some improvisations based on mechanical formula hopefully to be a successful method which will be a benefit to the community.

1.1 OBJECTIVE

The purpose of this project is to design feasible clothes drying apparatus for house hold consumption utilizing waste-heat from air condition. This project also allows us to fully utilize waste heat from domestic appliances for drying purposes.

1.2 SCOPE

For this project the feasible design of cost effective clothes drying without disturbing air-conditioning system will be made and this study is limited for domestic use only. The proposed dryer was suggested as night dryer or during wet season dryer.

The theory of the design of clothes dryer was reviewed from various sources such as journals, books, preview reports and the world wide website. Summary of this literature review was presented in Chapter 2. For the design work, it will be divided into 2 parts. The first part is the concept of the design referring to the entire source that had been found. The second part is the sketching/draft of the proposed design. The design will then be constructed and tested for its feasibility and effectiveness.

All the data from the experiment will be collected. The data will be analyzed to obtain the effect of cloth dryer to the air condition/refrigeration that is used in this experiment. Data comparison for each part will be done and the results will be discussed and the result obtained in this research will be compiled and discussed. Finally, the conclusion and recommendations for future research will be presented.

CHAPTER 2

LITERATURE REVIEW

Drying is the one most energy-intensive operation in the wide range of textile process. The raw material is very humid. The humidity of the fabric is reduced by means of dryers. During drying, the warm moist air is sent to the atmosphere. However, this waste heat should be used in the drying machines. (R. Tugrul Ogulata, 2004)

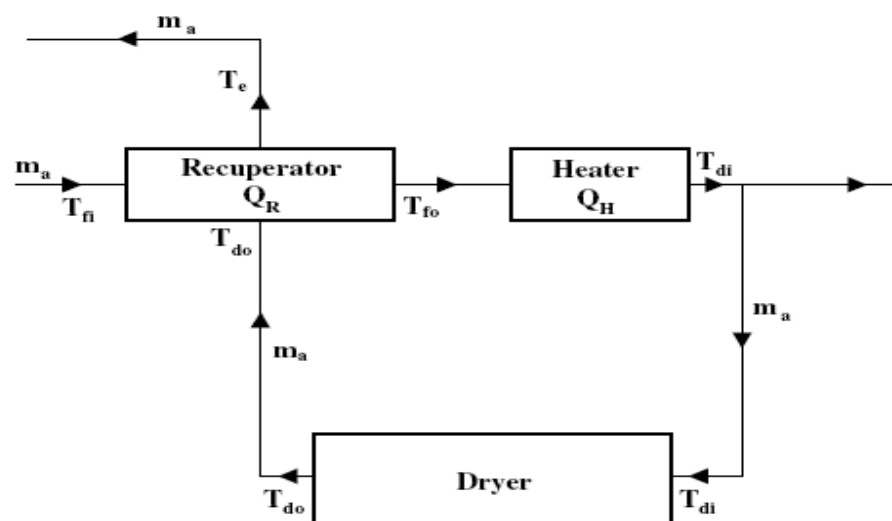


Figure 2.1: Diagram of a textile drying system with waste-heat recovery.

(Source: R. Tugrul Ogulata, 2004)

Figure 2.1 shows the drying system with waste-heat recovery studied by R. Tugrul Ogulata (2004). As seen in the Figure above, humid and dirty waste-air from the drying machine is sent to the heat exchanger. Heat transfer via the plate-type heat-exchanger (cross-flow) is realized between the fresh air from the environment and the waste air. While the waste air passes through one channel, the fresh air passes through the abutting channel. Thus, the fresh air temperature is raised and the waste air is cooled and sent to the ambient environment. The temperature of the pre-heated fresh air is further raised in the air heater (R. Tugrul Ogulata, 2004).

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 through either mechanical or natural ventilation means. If clothes drying are achieved by either an electrical- or a gas-powered dryer, the drying process may be completed within hours but at the expense of additional energy use and associated pollution. In an evaporative clothes dryer, air is heated, by either electricity or gas, to a higher temperature (50° – 70° C) and the hot air stream is then used to dry clothes. Hot and humid air that carries away the moisture after passing through clothes is discharged outdoors, contributing to local heat and air pollution.

Household tumble-dryer are generally considered as inefficient devices. Their energy consumption has attracted attention due to establishing of minimum energy-performance standard (MEPS) and various utility objectives to encourage consumers to use more efficient units. They show that an open-cycle condensing dryer, with heat recovery, was more efficient than a standard air-vented-dryer. Recirculation has been shown to increase the overall energy-efficient of a tumbler dryer. (V. Yadav and C.G. Moon, 2007).

Based upon the literature study, the following basic assumptions are necessary for successful modeling of various processes occurring inside the dryer (V. Yadav, 2008):

- The thermo-physical properties of the fabric material are uniform throughout the volume occupied.
- Dispersion of moisture content within the fabric material is homogeneous.
- Instantaneous distribution of moisture within the working fluid is uniform.
- The temperature of the fabric material and the wet-bulb temperature of the working fluid are the same.
- Instantaneous temperature-distribution within the bulk of the fabric material is uniform.
- Transfer of moisture from the fabric material to the working fluid takes place inside a cylindrical enclosure where the material is placed.
- The cylindrical enclosure and the material being dried may be static or in motion – both cases are considered.
- The hot fluid with low moisture-content enters from one axial direction and leaves via another.
- For the model implementation purpose, all thermo-physical properties of the working fluid are considered to be the same as that of air.

The first step in addressing dehumidification need involves comprehensive system design. (Jung-Ho Huh et.al, 2007) Design and selection of an appropriate heating, ventilating and air-conditioning, HVAC and dehumidification system requires that the system meet both sensible and latent loads. However, since design conditions typically occur at times of high sensible load, off-design conditions often present situations of low sensible load but high latent load. It is necessary to operate the system to match the equipment performance with the building loads over a broad range of off-design operating conditions, while constrained to maintain temperature and humidity within a desired range. The “match” between the sensible and latent components of the equipment capacities and building loads is represented by the sensible heat ratio, SHR (Jung-Ho Huh et.al, 2007).

The equipment capacity SHR is defined as the ratio of the sensible capacity to total capacity, and the load SHR is defined as the ratio of sensible load to total load where the total is the sum of the sensible and latent.

$$SHR_{cap} = \frac{CAP_{sen}}{CAP_{sen} + CAP_{lat}} \quad (1)$$

$$SHR_{load} = \frac{Q_{sen}}{Q_{sen} + Q_{lat}} \quad (2)$$

Low SHR implies a greater latent fraction and better dehumidification. Under steady-state conditions, energy admass balances dictate that $SHR_{cap} = SHR_{load}$. Given a particular system design, the goal of this research is to develop optimal operational strategies for a direct expansion (DX) HVAC system with respect to both energy consumption and thermal comfort. The objective was achieved by applying numerical optimization techniques with a validated simulation model. Optimization techniques have not been widely used in the study of HVAC system operation, and relatively little research on optimal HVAC system operation has been reported in the literature (Jung-Ho Huh et.al, 2007).

Several HVAC systems have been previously studied for optimal control in meeting temperature-cooling requirements only. To date there has been no comprehensive study on the optimal set of HVAC operating parameters for the complete thermal environment. In most applications both temperature and humidity must be maintained, presenting a tougher optimization problem than simple temperature control. Since providing greater comfort is one of main objectives in today's HVAC industry, the need for efficient active humidity control becomes more important. Earlier optimization studies of HVAC systems mainly focused n control of water-side equipment in a chilled water plant, not air-side, and room air humidity was not controlled directly (Jung-Ho Huh et.al, 2007).

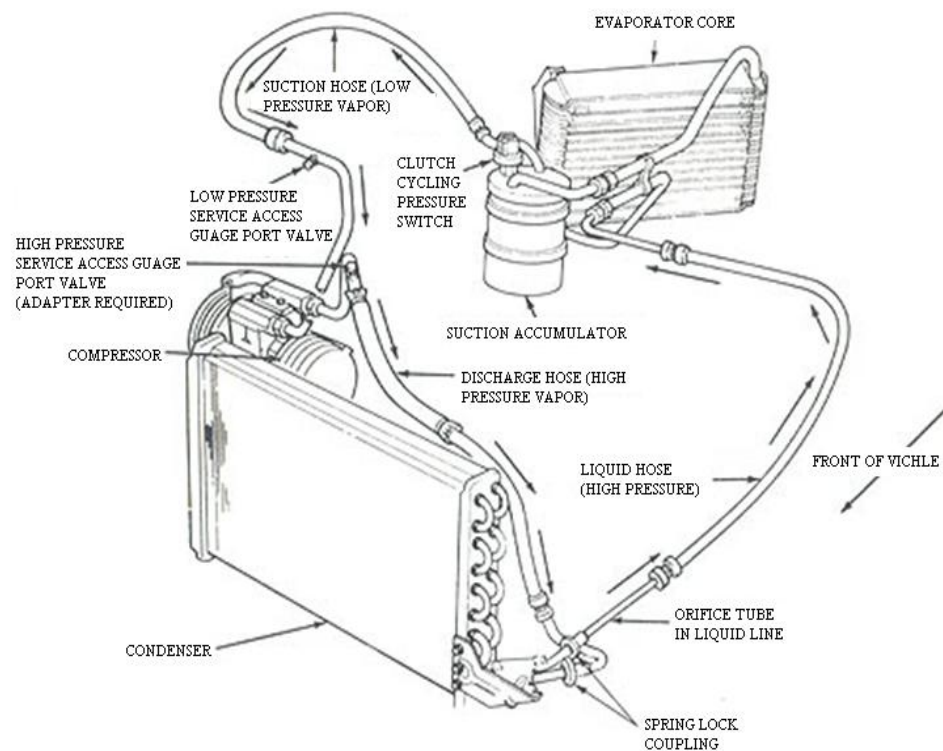


Figure 2.2 Simple of RAC systems

Refer to figure 2.2: residential air conditioning is usually by discrete systems, using either window type or split type RACs. Given a choice, a split-type RAC is preferred because of not only its quieter operation but also its flexibility for multi-room services. For a split-type RAC, ambient 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 . (J.E. Braun,2001)

This presents an opportunity to re-use the heated air exiting from an air-cooled split-type RAC for clothes drying in residential buildings 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. The concept of using condenser heat for household drying purpose was previously adopted in a multi-function heat pump system. The system integrated multi-functions in a household, such as air conditioning, hot water supply, heating and drying into a refrigeration system, and was therefore too complicated for practical application. (Shiming Deng, 2004)

In the research of Shiming Deng (2004), he studies on the effectiveness of CDURH with a split-type RAC. An experimental rig has been set up and extensive experimental work has been carried out. The effectiveness was evaluated based on the comparisons by various drying methods, in terms of required drying duration, energy consumption, under Asia's climatic conditions.

The drying-process time had been discussed in detailed by V.Yadav et.al (2008) in their paper entitled "Fabric Drying Process in Domestic Dryer". According to their study the order of magnitude for the drying time can be obtained as:

$$(\Delta t)_{DP} = \frac{M_{BD}X}{m \Delta \omega} = O(10^4 s) \quad (3)$$

Where $\Delta \omega$ is the humidity ratio between the dryer inlet and exit.

The order for $(\Delta t)_r$ and $(\Delta t)_h$ are nearly equal and considerably smaller than $(\Delta t)_{DP}$. The temperature and moisture content of the load are to be assumed constant during a time step Δt and the heat-and-mass transfer processes during the time step are assumed to be in a steady state: the magnitude of Δt has to be sufficiently less than $(\Delta t)_r$ or $(\Delta t)_h$.

In order to evaluate the rate of change of temperature for the load with time, the approximate energy balance within the drum (over a time interval Δt) can be given as:

$$\dot{Q}_{\text{gained due to drum loss}} + \dot{Q}_{\text{supplied by the heater}} = \dot{Q}_{\text{absorbed in drum}} + \dot{Q}_{\text{lost due to evaporation}} \quad (4)$$

Introducing appropriate expressions for the different terms, we get

$$\dot{m}_a(h_4 - h_3)\Delta t + \dot{Q}_{\text{lost}}\Delta t = \sum m C_p \Delta T = \dot{Q}_{\text{evap}}\Delta t \quad (5)$$

On rearranging the terms

$$T_{m, \Delta t} = T_{m, t} + \left[\frac{\dot{m}(h_4 - h_3) - \dot{Q}_{evap} + \dot{Q}_{D, loss}}{M_{BD}C_{p, cl} + XM_{BD}C_{p, w} + M_D C_{p, D}} \right] \Delta t \quad (6)$$

Where $T_{m,t}$ and $T_{m,\Delta t}$ are the temperature at the time t and $t + \Delta t$, respectively; and M_D is the mass of the drum. Furthermore, $C_{p,w}$ and $C_{p,D}$ are the specific-heat values for water and drum mass, respectively.

Heat is energy transferred between two objects because of a temperature difference between them. Heat always travels from hot to cold. Temperature is a measure of the energy, or heat, of something. It is a property that an object has based on the random motions of the particles in that substance. The faster that the molecules move, the higher the temperature and therefore the more heat transferred to a new object. Therefore, heat transfer is the movement of energy from something with high energy (a hot object) to something with low energy (a cold object). Heat transfer can occur three ways. (H.I. Abu-Mulaweh, 2005)

Conductive heat transfer is the movement of heat through solids or between two solids that are touching. An example of conductive heat transfer is common when cooking on the stovetop. We set the pan on top of the stove. The stove heats the pan at the bottom of the pan, but it is not just the bottom of the pan that gets hot. The handle of the pan often gets hot also. This is because conduction occurs within the pan that transfers the heat from the bottom of the pan, throughout the pan to the handle. In the potato example, heat is conducted from the oven rack that the potato is sitting on, to the potato skin, and again from the outside of the potato to the inner potato. When hot food is placed on a cold plate, heat is transferred via conduction from the hot food that is touching the plate to the plate. Conductive heat transfer can be represented by a basic equation. Our task is to introduce this equation and dissect it into understandable parts. . (H.I. Abu-Mulaweh, 2005)

$$Q = -kA(D T)/(D x) \quad (7)$$

Heat transfer can be represented by numerous different equations. Convective heat transfer is the movement of heat due to fluid movement. If you were to fill a bathtub full of water and then realize that it was too hot, you would add more cold water. If you can relate to such an instance, you know that the cold water is often at the faucet end of the tub, while the hot water stays at the other end. If you swirl the water around though, it mixes. The hot water transfers heat to the cold water by heat convection due to the swirling. . (H.I. Abu-Mulaweh, 2005)

$$Q = -hA(T_s - T) \quad (8)$$

Radiant heat transfer is the transfer of heat from a heated surface. The most common form of radiant heat transfer is the transfer of heat from the sun to the earth. This is what keeps us warm. We can also see radiant heat transfer while baking a potato in the oven. The oven is heated up and then the heat is transferred radiantly from the walls of the oven to the potato in the oven. Radiant and convective heat transfer is represented by a similar equation. Our task is to introduce the equation and dissect it into understandable parts. The equation below represents both radiant and convective heat transfer. . (H.I. Abu-Mulaweh, 2005)

$$Q = -hA(T_s - T) \quad (9)$$

Mathematical formulation for drying process had been discus by R. Tugrul Ogulata (2004) in his study of “Utilization of Waste-heat Recovery in Textile Drying”. In his study, he defined Effectiveness, ε , of the heat exchanger is defined as the ratio between actual heat-transfer rate and the maximum possible heat-transfer rate from one stream to another.

$$\varepsilon = Q/Q_{\max} \quad (10)$$