ISSN 2347 - 3983
Volume 8. No. 10, October 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter1018102020.pdf
https://doi.org/10.30534/ijeter/2020/1018102020

Utilization of Waste Heat Recovery from Domestic HVAC System for Hot Water System

Sharul Nizam Yaakop[1], Muhammad Hafidz Fazli Md Fauadi[2,*], Amir Abdullah Muhamad Damanhuri[3], Ahamad Zaki Mohamed Noor[4], Samad Ramlan[5]
[1,2]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia, Email:[1]sharulnizamhvac@gmail.com, [2,*]hafidz@utem.edu.my
[3]Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia, Email: amir.abdullah@utem.edu.my
[4]System Engineering and Energy Laboratory, Universiti Kuala Lumpur Malaysian Spanish Institute, 09000, Kedah, Malaysia, Email: ahamadzaki@unikl.edu.my
[5]Silterra Malaysia Sdn. Bhd, 09000 Kulim, Kedah, Malaysia, Email: samad_ramlan@silterra.com
* Corresponding author

ABSTRACT

Significant efforts have been taken globally to develop a sustainable environment. Harnessing natural energies from multiple sources including wind energy, hydroelectric, solar energy, geothermal energy, and biomass are the example of renewable energy which often frames as the key solution to the global climate challenge. However, there are other sources of energy wasted due to inefficient technological ability. This includes the heat energy waste from the Heating, Ventilating and Air Conditioning (HVAC) system. It is found that HVAC system contributes to the highest energy consumption for residential, commercial and industrial buildings. Typical energy consumption in a commercial building by the HVAC system is 39%, it is the highest percentage compared to other equipment. It is critical to minimize the waste produced in ensuring sustainable processes could be achieved. To optimize energy consumption efficiency, many waste heat recovery methods have been studied. In this article, an extensive review of state-o-the-art technologies is carried out for the HVAC system in the domestic hot water. For the case of domestic hot water, the space cooling Coefficient of Performance (COP) can be increased when integrated with water heating mode, which can achieve the highest COP of 5.42 when the water at 20°C was heated to 55°C. The COP was increased by 84% compared to space cooling mode only. This paper is summarized in terms of the fundamental idea, methodology, contributions and recommendation for future research.

Key words : Waste Heat, Heat Recovery, Air Conditioning, HVAC System, Renewable Energy.

1. INTRODUCTION

Nowadays, air conditioning usage at residential and industrial become a necessity due to climate change and to get thermal comfort conditions in the building [1]. The Department of Industry from Australia stated that HVAC energy consumption in an office building is the highest which is 39%, followed by 25% of lighting, 22% of equipment, 9% of others, 4% of lifts and 1% of domestic hot water [2]. The energy consumption breakdown is shown in Figure 1.

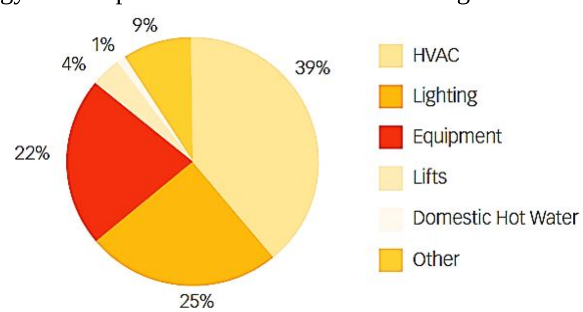


Figure 1: Breakdown of energy consumption for commercial building (office) [2]

Recently, many researchers extensively conduct the study on how to manage the highest energy consumption from the HVAC system in including in the residential, commercial and industrial buildings by recovering the waste energy produced by this system [3] [4]. Waste heat energy is the source of energy that is produced in mechanical processes which are unused and are discarded into the environment [5]. The heat transfer process, including conduction, convection and radiation from machine processes are the main source of the waste heat [6]. There are basically three grades of waste heat energy which are high, medium and low-temperature grades [7]. From the grades of the waste heat, it could be categorized into four classes which are liquid streams (50-300˚C), flue gases (150-800˚C), steam (100-250˚C), and vapour (80-500˚C) [8]. The minimum temperature and maximum temperature for each category are shown in Figure 2.

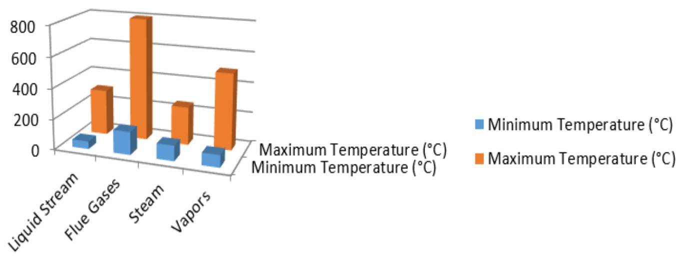


Figure 2: Temperature range for waste heat energy categories

Waste heat recovery (WHR) systems are presented for every variety of waste heat to permit the optimal level of recovery efficiency [9]. There are several WHR systems such as steam Rankine cycle, Organic Rankine Cycle (ORC), Kalina cycle, Brayton cycle, Trilateral flash cycle, supercritical CO_2 power cycle and Stirling cycle [8],[10],[11]. Most of the researches conducted to realize the waste of heat released from the HVAC system deriving from the second law of thermodynamics which is a vapor compression refrigerant (VCR) system. The main focus of this article is to review the state-of-the-art researches conducted on WHR technology from HVAC system. Other than that, the overall findings will be summarized in terms of the fundamental idea, methodology, contributions and recommendation for future research.

2. VAPOUR COMPRESSION CYCLE SYSTEM

2.1 Working Principle

All air conditioning system operates based on vapor compression refrigerant (VCR) system with four fundamental principle component, which is a compressor, condenser, expansion valve and evaporator [12]. There is a huge volume of waste heat from the condenser unit in the VCR system, which is approximately 1.2 times based on the evaporating capacity. Additionally, in some cases such as involving CO_2, the condensing heat generated could reach up to 80°C [13]. Hence, it is compulsory to recover the waste heat to be utilized for relevant useful purposes. This will further enhance the efficiency of the VCR system.

The compressor uses electric power to compress the refrigerant and create high-pressure and high-temperature vapor levels [14]. The compressed refrigerant removes its hotness to the condensing unit and condensed to liquid form [15]. This warmness refrigerant will be regulated to low pressure and low temperature through an expansion valve [16]. Evaporator function to absorb heat in the specified area, which affected of increasing temperature of the refrigerant [17].

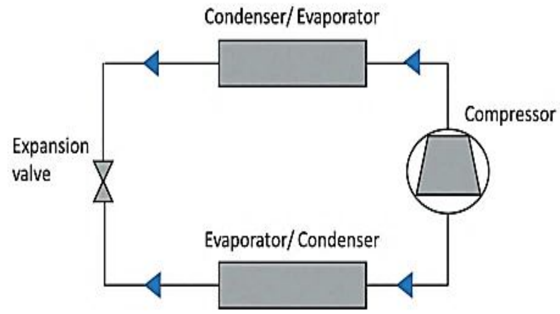


Figure 3: Schematic diagram of basic VCR system [18]

Figure 3 illustrates a basic diagram of the fundamental components in a VCR system. In the VCR system, the hotness refrigerant from the compressor will release heat from the condensing unit, and this waste heat is exposed to an atmospheric air which heats up with constant humidity ratio “w”. Generally, this hot air is discharged into the surrounding without any recovery to useful application. In order to reduce the discharge, a technology for waste heat recovery must be used to capture this issue.

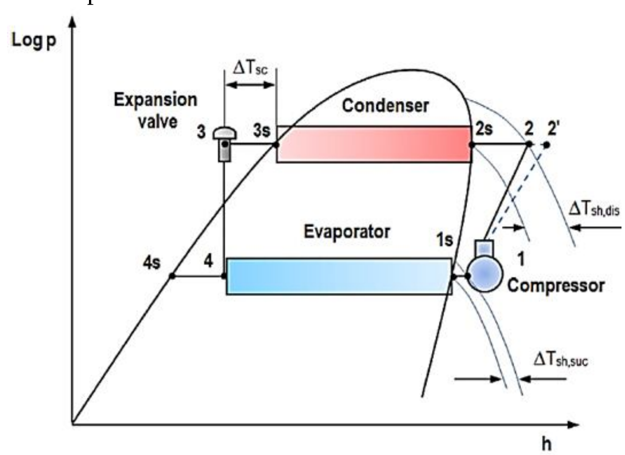


Figure 4: The p-h diagram for VCR system [19]

Based on the Figure 4, compression cycle can be seen starting at point 1 (low-pressure; low temperature refrigerant) to point 2 (high-pressure; high temperature refrigerant), point 2 to point 3 (from vapor to liquid), point 3 to point 4 (low temperature), point 4 return to point 1 and the cycle repeated in a closed-loop system. Hot air rejected at condenser side from point 2 to point 3 can be used for energy recovery system to increase the efficiency of the vapor compression system and to take full advantage of the energy usage for the cooling system at evaporator side in the conditioned area.

2.2 Evaporator

During a process of heat transfer, the rate of capacity, $\dot{Q}_e$ is given by:

$$\dot{Q}_e = \dot{m}(h_1 - h_4) \tag{1}$$

where $\dot{m}$ is the mass flow rate of refrigerant in kgs^{-1}, h_1 is the specific enthalpies at the outlet of an evaporator, and h_4 is the specific enthalpies at the inlet of an evaporator.

2.3 Compressor

After refrigerant passed through the evaporator, it will go to the compressor. The input power for the compressor, $\dot{W}_C$ is given by:

$$\dot{W}_C = \dot{m}(h_2 - h_1) \tag{2}$$

where h_1 is the specific enthalpies at the inlet of the compressor and h_2 is the specific enthalpies at the outlet of the compressor.

During the refrigerant cycle at any phase, the refrigerant mass flow rate $\dot{m}$ can be written by using mass flow rate equation at the suction point in terms of specific volume and volumetric flow rate.

$$\dot{m} = \frac{\dot{V}_1}{v_1} \tag{3}$$

where $\dot{V}_1$ is the volumetric flow rate at the suction point of the compressor and v_1 is the specific volume at the same point.

Ratio of the compression at the compressor is presented by:

$$\varepsilon = \frac{P_c}{P_e} \tag{4}$$

where P_c is the absolute pressure of condensing and P_e is the absolute pressure of evaporating.

The compressor's volumetric efficiency is:

$$\eta_v = \frac{\dot{m}_r v_1}{v_C \eta / 60} \tag{5}$$

where V_c is the compression volume of compressor and η is the speed of the compressor.

Isentropic efficiency of the compressor is given by:

$$\eta_v = \frac{\dot{W}_S}{\dot{W}_C} \tag{6}$$

where $\dot{W}_s$ is the isentropic work produced by the compressor.

2.4 Condenser

The high-pressure refrigerant from the compressor will be cooled by the condenser unit. The heat transfer rate at this stage, $\dot{Q}_c$ is defined by:

$$\dot{Q}_C = \dot{m}_r (h_2 - h_3) \tag{7}$$

where h_2 is the specific enthalpies at the inlet of the condenser and h_3 is the specific enthalpies at the outlet of the condenser.

2.5 Expansion Valve

During the expansion process at the specific device, it is expected to have no heat transfer occur to the surrounding area and the change in potential energy and kinetic energy are negligible. Therefore, this condition come out with the following expression:

$$h_3 = h_4 \tag{8}$$

The coefficient of the performance for the vapor compression cycle system is the ratio between the evaporator load with the power of the compressor:

$$COP = \frac{\dot{Q}_e}{\dot{Q}_c} \tag{9}$$

The coefficient of performance for the electric power input is the ratio between the evaporator load with the total power consumption of the electric power in the system:

$$COP_{el} = \frac{\dot{Q}_e}{\dot{W}_{el}} \tag{10}$$

where $\dot{W}_{el}$ is the total of electric power inputs generate to the compressor, condenser fan motor and evaporator fan motor.

3. HEAT RECOVERY TECHNOLOGY FROM CONDENSING UNIT

3.1 Introduction

In a VCR system, the condensing unit plays their roles as to reject heat from a refrigerant in the condensing process. It produces very much of waste heat which is about 1.15 to 1.25 times of the cooling effect in the evaporator side [20]. This percentage is more significant due to heat of compression is added into the system. The real proportion that arises be subject to on the discharge temperature and suction temperature. High discharge temperature and or low suction temperature will increase the percentage, respectively.

Recently, there has been significant increase in the amount of literature to discover the energy-efficient and industrial technology by using heat recovery from the condensing unit. This is widely reported and extensively explored in the previous literature conducted to deliver domestic hot water by using, directly and indirectly method, and heat recovery for air dryer chamber as shown in Figure 5. The fundamental of these technologies are similar in which to collect, recover and convert heat with latent energy with respect to specific application.

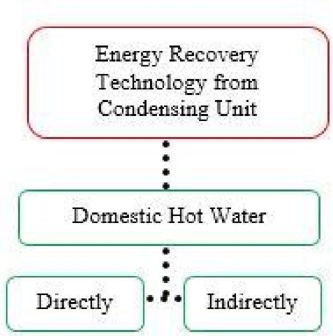


Figure 5: Recent literature review for energy recovery technology from condensing unit

3.2 Domestic Hot Water

During the summer season, most of the residential building should stipulate two conventional independent systems which are air cooling and water heating. Air cooling was produced from an air conditioning system that dissipates the waste heat into the surrounding area. The water heating was produced from the hot water application system. Individual heaters powered by electric or fuel gas are commonly used to generate domestic hot water within residential buildings, particularly during the peak hours [21].

Based on several researches, it is acknowledged that the dissipating heat from the air-conditioning system can be recovered to replace the conventional electric water heater. This recovery system can encounter the demand for regular hot water in residential, commercial and industry to gain energy saving. Domestic hot water can be recovered either directly or indirectly when there is thermal energy storage available.

3.3 Direct Domestic Hot Water

Figure 6 shows that the hot water supply to users being heated directly by the waste heat produced at condenser in the heat recovery equipment [13].

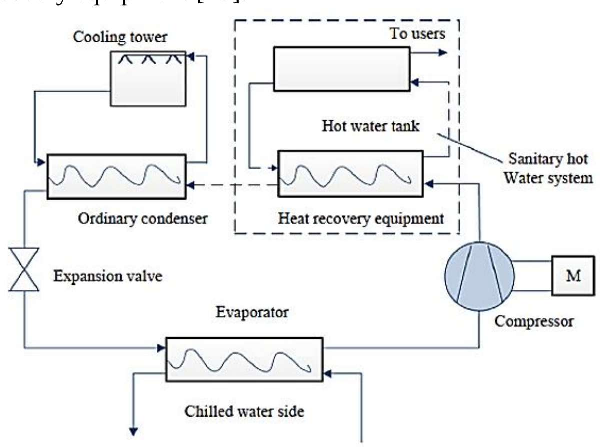


Figure 6: Schematic of a vapour-compression refrigeration cycle with direct heat recovery [13]

Early in the sixties [23], there is an investigation showed that the heat recovery room-air conditioner (HRAC) could provide energy-saving possible and permitted a reimbursement period to end-user. Start from that, many kinds of research attractive to do investigation and experimental in the waste heat recovery system.

Their experimental and mathematical outcomes showed that the total heat recovering from the condensing unit could be reclaimed is about 20% from domestic hot water and the COP of the application is improved. [24] investigated on an air-water heat pump working with a conventional air-conditioner, the outcomes found that the COP of the air conditioning system has improvement of about 10% as shown in Figure 7.

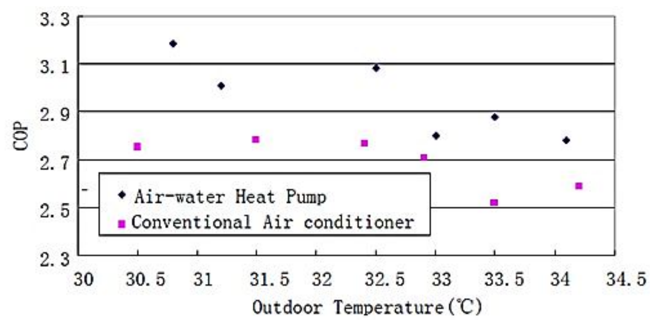


Figure 7: COP between the air-water heat pump and conventional air-conditioner [22]

The result has shown that when the conventional air conditioner running with an outdoor temperature range from 30.5°C to 31°C the COP will be 2.8 while using an air-water heat pump, the COP will be increasing to 3.2. The most significant observation from their study is the COP of the air-water heat pump will start decreased remarkably after the typical temperature level in the tank reach 35°C. This is an area or issue that requires further exploration. In order to preserve the higher COP of the system while getting an average temperature of the water tank at 35°C and above, the water tank must be installed with the thermal energy storage material.

Several studies have explored the effects of cooling load toward hot water temperature and air conditioning performance [23]. The outcomes illustrated that the higher the cooling capacity is specified in the test compartment, the higher the evaporator will absorb the heat. As a result, the higher the water temperature in the tank and the COP of the air conditioning becomes increasing, as shown in Figure 8. In summary, this novel study shows that air conditioning can be working with water heating so that water heating and space cooling can occur concurrently, and the system efficiency can be improved significantly.

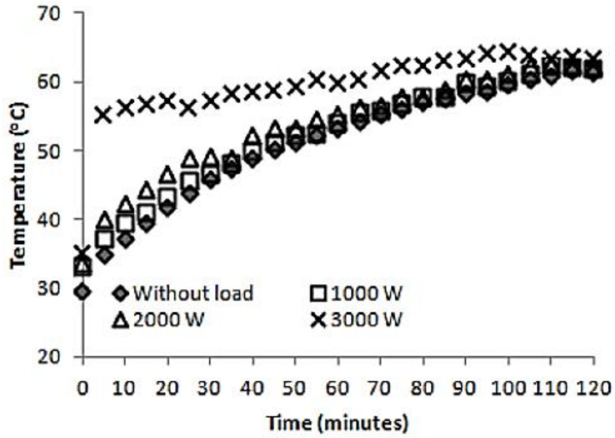


Figure 8: Water temperature in a tank vs time at different cooling load [23]

A pilot studied was conducted on a water heater (MDACWH) integrated with conventional domestic air conditioner [24]. The experimental study was carried out with a prototype modified from conventional air conditioning, with additional accessories of a plate type heat exchanger. The nominal cooling capacity of an air conditioning unit used for the prototype is 3.3 kW and a refrigerant by using R22 gas. In order to select the domestic hot water tank, there are several criteria to be considered, such as cooling capacity, usage time per day and residents living behaviors. In this experiment, the 100L cylinder type of hot water tank was selected as it is enough for the hot water necessity of a nuclear household. Figure 9 shows the schematic diagram for a conventional domestic air conditioner combined with the hot water system.

Based on Figure 9, there are two condition tests in the experiment. Condition A will remain the air conditioning system running as a regular operation. The condenser heat after compressor will go through a plate heat exchanger, pass through the outdoor condenser coil, expand in capillary 1 and absorb heat at indoor evaporator unit before return to the compressor as one complete cycle. The water pump will circulate water in a hot water tank to heat exchanger plate type to rise the water temperature. Condition B has additional bypass 1 and bypass 2 as a technical idea in the experiment.

Air conditioning system will be running in the others way, which is condenser heat after plate heat exchanger will straight away go through capillary 1 instead of going through the outdoor condenser coil. Once the temperature in the water tank achieves 42°C, the water pump will shut off to minimize power consumption. Refrigerant gas will flow through their regular operation as condition A. The new capillary tube 2 at bypass 1 function as to deliver the refrigerant stuck in the condenser coil return to oil separator continuously. This method will ensure that the amount of refrigerant return to the compressor is enough.

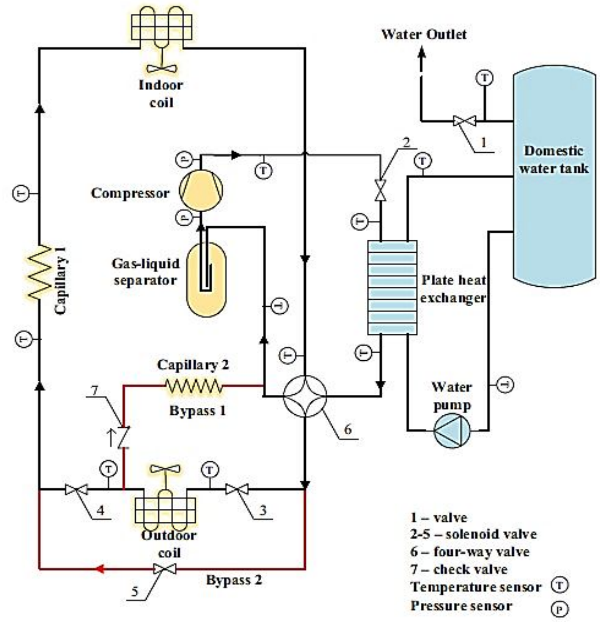


Figure 9: Schematic of MDACWH

After rigorous examination, it was discovered that the low heating capacity for domestic water could reach 2699W in condition B. Other than that, the coefficient of performance for the air conditioning increase to 4.32, which was about 1.58 higher than condition A. For complete water heating process, the condition B consumed 0.38kWh of electricity, which was only 16% of the electricity consumed by condition A as shown in Figure 10.

The most recent and advanced theory proposed by [27] offers a new approach for the energy recovery is a domestic condensing heat recovery air conditioning (DCHRAC). The experimental for the proposed system was set up as per the schematic diagram shown in Figure 11. The working principle for DCHRAC was designed for four working principle which is the space heating, space cooling, CHR for water-heating mode and an air–based water heating mode.

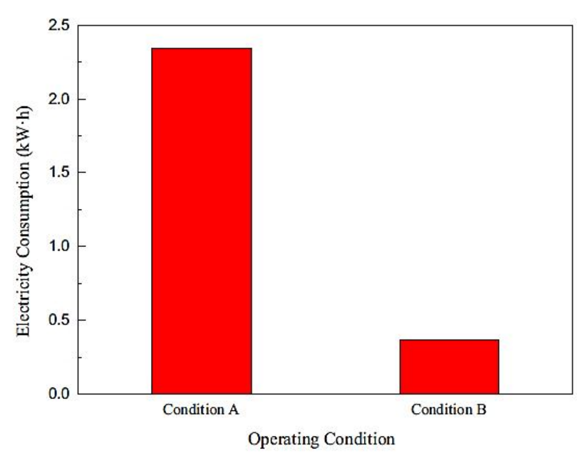


Figure 10: Electricity consumption of Conditions A and B [24]

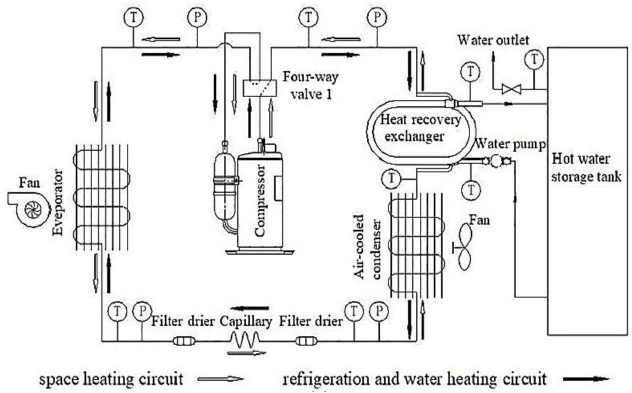


Figure 11: Schematic diagram of DCHRAC [25]

In water heating mode by using heat recovery from the condenser, the refrigerant flows in two ways, which are in hot water and space cooling concurrently required as shown in Figure 11 as a solid arrow. The operating system of this mode will bring the high-pressure vapor and high temperature vapor released from the compressor into the heat recovery exchanger to heat the water while the condenser fan will off. After that, the refrigerant will further be cooled in the air-cooled condenser unit and running to capillary tube and evaporator before completing their cycle return to the compressor. The nominal cooling capacity of an air conditioning unit used for the prototype is 3.4 kW with R22 gas as the refrigerant. Hot water tank use in this experiment is 150L with a supreme working pressure of 0.6MPa was design to encounter the everyday hot water usage for a typical household. The external insulation of the water tank was insulated by a polystyrene foamed plastic with 50mm thickness and finishing cladding by a plate of stainless steel to keep the thermal energy of the heated water.

From the results shown in Figure 12, it is clear that the water heating mode by condensing heat recovery, the average COP_{wh} = 2.58. The COP_{sc} = 2.84, with the total coefficient of performance COP_{cw} rise to 5.42, and the waste heat recovery rate was around 95%. The experimental outcomes showed that the DCHRAC could be functioned compliantly in several modes conditional on user demands.

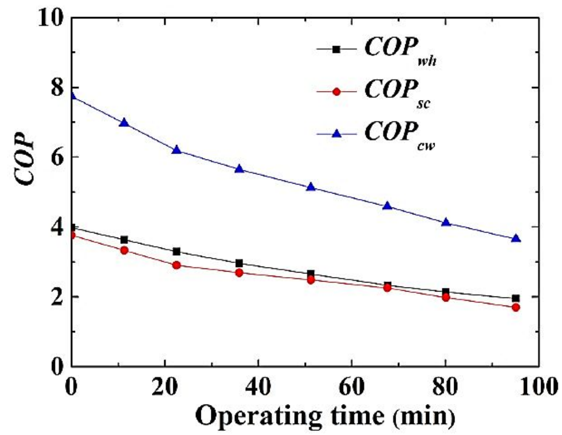
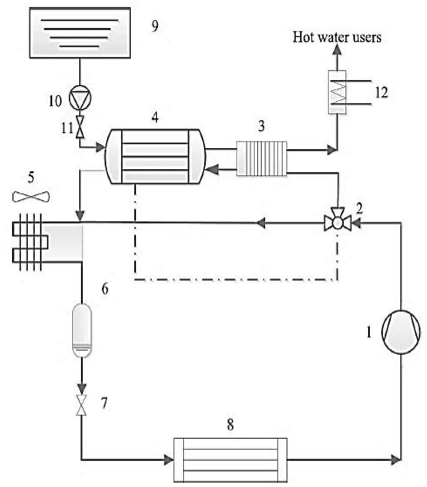


Figure 12: COP variants for water heating mode [25]

3.4 Indirect Domestic Hot Water

Air conditioning frequently using by end-users as a solution for human thermal comfort and indoor air quality [26]. The highest peak load for cooling will occur around noon and the hot water usage mostly required in the evening. The mismatch of the usage of air conditioning integrated with the hot water will cause the heat recovery from air conditioning to produce hot water will entirely depend on the cooling load. This phenomenon has been widely observed in the domestic hot water system with the direct method. In order to solve the issues, thermal energy storage (TES) was proposed by the recent researcher [27]. Latent heat thermal energy storage (LHTES) including phase change material (PCMs) has excellent potential to address the intermittency and instability issues typically occur during energy recovery process [28] [29]. By using PCMs, a huge amount of energy recovered from air conditioning could be kept to deliver domestic hot water [30]. Figure 13 illustrates the schematic of the air conditioning system with condensing heat recovery of the indirect method.

Recently, an experimental work was conducted by using paraffin wax as PCMs for charging and discharging to relate air conditioning with and without the combination of the thermal energy storage vessel [32]. Other than that, [33] designed cold storage for waste heat recovery from the condenser unit with a combination of PCMs. They established few innovative materials with huge latent heat and advanced thermal conductivity. Moreover, an additional phase change temperature is obtained. The latest researcher focused on using thermal energy storage equipped with phase change materials as a medium to enhance the COP of the air conditioning system [31]–[32].



1-Compressor, 2-Three-way valve, 3-Higher temperature accumulator (accumulator 1), 4-Lower temperature accumulator (accumulator 2), 5-Cooling tower, 6-Liquid storage tower, 7-Valve, 8-Evaporator, 9-Tap water tank, 10-Water pump, 11-Tap water valve

Figure 13: The schematic of an indirect condensing heat recovery for air conditioning system [13]

3.5 Summary of Domestic Hot Water

In summary, the air conditioning system is the most application used by the end-users. This application contributes to harms the environment by released hot air temperature from the condensing unit. The waste heat generates in the air conditioning can be recycled for another useful application such as to heated water for everyday hot water usage. To recoup the waste heat from the air condition for hot water, there are two ways either directly or indirectly method. Air conditioning system integrated with the domestic hot water system can enhance the system energy and performance efficiency.

The disadvantages of this integrated system are there is the mismatch of the demand for both systems. To solve this issue, an indirect domestic hot water system was proposed. In the indirect method, thermal energy storage was used to keep the heat generated from the application. Phase change materials were developed excellently for condensing heat storage. However, continuous researches should focus on investigating the complex system with PCMs as the thermal energy storage medium in to further enhance the performance. Table 1 shows the summary of related studies on generating domestic hot water from waste heat recovery process.

5. CONCLUSION

In order to encounter the challenges of speedily growing cooling load demand by users, it is vital to enhance the performance and the efficiency of vapor compression refrigeration systems (VCRS). Besides, it is critical to minimize the power consumption produced by the speedy surge of cooling load demand. In order to enhance the performance and the efficiency of the VCRS, waste heat from the condensing unit of VCRS must be recycled to use for other applications such as domestic hot water process. As a result of the previous study, all experiments conducted have success to raise the COP of the VCRS.

Research gap found from the previous research is the application type of VCRS used as waste heat recovery sources mainly focus on conventional air conditioning system. In HVAC technology, the household also considers as the HVAC system because it uses the same VCRS cycle. Moreover, for applying the hot water recycle technology by waste heat for residential, it is more effective by using a household refrigerator because of the use of refrigerator already a necessity for every house. Cooling and freezing process for beverage can be used with hot water system that can take place concurrently, and the system performance and efficiency of the refrigerator can be increased significantly.

Table 1: Summary of related researches

Authors	Contributions	Remarks
Wang et al. [22]	Observation of a conventional air-conditioner used as an air-water heat pump. The outcomes showed that the COP of the air conditioning system has been improved by 10%.	The COP of the air-water heat pump will start to decrease after the average temperature in the water tank become 35°C.
Aziz & Satria [23]	Investigation on the effects of cooling load toward hot water temperature and air conditioning performance. The system performance increases when the cooling load was increasing.	The temperature of the hot water fluctuates and depends on the cooling load. No condensing heat can be heated the water when the compressor cut off after cooling load demand achieves in a conditioned area.
Dong et al. [24]	Experimental results prove that the air conditioning system can be integrated with water heating for domestic usage. The COP of the air conditioning can increase up to 4.32, and the electricity consumption can save up to 84% compared to a conventional air conditioning system.	An in-depth technical study needs to be considered in the future work for the heat exchanger type, which may affect the compressor lifetime. The proposed prototype more suitable for inverter compressor instead of a fixed compressor due to cooling load and heating load will fluctuate significantly.
Qiu et al. [25]	The space cooling COP can be increased when integrated with water heating mode, which can	The flash gas or vapour content will continue to increase with the progression of time that

Authors	Contributions	Remarks
	achieve the highest COP of 5.42 when the water at 20°C was heated to 55°C. The COP was increased by 84% compared to space cooling mode only.	proves when water temperature increases, it leads to a decrease in the degree of supercooling.

ACKNOWLEDGEMENT

The authors thank Universiti Teknikal Malaysia Melaka in enabling and facilitating the research.

REFERENCES

[1] W. Wei *et al.*, **Energy & Buildings Energy consumption , indoor thermal comfort and air quality in a commercial office with retrofitted heat , ventilation and air conditioning (HVAC) system**, *Energy Build.*, vol. 201, pp. 202–215, 2019.

[2] Aus Govt - Department of Industry, **HVAC Energy Breakdown**, no. January 2012, pp. 36–37, 2013.

[3] T. Li, M. Alavy, and J. Siegel, **Measurement of residential HVAC system runtime**, *Build. Environ.*, 2019.

[4] C. Yue, L. Tong, and S. Zhang, **Thermal and economic analysis on vehicle energy supplying system based on waste heat recovery organic Rankine cycle**, *Appl. Energy*, vol. 248, no. January, pp. 241–255, 2019.

[5] D. Brough and H. Jouhara, **The aluminium industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery**, *Int. J. Thermofluids*, vol. 1–2, February 2020, 100007p., 2020.

[6] H. Jouhara, N. Khordehgah, S. Almahmoud, B. Delpech, A. Chauhan, and S. A. Tassou, **Waste heat recovery technologies and applications**, *Therm. Sci. Eng. Prog.*, vol. 6, no. January, pp. 268–289, 2018.

[7] K. Shin, J. Lee, T. Lee, D. Sim, and D. Jung, **Heat energy harvesting by utilizing waste heat with small temperature differences between heat source and sink**," vol. 34, no. 1, pp. 443-455, 2020.

[8] A. Mahmoudi, M. Fazli, and M. R. Morad, **A recent review of waste heat recovery by Organic Rankine Cycle**, *Appl. Therm. Eng.*, vol. 143, no. July, pp. 660–675, 2018.

[9] L. Shi, G. Shu, H. Tian, and X. Wang, **Assessment of waste heat recovery system for automotive engine with weight effect**, *Energy*, vol. 193 no. 15, 116663, 2020.

[10] J. Milewski and J. Krasucki, **Comparison of ORC and Kalina cycles for waste heat recovery in the steel industry**, *J. Power Technol.*, vol. 97, no. 4, pp. 302–307, 2017.

[11] C. Toro and N. Lior, **Analysis and comparison of solar-heat driven Stirling, Brayton and Rankine cycles for space power generation**, *Energy*, vol. 120, pp. 549–564, 2017.

[12] R. Hart, **Introduction to Commercial Building HVAC Systems and Energy Code Requirements**, *Pacific Northwest National Lab.*, 2016.

[13] X. She *et al.*, **Energy-efficient and -economic technologies for air conditioning with vapor compression refrigeration: A comprehensive review**, *Appl. Energy*, vol. 232, pp. 157–186, 2018.

[14] T. Aized and A. Hamza, **Thermodynamic Analysis of Various Refrigerants for Automotive Air Conditioning System**, International Institute of Refrigeration," *Arabian Journal for Science and Engineering*, vol. 44 no. 2, pp. 1697-1707, 2019.

[15] X. Luo *et al.*, **Mathematical modelling and structural optimization of a micro-channel liquid separation condenser in organic Rankine cycle and refrigeration cycle**, vol. 152, no. 100, pp. 231–246, 2019.

[16] H. R. Takleh and V. Zare, **Performance improvement of ejector expansion refrigeration cycles employing a booster compressor using different refrigerants : Thermodynamic analysis and optimization**, *International Journal of Refrigeration*, vol. 101, pp. 56–70, 2019.

[17] S. K. Wang, **Air Conditioning Systems: System Classification, Selection, and Individual Systems**, *Handbook of Air Conditioning and Refrigeration*, 26-1, 2001.

[18] H. El Hage, M. Ramadan, H. Jaber, and M. Khaled, **Environmental Effects A short review on the techniques of waste heat recovery from domestic applications**, *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 42, no. 24, pp. 3019-3034, 2019.

[19] N. Kocyigit, H. Bulgurcu, and C. X. Lin, **Fault diagnosis of a vapor compression refrigeration system with hermetic reciprocating compressor based on p-h diagram**, *Energy Econ.*, vol. 45, pp. 44–54, 2014.

[20] A. Bhatia, **Heat Rejection Options in HVAC Systems,** *Continuing Education and Development, Inc*, 2012.

[21] M. Ravina, C. Gamberini, A. Casasso, and D. Panepinto, **Environmental and Health Impacts of Domestic Hot Water (DHW) Boilers in Urban Areas : A Case Study from Turin**, **NW Italy**, *International Journal of Environmental Research and Public Health*, vol. 17 no. 2, p.595, 2020.

[22] Y. Wang, Y. You, and Z. Zhang, **Experimental investigations on a conventional air-conditioner working as air-water heat pump**, *Procedia Eng.*, vol. 23, pp. 493–497, 2011.

[23] A. Aziz and A. B. Satria, **Performance of Air Conditioning Water Heater with Trombone Coil Type as Dummy Condenser at Different Cooling Loads**, *Proceeding 1st Int. Conf. Ocean. Mech. Aerospace Science Eng.*, vol. 1, no. March, pp. 150–154, 2014.

[24] J. Dong, H. Li, Y. Yao, Y. Jiang, and X. Zhang, **Experimental study on the performance of a multi-functional domestic air conditioner with integrated water heater**, *Applied Thermal Engineering*, vol. 120, pp. 393–401, 2017.

[25] F. Qiu, B. Li, and T. Xu, **Experimental investigations on the thermal performance of a domestic condensing heat recovery**, *Advances in Mechanical Engineering*, vol. 11, no. 2, p. 1687814018822349, 2019.

[26] G. Papadopoulos, G. Panaras, and E. Tolis, **Thermal comfort and Indoor Air Quality assessment in university classrooms**, *IOP Conference Series: Earth and Environmental Science,* vol. 410, no. 1, p. 012095, IOP Publishing 2020.

[27] S. Höhlein and D. Brüggemann, **Detailed exergetic analysis of a packed bed thermal energy storage unit in combination with an Organic Rankine Cycle**, *Appl. Therm. Eng.*, vol. 165, p.114583, 2020.

[28] J. Yang, L. Yang, C. Xu, and X. Du, **Experimental study on enhancement of thermal energy storage with phase-change material**, *Appl. Energy*, vol. 169, pp. 164–176, 2016.

[29] B. Nie, X. She, B. Zou, Y. Li, Y. Li, and Y. Ding, **Discharging performance enhancement of a phase change material based thermal energy storage device for transport air-conditioning applications**, *Appl. Therm. Eng.*, vol. 165, p. 114582, 2020.

[30] A. Safari, R. Saidur, F. A. Sulaiman, Y. Xu, and J. Dong, **A review on supercooling of Phase Change Materials in thermal energy storage systems**, *Renew. Sustain. Energy Rev.*, vol. 70, no. July, pp. 905-919, 2017.

[31] M. A. Said and H. Hassan, **Effect of using nanoparticles on the performance of thermal energy storage of phase change material coupled with air-conditioning unit**, *Energy Convers. Manag.*, vol. 171, pp. 903–916, 2018.

[32] M. A. Said and H. Hassan, **Parametric study on the e ff ect of using cold thermal storage energy of phase change material on the performance of air-conditioning unit**, *Appl. Energy*, vol. 230, pp. 1380–1402, 2018.

[33] A. Aziz, I. Mainil, and K. Mainil, **Comparative Study of Residential Split Air Conditioner as Water Heater (RSACWH) Using R-22 and HCR-22 Refrigerant**, The 2nd International Conference on Ocean, Mechanical & Aerospace -scientists & engineers (OMASE 2015), 23 -24 November 2015, Pekanbaru, Indonesia, 2015.