UTILIZATION OF WASTE HEAT RECOVERY FROM AIR CONDITIONING SYSTEM FOR CLOTHES DRYING APPLICATION

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MASTER OF SCIENCE IN MANUFACTURING ENGINEERING

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DECLARATION

I declare that this thesis entitled “Utilization Of Waste Heat Recovery From Air Conditioning System For Clothes Drying Application “ is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :..

Name :..Sharul Nizam bin Yaakop.............................

Date :....05 July 2025...

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in .Manufacturing Engineering

Signature :..

Name : Associate Prof. Ts. Dr. Muhammad Hafidz Fazli bin Md Fauadi............................

Date :....05 July 2025...

DEDICATION

To my beloved wife and parents, I acknowledge my sincere appreciation to them for their love, vision, and sacrifice throughout my life. I am thankful for their understanding, tolerance, and consideration that were essential to make this effort possible. Their support has always inspired me from the day I learned how to read, write, and think until what I have become now. I am unable to find the most appropriate words that could properly describe my appreciation for their devotion, encouragement, and faith in my ability to reach my dreams. Lastly, I would like to extend my gratitude to any person who has contributed to this project either directly or indirectly. I am truly grateful for their comments and suggestions, which are crucial for the successful completion of this research.

ABSTRACT

Air conditioning (AC) systems are designed to regulate indoor air quality and provide thermal comfort. In a conventional vapor compression cycle system (VCCS), a considerable amount of waste heat is released from the condenser unit. This study focused on recovering this waste heat to be reused in an air dryer prototype for clothes drying purposes, targeting improved energy efficiency and drying performance. The methodology was carried out in three main phases. The first phase involved the identification and modelling of critical elements in the heat rejection process from the VCCS, with drying time set as the model output. A model was then integrated and validated based on predicted drying time. The second phase included the development of an actual prototype based on the model design, followed by experimental testing. Data were collected by varying several parameters such as ambient dry-bulb temperature, clothes' mass (1950 g, 4255 g, and 6350 g), and condenser fan speed. These data were analyzed to verify whether the performance fulfilled the modeled expectations. In the final phase, the collected data were analyzed using COOLPACK 1.49 software to evaluate key performance indicators. The validation was conducted based on achieving a coefficient of performance (COP) greater than 2.5 and a drying time below 120 minutes. The experimental results successfully showed that clothes were dried within 55 to 110 minutes, depending on load size, using air expelled at a flow rate of 0.34 m^3/s in a 33°C environment. The integration of the heat recovery system improved the COP from 2.36 to 2.70 (14.4%). This study demonstrated that an HVAC-based heat recovery system is a viable and energy-efficient alternative to conventional electric dryers by utilizing waste thermal energy, leading to reduced electricity consumption and improved system performance.

PENGGUNAAN PEMULIHAN SISA HABA DARI SISTEM PENYAMAN UDARA UNTUK APLIKASI PENGERINGAN PAKAIAN

ABSTRAK

Sistem penyaman udara (AC) direka bentuk untuk mengawal kualiti udara dalaman dan memberikan keselesaan haba kepada penghuni. Dalam sistem kitaran mampatan wap (VCCS) konvensional, sejumlah besar haba buangan dilepaskan dari unit kondenser. Kajian ini memberi tumpuan kepada pemulihan haba buangan tersebut untuk digunakan semula dalam prototaip pengering udara bagi tujuan pengeringan pakaian, dengan sasaran peningkatan kecekapan tenaga dan prestasi pengeringan. Kaedah kajian dilaksanakan dalam tiga fasa utama. Fasa pertama melibatkan proses mengenal pasti dan pemodelan elemen kritikal dalam proses pelepasan haba dari VCCS, dengan masa pengeringan dijadikan output utama model. Seterusnya, model ini diintegrasikan dan disahkan berdasarkan jangkaan masa pengeringan. Fasa kedua merangkumi pembangunan prototaip sebenar berdasarkan model tersebut, diikuti dengan ujian eksperimen. Data dikumpulkan dengan memvariasikan beberapa parameter seperti suhu mentol kering persekitaran, jisim pakaian (1950 g, 4255 g dan 6350 g), serta kelajuan kipas kondenser. Data ini dianalisis untuk menilai sama ada prestasi sistem memenuhi jangkaan model yang telah dibina. Fasa ketiga melibatkan analisis data menggunakan perisian COOLPACK 1.49 bagi menilai penunjuk prestasi utama. Pengesahan dilakukan berdasarkan dua syarat utama: Pekali Prestasi (COP) melebihi 2.5 dan masa pengeringan di bawah 120 minit. Hasil eksperimen menunjukkan pakaian berjaya dikeringkan antara 55 hingga 110 minit bergantung kepada saiz beban, menggunakan aliran udara panas pada kadar 0.34 m^3/s dalam persekitaran bersuhu 33°C. Integrasi sistem pemulihan haba ini telah meningkatkan COP daripada 2.36 kepada 2.70 (14.4%). Kajian ini membuktikan bahawa sistem pemulihan haba berasaskan HVAC adalah alternatif yang berdaya maju dan cekap tenaga berbanding pengering elektrik konvensional, dengan memanfaatkan tenaga haba buangan untuk menjimatkan penggunaan elektrik serta meningkatkan prestasi keseluruhan sistem.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

et al.	-	Et alii
HVAC	-	Heating, Ventilating, and Air Conditioning
VCC	-	Vapor Compression Cycle
VCCS	-	Vapor Compression Cycle System
WHR	-	Waste Heat Recovery
ORC	-	Organic Rankine Cycle
CO_2	-	Carbon Dioxide
VCR	-	Vapor Compression Refrigerant
VCRS	-	Vapor Compression Refrigeration System
HRAC	-	Heat Recovery Room Air Conditioner
COP	-	Coefficient of Performance
MDACWH	-	Multi-functional Domestic Air Conditioner Water Heater
DCHRAC	-	Domestic Condensing Heat Recovery Air Conditioning
TES	-	Thermal Energy Storage
LHTES	-	Latent Heat Thermal Energy Storage
PCMs	-	Phase Change Materials
RSACWH	-	Residential Split Air Conditioner Water Heater
AC	-	Air Conditioning
SMER	-	Specific Moisture Extraction Rate
RH	-	Relative Humidity
CHP	-	Combined Heat and Power

LIST OF APPENDICES

LIST OF PUBLICATIONS

The following is the list of publications related to the work on this thesis:

Sharul Nizam Yaakop, Muhammad Hafidz Fazli Md Fauadi, and Amir Abdullah Muhamad Damanhuri, 2023. Experimental Study on Heat Recovery of Air Dryer from Waste Heat Energy of Condensing Unit from VCRS Air Conditioner. *International Journal of Nature Environmental and Pollution Technology (NEPT),* Vol. 22, No. 1, pp. 149-157. (ISSN 23953454, Q4 (2023)

Sharul Nizam Yaakop, Muhammad Hafidz Fazli Md Fauadi, Amir Abdullah Muhamad Damanhuri, Ahmad Zaki Mohamed Noor, and Samad Ramlan, 2020. Utilization of waste heat recovery from domestic HVAC systems for hot water systems. *International Journal of Emerging Trends in Engineering Research (IJETER),* Vol. 8, No. 10, pp. 7262-7270. (ISSN 23473983, Q3 (2020))

CHAPTER 1

INTRODUCTION

1.1 Background

The increasing global demand for energy, coupled with the continued reliance on fossil fuels, has led to significant environmental challenges, particularly in terms of energy inefficiency and excessive heat loss. Although renewable energy technologies such as solar, wind, and geothermal have progressed, their integration into mainstream energy systems remains insufficient due to technological, economic, and policy limitations. As a result, energy systems continue to operate inefficiently, with a considerable portion of generated energy being lost as waste heat. This waste heat not only represents lost energy potential but also contributes to rising ambient temperatures, especially in urban environments where high-density development and anthropogenic activities exacerbate the heat island effect.

In response to the growing urgency of climate change, many nations have now committed to achieving net-zero greenhouse gas emissions by 2050, as outlined in global frameworks such as the United Nations Net Zero Coalition. This updated target builds upon earlier efforts like the Paris Agreement, moving from merely limiting global temperature rise to implementing actionable pathways that eliminate carbon emissions through energy efficiency, decarbonization, and technological innovation (UN, 2023; Warren et al., 2022). Achieving this target requires not only the adoption of cleaner energy sources but also the optimization of energy use by minimizing losses and recovering waste heat wherever possible. Waste heat recovery presents a promising strategy in this regard, as it allows previously lost energy to be captured and reused for secondary applications such as water heating, air drying, and power generation.

In many conventional systems, such as internal combustion engines, industrial boilers, and domestic air conditioning units, waste heat is a byproduct of operation. Internal combustion engines, for example, are widely used in vehicles, generators, and various machinery. According to Di Battista and Cipollone (2023), only about 35% of the energy in fuel is converted into useful mechanical work, while the rest—over 60%—is expelled as waste heat. Similarly, Shin et al. (2023) highlighted that industrial boilers often lose significant amounts of thermal energy during combustion and exhaust. In the residential sector, Gholamian et al. (2020) noted that split-type air conditioners release substantial heat into the environment during normal operation, particularly from their outdoor condensing units.

The concept of capturing and reusing this thermal energy has gained traction in recent years. Thakar et al. (2018) conducted an experiment using a novel heat exchanger design to recover exhaust heat from diesel engines, demonstrating improved fuel efficiency and reduced emissions. Yang et al. (2019) reported on China's shift from coal-fired to gas-fired boilers, in part to enable better heat management and lower environmental impact. Suntivarakorn and Treedet (2016) demonstrated that retrofitting boilers with heat recovery systems improved efficiency by 0.41% and reduced fuel moisture content by 3%, proving the practical feasibility of such systems.

In air conditioning systems, the Heating, Ventilation, and Air Conditioning (HVAC) sector has been identified as a major contributor to energy consumption in buildings, accounting for up to 60% of total building energy use (Asim et al., 2022). HVAC systems, especially those based on the vapor compression cycle, generate a considerable amount of waste heat during the cooling process. Recent research has explored thermodynamic models and system simulations to understand and improve the energy performance of these systems. Borri et al. (2017), for instance, performed a simulation study integrating an absorption chiller into an HVAC system. Their results showed an 11.5% increase in energy efficiency and a 10% reduction in energy consumption, underlining the importance of simulation-based optimization.

According to prior research, Heating, Ventilation, and Air Conditioning (HVAC) systems account for approximately 40% to 60% of the total energy consumption in residential, commercial, and industrial buildings (Asim et al., 2022). A significant portion of this energy is ultimately lost as waste heat, particularly during the compression and condensation processes. In recent years, growing attention has been given to the recovery and utilization of this waste heat, driven by both economic and environmental imperatives. Waste heat from HVAC systems, especially from the condenser unit, presents a valuable low-grade thermal energy source that can be captured and repurposed in various applications.

One common application is domestic water heating, where waste heat is transferred to a heat exchanger to preheat water, reducing reliance on electric or gas heaters. For instance, Ramadan et al. (2015) successfully demonstrated that hot air from an HVAC condenser can heat water from 25°C to 70°C, depending on mass flow rate and system capacity. In another study, Gholamian et al. (2020) highlighted how integrating waste heat recovery systems into residential HVAC units improved energy performance and reduced electricity bills.

In commercial and industrial settings, waste heat from large-scale HVAC systems can be harnessed to power absorption chillers, regenerate desiccants in dehumidification systems, or even assist in drying processes for food, textiles, or chemicals. For example, Turap et al. (n.d.) conducted simulations integrating absorption chillers with waste heat sources, reporting a 10% reduction in specific energy consumption (from 537 kWh/t to 478 kWh/t) and an 11.5% improvement in system efficiency.

Waste heat from HVAC units is also being applied in greenhouse climate control, where recovered heat stabilizes internal temperature during cooler periods, promoting plant growth while reducing heating costs. Furthermore, in laundry and textile industries, warm air from condensers is redirected to drying chambers to enhance evaporation, shortening drying times and reducing electrical heating demand.

These applications show that HVAC waste heat is not merely a by-product but a valuable secondary energy source when integrated with appropriate recovery systems. This study explores such an application by designing a system that recycles condenser heat to operate an air dryer. This concept aims to demonstrate that even low-grade thermal energy from household-level HVAC systems can be utilized efficiently, supporting the broader goals of energy conservation and sustainable development.

In summary, waste heat recovery represents a vital opportunity for improving overall energy efficiency and mitigating environmental impact. With continued growth in energy demand, especially in the HVAC sector, it is critical to explore sustainable methods to harness waste heat. Air conditioning units, being ubiquitous in homes and buildings, are ideal candidates for such interventions. Capturing the expelled heat from condenser units and redirecting it for use in processes like drying or preheating water can significantly enhance energy savings while reducing the urban heat burden. This study addresses this potential by proposing a system that utilizes waste heat from air conditioning units to power an air-drying mechanism, aiming to validate the concept through modeling and experimental testing.

Figure 1.1 illustrates the basic concept of waste heat recovery from a split-type air conditioning system. In a typical vapor compression cycle, hot refrigerant gas exits the compressor and flows through the condenser, where it rejects heat to the surrounding air. Instead of allowing this thermal energy to dissipate entirely into the environment, a heat exchanger—often a finned-tube or parallel-pipe design—is integrated near the condenser to capture part of this waste heat. The recovered heat can then be redirected to secondary applications such as preheating ambient air for drying processes or heating domestic water, thereby reducing the need for additional energy input. This concept enhances the overall system efficiency and contributes to sustainable energy use. According to Aridi et al. (2021), heat recovery units in HVAC systems can reclaim up to 60% of waste heat, significantly improving building energy performance. This approach not only reduces environmental impact but also aligns with energy conservation targets and net-zero emission goals by 2050.

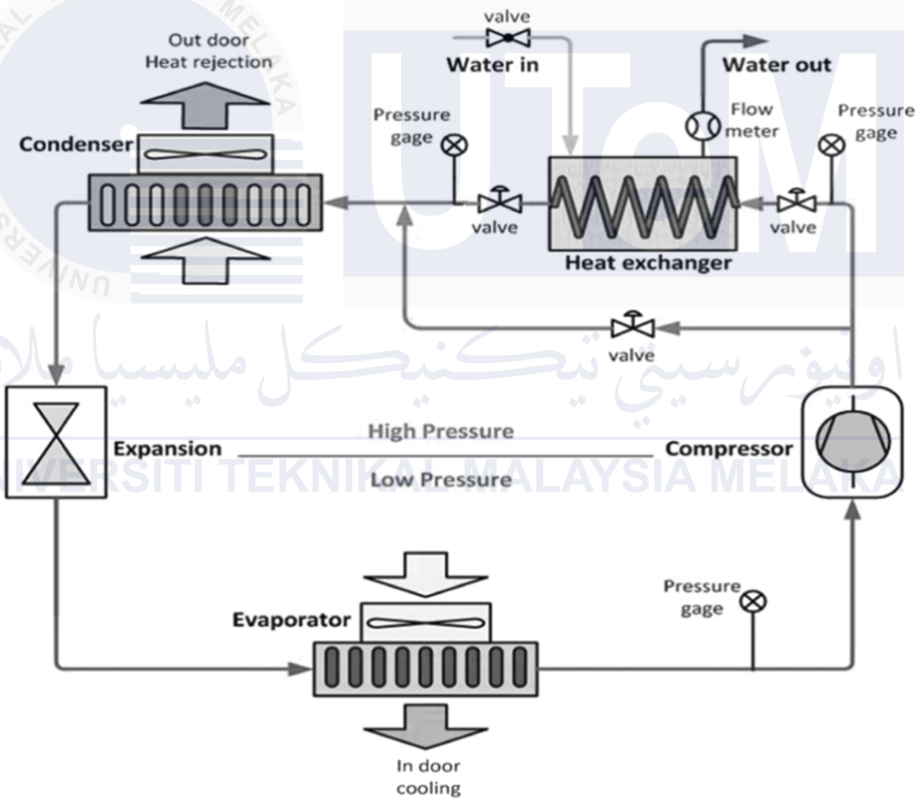

Figure 1.1: Schematic diagram illustrating the waste heat recovery process from an air conditioning system (Aridi et al., 2021)

1.2 Problem Statement

The global shift in climate and the increasing demand for indoor thermal comfort have made air conditioning systems essential in both residential and commercial sectors. As cities continue to grow and outdoor temperatures climb, air conditioners have become indispensable for maintaining acceptable indoor living conditions. However, this reliance on air-conditioning comes with a trade-off: high energy consumption and significant waste heat generation. Most air conditioning systems operate on the vapor compression cycle (VCC), comprising four primary components—compressor, condenser, expansion valve, and evaporator (Alsouda et al., 2023). The compressor increases the refrigerant pressure and temperature, which then releases heat via the condenser to the surrounding environment. This heat rejection, particularly during the day, contributes to environmental warming and energy inefficiency.

A critical and often overlooked issue is the amount of thermal energy wasted during the normal operation of the condenser unit. In cities with dense building coverage and high air-conditioning usage, such as those in tropical climates, the cumulative waste heat released can significantly affect local microclimates. According to Farahani et al. (2021), nighttime ambient air temperatures in some urban environments can rise by up to 1°C due to heat emissions from HVAC systems. This added thermal load not only increases local cooling demand but also perpetuates a feedback loop of energy usage and greenhouse gas emissions. The compounding effects of this phenomenon highlight the urgency of addressing heat waste in HVAC systems.

Several researchers have explored waste heat recovery methods using air-conditioning systems. For example, Ramadan et al. (2015) successfully utilized condenser exhaust air to preheat domestic water, achieving temperature increases from 25°C to 70°C depending on flow rates and cooling loads. Similarly, Gholamian et al. (2020) demonstrated