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REVOLUTIONIZING RESIDENTIAL REFRIGERATION: BOOSTING EFFICIENCY WITH CUTTING-EDGE WASTE HEAT RECOVERY SYSTEMS FOR ENHANCED COP OF REFRIGERATOR

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Abstract
The purpose of this research paper is to investigate the design and development of a waste heat recovery system aimed at improving the coefficient of performance (COP) of residential refrigerators. Domestic refrigerators are common household equipment, and increasing their energy efficiency is critical for lowering energy consumption and environmental effects. In this paper, we present a unique waste heat recovery system that captures excess heat generated by the refrigerator's chilling cycle and uses it to improve the appliance's overall efficiency. The theoretical background, design considerations, and practical implementation of this waste heat recovery system are all covered in the manuscript. We hope to raise the COP of household refrigerators by properly utilizing waste heat, consequently reducing energy consumption and running expenses for consumers. Also discuss the environmental benefits of reduced energy consumption, making this research extremely relevant in the context of sustainability and energy conservation. Demonstrate the possibility for large increases in the efficiency of residential refrigerators through experimental results and performance evaluations. This study adds to the development of environmentally friendly household appliances and provides a possible route for increasing energy efficiency in the residential sector.

Keywords:
WHRS, 165-liter Domestic refrigerator, air-cooled condenser, Experimental analysis, COP of a refrigerator.

I. Introduction

Waste heat typically encompasses the energy content within effluents of air, gases, and liquids that exit a system and disperse into the environment. When waste heat is expelled from a process at a temperature significantly above the ambient conditions, it offers an opportunity to economically recover energy for practical applications. The significance of heat lies not only in its quantity but also in its utility. Waste heat recovery and utilization refer to the practice of capturing and repurposing waste heat for beneficial uses. In their study on waste heat recovery systems (WHRS) within refrigeration units, Kaushik and Singh [1] conducted experiments to determine the practicality of heat recovery. They established that, under typical operating conditions, a notable 40% of condenser heat could be effectively harnessed through the utilization of the Canopus heat exchanger. In their investigations of waste heat recovery (WHR) from air conditioning systems, Shrinivasan [2, 3] demonstrated the feasibility of recovering and utilizing energy without compromising comfort levels. Their studies also established the economic viability of such systems. Furthermore, reducing energy consumption and minimizing environmental pollution can be achieved by the implementation of energy-efficient equipment. Additionally, F.N.Yu and K.T.Chan [4] explored advancements in condenser design for air-cooled chillers.This study looks at a Waste Heat Recovery System (WHRS) that is meant to collect condensation heat from a 165-liter household refrigerator. Refrigeration machines typically emit a significant quantity of heat into the atmosphere via their condenser coils. This waste heat is absorbed and recycled by strategically incorporating the WHRS within the device. It performs a variety of purposes, including warming snacks and meals, heating water for use in

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healthcare facilities, schools, and industrial processes, assisting in can washing at dairy plants via hot condensate, and facilitating the drying of garments, cereals, and other materials. This multimodal strategy considerably contributes to energy conservation.

Refrigeration plants are used by industrial and commercial businesses of various sizes and industries to reduce the temperature of buildings. Refrigeration is also used in the food business for the manufacture and storage of food and beverages. To conduct energy, exergy, and economic analysis. Then, important cycle parameter include the fact that, in order to recover heat from the refrigerator using WHRS technology, the steam rankine cycle is typically applied [10].

Heat recovery technology can be retrofitted to existing plants, or corporations might design new plants with heat recovery built in. In both circumstances, the method enables the reuse of waste heat for space heating or water mechanical behavior of the material can change the refrigeration using the GA method [11, 12].

The investment cost varies depending on the size of the system, but even on smaller units, businesses may repay their costs in less than five years. For example, the installation of heat recovery equipment for a 200kW chiller would cost around Rs 8, 00,000. Assuming the chiller runs for 3,000 hours per year at current petrol prices, the recovered heat might save Rs 4, 32,000, resulting in a return on investment in less than two years. Similarly, the installation of a new 150kW chiller with full heat recovery would cost roughly Rs 20, 80,000. Running under the same working hours as previously suggested, this configuration might save Rs 10, 80,000 and pay for itself in about two years.

The refrigeration cycle includes a heat dissipation phase that cools the refrigerant before it is recycled inside the system. During the condensation process, heat is released, providing an opportunity for recuperation and reutilization. This guidebook is designed primarily for refrigeration systems that use compressors to improve refrigeration efficiency rather than absorption chillers. The availability of either high or low-grade heat is dependent on the installation configuration and refrigerant used.

1.1 System description

The major goal of the proposed system is to effectively harness a greater amount of exergy, notably waste heat. Extensive calculations were performed to determine the appropriate size and length of the condenser, resulting in the design of a Waste Heat Recovery System (WHRS). However, after a series of conversations and rigorous heat transfer rate calculations, the project evolved into the final concept: an insulated cabin with a small design and a fair price. A novel strategy was used to maximize heat extraction while minimizing heat losses. The installation of two air-cooled condenser sections, one at the bottom and one at the top of the insulated cabin, which sits atop the refrigerator, was required. This ingenious design has the advantage of trapping the most heat with the least amount of energy loss.

The Waste Heat Recovery System (WHRS) has been divided into three distinct portions for analytical purposes, namely "A," "B," and "C".

SECTION “A”- HEAT EXCHANGER, SECTION “B”- OVEN, SECTION “C”- PIPE

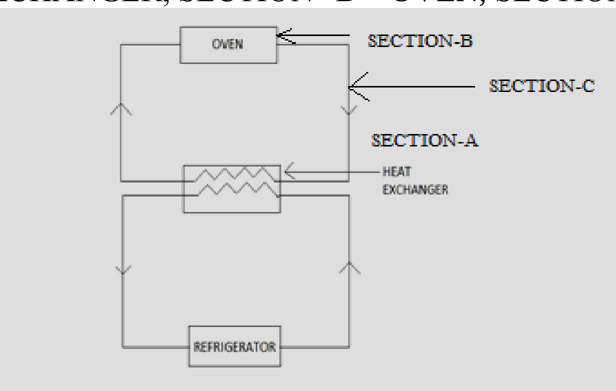

Figure 1: Section model of WHRS of Domestic Refrigerator

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II. Refrigerator

A refrigerator, sometimes known as a refrigerator, is a common household appliance that consists of an insulated compartment and a heat pump mechanism that can be mechanical, electronic, or chemical. The objective of this heat pump is to transport heat from inside the fridge to its surrounds, resulting in the refrigerator's interior being cooled to a temperature that is less than the room's average. In developed nations, refrigeration plays a significant role in the preservation of food. The cooler temperature within the fridge slows the growth of bacteria, extending the shelf life of food. Refrigerators are built to keep a temperature a few degrees over the freezing point of water, as seen in Figure 2. Perishable goods should be stored at temperatures ranging from 3 to 5 degrees Celsius (37 to 41 degrees Fahrenheit).

A freezer is a comparable appliance that functions at temperatures below the freezing point of water. Refrigerators replaced iceboxes, which had been a standard domestic appliance for about one hundred and fifty years before their introduction.

The refrigeration cycle includes a heat dissipation phase that cools the refrigerant before it is recycled inside the system. During the condensation process, heat is released, providing an opportunity for recuperation and reutilization. This handbook is mainly intended for refrigeration systems that, instead of using absorption chillers, increase refrigeration efficiency by use of compressors. The installation layout and refrigerant type determine whether high-grade or low-grade heat is available.

Figure 2: Domestic Refrigerator

2.1 Principle

The principle of refrigeration is straightforward the object to be cooled is continuously surrounded by a cooler liquid. As it flows, it absorbs heat from the object. In the illustration, a cold liquid is poured over an apple that has to chill as in Figure 3. Because of the temperature differential, the heats the refrigerant liquid. As a result, the refrigerant absorbs heat from the apple and warms up.

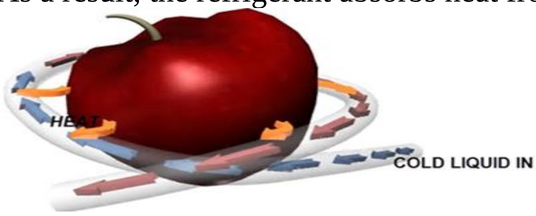

Figure 3: Sensation of refrigeration [3]

The essential premise of refrigeration technology, as represented in Figure 3, is the continual creation of cold liquid refrigerant to permit uninterrupted refrigeration. This fundamental principle is

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supplemented by adherence to the second law of thermodynamics, as established by Clausius and Kelvin-Plank assertions. It is vital to note that in refrigeration, external activity is required to generate the desired cooling effect.

2.2 Constituents of Refrigerator and Working

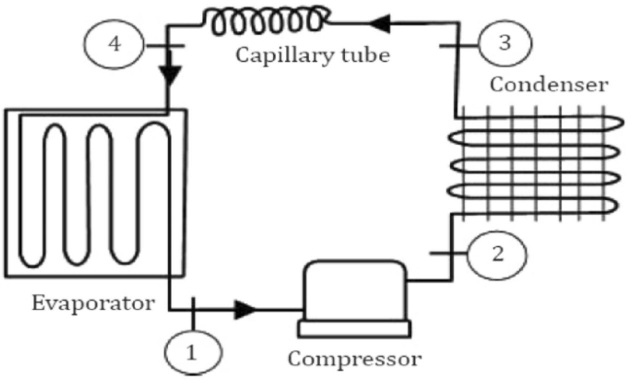

Figure 4: Diagram of a Domestic refrigerator in line [6]

The compressor, condenser, evaporator, and throttling device are the refrigerator's four essential components. Among these components, the throttling device is critical in producing the cold liquid required for the refrigeration process. As a result, our initial focus will be on a thorough examination of the throttling mechanism, followed by an examination of the operation of the remaining components.

2.3 Throttling Device

The throttling device helps to produce cold liquid by slowing the flow of liquid. In this instance, the throttling mechanism is a capillary tube that, as shown in Figure 4, has an internal diameter of around 0.6 millimetres and an approximate length of 2 metres. This tube significantly restricts the liquid's ability to travel through.

Figure 5: Throttling device [2]

To achieve effective throttling at the inlet, it is essential for the refrigerant to exist as a high-pressure liquid. When the refrigerant encounters the throttling device, it experiences a significant pressure reduction, leading to a lowered boiling point and subsequent vaporization. The energy needed for this phase change is drawn from the refrigerant itself, causing it to release heat and consequently lower in temperature. This temperature drop is evident when observing the temperature gradient across the throttling device. It is inaccurate to describe throttling as a distinct process. We can only define its initial and final states, that is, the conditions before and after throttling. The intermediate states remain uncertain due to the highly irreversible nature of this transformation. Therefore, it is more accurate to characterize throttling as a phenomenon rather than a process.

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2.4 Evaporator

The following phase is quite easy: while the refrigerant absorbs heat, the cold liquid is directed over the target location to aid in cooling. The refrigerant evaporates as a result of this heat absorption. further, converting it to pure vapour. An effective heat exchanger, known as an evaporator, is required to transport the cool refrigerant across the target region is shown in Figure 6.

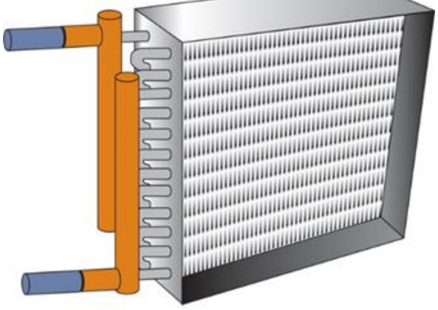


Figure 6: Refrigerator Heat Exchanger Process through Evaporator [6]

After achieving the desired cooling effect, the capacity to repeat this process is dependent on restoring the low-pressure vapor refrigerant to its pre-throttling state, which is the high-pressure liquid state. To begin this trip, we must first increase the pressure.

2.5 Compressor

A compressor is used to achieve this process. Its principal duty is to restore the starting pressure of the refrigerant. However, the temperature of the gas will certainly rise during the compression process. In essence, the compressor uses a dry compression process, as shown by T-S or P-V diagrams with the curve in the superheated zone. As shown in Figure 7, this dry compression method serves the dual objective of reducing compressor component corrosion and prolonging the lifespan of the refrigerator.

Figure 7: A compressor is raise the pressure of the refrigerant[4]

The refrigerant has transformed into a high-pressure vapour. Another heat exchanger is required to transform it into a liquid state.

2.6 Condenser

The refrigerant in this heat exchanger, which is located outside the refrigerator, is often warmer than the surrounding air. As a result, heat is released into the surroundings, which returns the vapour to its liquid state and raises the temperature to a comfortable level.

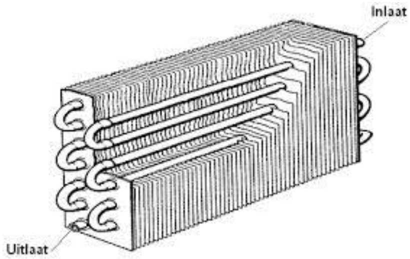


Figure 8: Refrigeration System Condenser: Heat Rejection to Surroundings [5]

The refrigerant has returned to its original state—a high-pressure liquid—at this point. This method can be performed indefinitely to maintain refrigeration. This cycle, known as the vapour compression cycle, provides the cornerstone for refrigeration technology shown in Figure 8, which is widely used in both home and industrial applications.

III. Heat Exchanger

An apparatus that facilitates the transmission of heat between two or more fluids is called a heat exchanger. These liquids can come into direct touch or be kept apart from one another by a physical barrier. Space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical facilities, petroleum refineries, natural gas processing, and sewage treatment are just a few of the many applications for heat exchangers. A traditional heat exchanger can be seen in the context of an internal combustion engine. Air passes over radiator coils, causing a circulating fluid known as engine coolant to flow through them. This procedure helps the engine's cooling and heating systems by simultaneously warming the incoming air and cooling the coolant.

3.1 Waste heat recovery units

Heat is recovered from a hot gas stream by a Waste Heat Recovery Unit (WHRU), which then transfers the heat to a working medium—usually water or oils. It is frequently used to extract heat from diesel engine exhaust, gas turbine exhaust and waste gases from factories and refineries. A Steam Rankine Cycle (SRC) in a WHRU can be advantageous for large-scale systems with high-temperature gas streams, but it may be too expensive for smaller installations. An Organic Rankine Cycle (ORC) WHRU is more effective at achieving low-temperature heat recovery since it requires distinct working fluids. These systems use organic refrigerants, which boil at lower temperatures than water, such as ammonia, penta-fluoropropane, and toluene. Heat exchangers come in two flow types: parallel flow and counter-flow are shown in Figure 9. Counter-flow involves fluids moving in opposite directions, offering greater heat transfer efficiency compared to parallel flow. The latter can result in large temperature differences and thermal stresses. Counter-flow maintains uniform temperature differences, reduces thermal stress, and allows the cold fluid to approach the hot fluid's highest temperature. In both flow types, heat transfer occurs via conduction and convection, causing temperature variations along the exchanger's length. Counter-flow's advantages make it favorable when fluids need to approach similar temperatures, making it a crucial choice in various heat exchange applications.

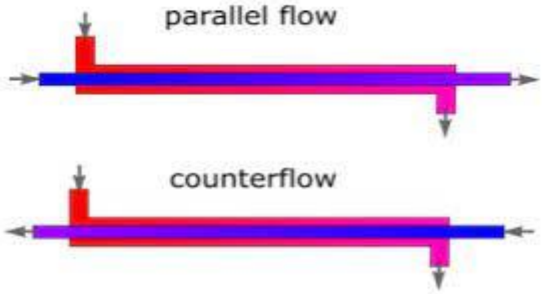


Figure 9: parallel and counter-flow Heat exchangers

3.2 Critical radius of insulation

The introduction of insulation typically increases the conductive thermal resistance, which comprises both conductive and convective thermal resistance. However, in certain scenarios, adding insulation can reduce convective thermal resistance, particularly when there's an increase in surface area, as observed in the cases of cylinders and spheres. This reduction in thermal resistance can actually enhance heat flow. The thickness at which heat flow peaks and subsequently diminishes is referred to as the critical thickness. Thermal insulation fundamentally involves curbing heat transfer between objects of differing temperatures, whether through specially engineered methods, processes, or appropriate shapes and materials. It creates a buffer where thermal conduction is minimized, and thermal radiation is reflected rather than absorbed by the cooler object. A material's insulating capacity is assessed via thermal conductivity (k), where lower values indicate superior insulating performance (high R-value). In thermal engineering, material properties like product density (ρ) and specific heat capacity (c) also bear significance are shown in Fig.10.

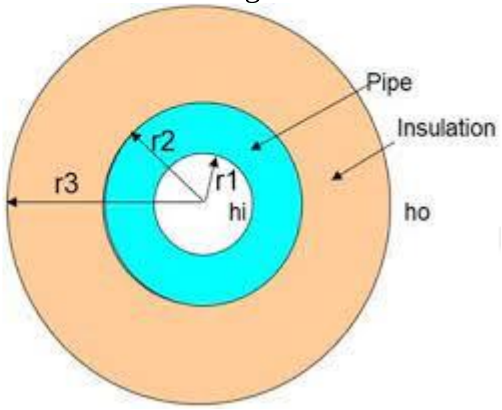


Figure10: Critical radius of insulation

Critical thickness of insulation for cylinder:

$$r = k/h0 \quad (1)$$

Critical thickness of insulation for sphere:

$$r = 2k/h \quad (2)$$

IV. Design of Heat Exchanger

A heat exchanger's design is a significant procedure that requires several key phases and considerations to ensure efficient and effective heat transfer, as shown in Figure 11. Here's a high-level overview of the heat exchanger design process:

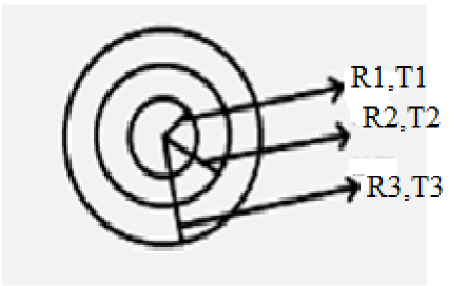


Figure 11: Heat Exchanger Insulation

Calculation of R2-

Where,

“r1 = radius of tube of refrigerator condensation

r2 = inner radius of the pipe
r3 = radius of pipe of insulation
T1= 45°C
T2= 40°C
T3= 30°C"
Applying heat transfer equation

$$heat\ transfer(1-2) = heat\ transfer(1-3) \quad (3)$$

$$\frac{45-40}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_{ref} l}} = ((45-30)/[\left(\frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_{ref} l}\right) + \left(\frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi k_{therm.} \times l}\right) + (1/(h_{air} 2\pi r_3 l)]) \quad (4)$$

Putting all known values, we get

$$3 = \frac{\ln\left[\frac{r_2}{2.5} \times \left(\frac{6}{r_2}\right)^{0.5} \times e^{0.4}\right]}{\ln\left(\frac{r_2}{2.5}\right)} \quad (5)$$

Now calculating the value of r_2 by hit and trial method

Table 1 Calculation of R_2

r_2	LHS	RHS
2.8	3	7.22
3	3	4.775
3.2	3	3.65
3.3	3	3.33
3.4	3	3.033

So R_2=3.4mm
For a Refrigerator of 165 liters capacity, given data from the Kirloskar Ltd manual follows [7]
Refrigerator cooling capacity (amount of refrigeration produced or heat extracted in refrigerator) =76 kcal/hr = 76×4.187×10003600 = 88.392 W
Power required running the compressor (work done on refrigerant) =
1/8 HP = 1/8×746 =93.25 W

$$Q_{condensor} = Q_{EVOPORATOR} + W_{COMPRESSOR} \quad (6)$$

=88.392+93.25
=181.642Watt
Assume the efficiency of the heat exchanger is 70%
So heat absorbed by heat exchanger =Q_A

$$\eta = Q_A/Q_{Condensor} \quad (7)$$

$$0.7 = Q_A/181.642 \quad (8)$$

$$Q_A = 127.149 \text{ Watt}$$

4.1 Design of oven

Since the temperature of air inside oven varies with time t

$$\frac{T_t - T_o}{T_i - T_o} = e^{\frac{-hA_s \times t}{\rho VC}} \quad (9)$$

where,
T_i= initial temperature of air (inside oven)
T_t = temperature of the air after time t
T_o= temperature of refrigerant
A_s= Surface Area (Perimeter×length)
V = volume of air inside the oven

ρ=density of air
Assumption

$$Ti = 20oC$$
$$Tt = 35oC$$
$$To = 40oC$$
$$h = 5watt/m2k$$
$$\rho = 1.12kg.m-3$$
$$C = 1.005KJ/kgoC$$
$$P = 2\pi \times r = 15.7mm$$
$$As = P \times l = 15.7 \times l\, mm2$$
$$V = 0.05m3$$

By putting these values, we get

$$\mathrm{T \times length} = 180 \tag{10}$$

Now heat transfer rate in the oven is given by-

$$\mathrm{Q(t) = hA\Delta T}$$
$$\mathrm{Q(t) = hA(Tt - Ti)}$$
$$\mathrm{T_t = T_O + (T_i - T_O)e^{\frac{-hAt}{\rho Vc}}}$$
$$\mathrm{Q(t) = hA(+(T_i - T_O)e^{\frac{-hAt}{\rho Vc}} - T_i)} \tag{11}$$

After integrating with respect to t, we get-

$$\mathrm{Q(t) = hA(To - Ti)[t + \frac{\rho Vc}{hA} e^{\frac{-hA_s \times t}{\rho VC}}]}$$

Now putting all known values,we get-

$$\mathrm{Q(t) = 1.571\left[t + \frac{716.94e^{-1.3948lt}}{l}\right]} \tag{12}$$

Energy absorbed by the air in the oven-

$$\mathrm{Q = mc\Delta t} \tag{13}$$

$$\mathrm{Q = 844.2}$$

By equating eqn(2) and eqn(3), we get

$$\mathrm{537.7 = lt + 716.94e^{-1.3948lt}} \tag{14}$$

Using eqn(1) and eqn(4), we get-

$$\mathrm{537.7 = l \times [300 + 716.94 \times 0.658^{l}]} \tag{15}$$

Table 2. Calculation of Length

l(m)	LHS	RHS
2	537.7	1220
1	537.7	771.7
0.9	537.7	712
0.7	537.7	584
0.6	537.7	514.9

So,

l=0.6m

And by putting the all values we get,
So, the total heat absorbed by the air inside the oven in 300 seconds is
Q =844.2J.

V. Fabrication and Assembly of WHRS

Various conversations and calculations were conducted to establish heat transfer rates throughout the design and development of a Waste Heat Recovery System for domestic refrigerators. Finally, we arrived at the final design, which includes an insulated cabin with a small, cost-effective frame [8]. We've included two air-cooled condenser sections, one at the bottom and one at the top of the enclosed cabin, to maximize heat extraction. This method tries to improve the energy efficiency of the refrigerator by capturing waste heat from the cooling process and reusing it for various applications such as preheating water or space heating. The arrangement of condenser sections at the cabin's top and bottom allows optimum heat recovery while being compact and cost-effective.

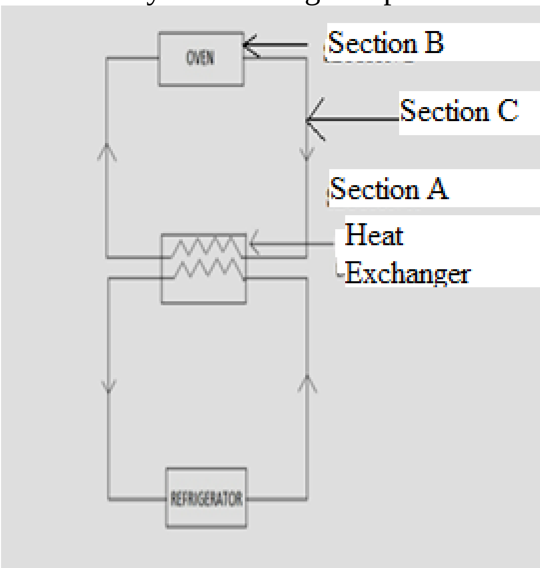


Figure 12: Assembly

As seen in Fig. 12, the entire system is placed atop the refrigerator. This design's key advantage is its capacity to maximize heat recovery while minimizing losses [9].

Given that this concept provides a comprehensive overview of harvesting waste heat at the household level, we chose to reuse a used 165-liter domestic refrigerator. The compressor, a customized air-cooled condenser, a capillary tube, a plate-type evaporator, a parallel-type heat exchanger, insulated pipework, and an insulated cabin are the basic components of this household refrigerator. The insulated chamber is a critical peripheral component for efficiently using the refrigerator's waste heat. Galvanized iron sheets are used

5.1 Major Equipment and Parts of Refrigerator

Table 3. Major equipment's of Domestic Refrigerator

Sr. No	Equipment	Type/ Material	Specification/ Capacity
1.	Refrigerator a.Compressor b. Condenser c. Evaporator	Domestic Type Hermetically sealed Copper, Air-cooled Plate type	165 Liters 1/8th HP No. of Tubes – 18, Surface Area -2798cm^2
2	Refrigeration	R134a	80gm

3.	Insulated Cabin a. Outer Box b. Inner box c. Door d. Insulation	Galvanized Iron G.I G.I G.I Thermocole	52.5cm × 50cm ×42.5cm 42.cm ×45cm ×32.5cm 52.5cm ×5cm ×42.5cm Thickness:- 3.50cm

5.2 Fabrication of Insulated Cabin

The building of an insulated cabin entails the construction of a structure designed to offer thermal insulation and housing equipment or processes that require temperature control. The following are the main steps in the construction of an insulated cabin:

5.2.1 Material Used: Galvanized Iron Sheet

A galvanized iron sheet, commonly referred to as GI sheet, is a type of steel sheet that has been coated with a layer of zinc to protect it from corrosion. The process of galvanization involves immersing the iron or steel sheet in a bath of molten zinc or applying a zinc coating through other methods like electroplating. This zinc coating creates a protective barrier that shields the underlying iron or steel from rust and corrosion.

5.2.2 Process used - Sheet metal forming

The process used for the fabrication of an insulated cabin, as described earlier, often involves sheet metal forming. Sheet metal forming is a manufacturing process that involves shaping and bending sheet metal to create various components, structures, or enclosures. In the context of an insulated cabin [10].

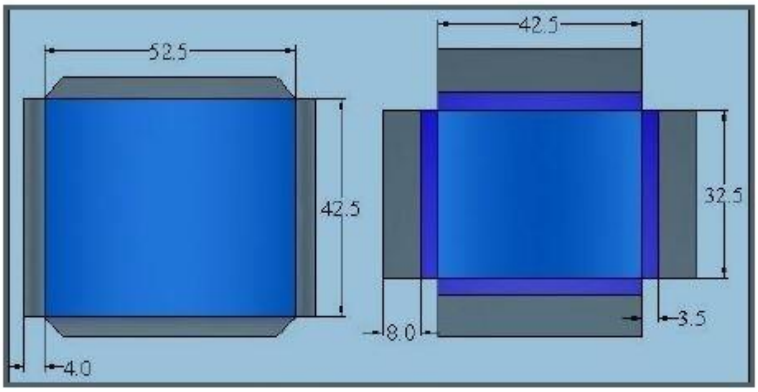
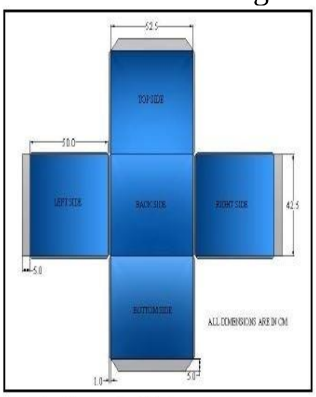


Figure 13: Door of cabin



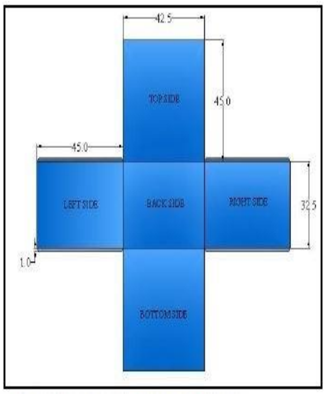


Figure 14: outer box of cabin Figure 15: Inner box of cabin

5.3 Fabrication of Cabin

The insulated cabin comprises several key components: Inner and Outer Boxes: Both the inner and outer shells of the insulated cabin are constructed using galvanized iron sheets. After defining the required dimensions, sheet metal working processes are employed to shape these boxes. To enhance their appearance and protect against corrosion, the cabin is painted in a silver color. Insulation Material: For insulation purposes, thermocole is used, and it measures 3.5 cm in thickness. This insulation material is inserted between the inner and outer boxes to minimize heat transfer and maintain a controlled temperature inside the cabin. Assembly: All the individual parts of the cabin, including the inner and outer boxes, insulation material, and any additional components, are assembled meticulously to ensure the cabin is structurally sound and provides effective thermal insulation.This well-structured assembly of galvanized iron boxes with thermocole insulation helps maintain the desired temperature within the insulated cabin while offering durability and protection against environmental factors.

Figure 16: Assembly of insulated cabin and condenser mounting

To maximize heat utilization, the condenser is located within the enclosed cabin, as illustrated in Figures 14 and 15. The condenser is divided into two sections to ensure a proper fit inside the cabin showmn in Figure 16. Copper tubes connect the compressor's output and the condenser's intake, and these connections are brazed within the insulated cabin. This setup enhances heat recovery efficiency, as the condenser operates in a controlled environment, allowing for the optimal utilization of waste heat.

RESULTS

The primary objective is to enhance the Coefficient of Performance (COP) of the system by harnessing available energy. Utilizing the heat from the condenser contributes to an increase in the system's COP. Calculations for the augmented rate of waste heat recovery are as follows: Heat Recovery Achieved (Q) is equivalent to the heat absorbed by the air. The given data includes a pot with a volume of 0.05 m^3, a specific heat capacity of air (Cp) at 1.005 KJ/Kg K, an initial air temperature of 20°C, and a final temperature of 35°C. Through these calculations, the system can effectively recover and utilize waste heat, resulting in improved overall energy efficiency Time required for reading Δt = 300sec

Heat Absorbed By air,

$$Q = \left(\frac{mC_P\Delta T}{(\Delta t)}\right)=\left(\frac{1.12\times0.05\times1.005\times10^3\times15}{(5\times60)}\right) \quad (8)$$

=2.814watt

Heat recovery achieved Q = Heat Absorbed by air
=2.814watt

$$COP_{actual}=\frac{\text{Heat extracted in refrigerator}}{\text{Work done by compressor}} \quad (9)$$

$$=\frac{88.392}{93.25} = 0.948$$

Improvement in COP Condenser heat is utilized, which is the part of compressor work. The denominator in equation (1) will reduce in value. Hence COP of system will improve.

$$COP_{improved} = \frac{\text{Heat extracted in refrigeration}}{\text{Work done by compressor} - \text{Heat recovery achieved}} \quad (10)$$

$$= \frac{88.392}{93.25 - 2.814} = 0.98$$

$$\text{Improvement in COP} = \frac{\text{COPimproved} - \text{COPactual}}{\text{COPactual}} \times 100$$

$$= \frac{0.98 - 0.948}{0.948} \times 100$$

$$= 3.3\%$$

The enhancement in the Coefficient of Performance (COP) is achieved by efficiently utilizing the heat from the condenser, a component of the compressor's workload. This improvement stems from the fact that the denominator in Equation (1) reduces in value when heat recovery is taken into account, consequently boosting the overall COP of the system. The improved COP is calculated as the ratio of the heat extracted in refrigeration to the difference between the work done by the compressor and the heat recovery achieved, as expressed in Equation (10), resulting in a COP of 0.98 after calculations. However, it's worth noting that the actual improvement in COP may vary from the calculated value due to certain factors: Inherent **Heat Leakage:** The precise evaluation of heat leakage while opening or closing the refrigerator door can be challenging, introducing uncertainties into the calculations. **Appliance Age:** The actual COP of the old refrigerator may differ from the assumed value, affecting the improvement estimation. **Air Leakage:** Air may leak in or out of the refrigerator due to worn-out gaskets or seals, contributing to variations in COP. These factors can result in a 3.3% improvement in COP, but it's essential to consider these uncertainties and variations in real-world applications

CONCLUSIONS

“The "Waste Heat Recovery System" represents a valuable tool for the preservation of available energy resources. In this context, an endeavor was undertaken to harness waste heat generated by a common 165-liter household refrigerator. This paper highlights the myriad applications for this recovered heat, including food and snacks warming, water heating, and grain drying, which translates into substantial time and energy savings. From the study, several significant conclusions can be drawn: The development of an appropriate heat recovery system tailored to each household refrigerator is a practical and viable endeavor. Experimental evidence demonstrates the feasibility of implementing such a system. Technical analyses confirm the economic viability of waste heat recovery. If adopted at the individual household level, the cumulative effect of waste heat recovery can be substantial. With a minor cost increment, reclaiming and reusing waste heat not only conserves energy but also enhances daily functionality. In the present era where household members are often on the move, the synergy between a refrigerator and a food warmer offers a boon to efficient housewives, simplifying their daily routines. In conclusion, the incorporation of waste heat recovery systems in domestic refrigerators has the potential to foster a culture of energy conservation. It not only enhances the efficiency of home appliances but also aligns with the broader global efforts to promote sustainability and resource utilization. By tapping into waste heat, we take a significant step towards a greener, more energy-conscious future while simplifying everyday tasks.

References

[1]Kaushik, S. C., & Singh, M. (1995). Feasibility and design studies for heat recovery from a refrigeration system with a canopus heat exchanger. *Heat Recovery systems and CHP*, *15*(7), 665-673.
[2]Patil, T., Nitesh, M., Yogesh, M., Kalpesh, N., & Dube, A. (2015). A review on recovering waste heat from condenser of domestic refrigerator. International Journal of scientific research and management (IJSRM), 3(3), 2409-2414.
[3]Fande, M., Andhare, A. M., & Patil, K. T. (2015). Experimental Investigation and Performance Evaluation of a Three in one Vapour Compression System using Refrigerant R134a. International Journal of Engineering Research & Technology, 4(05), 1109-1112.
[4]Yu, F. W., & Chan, K. T. (2006). Improved condenser design and condenser-fan operation for air-cooled chillers. Applied Energy, 83(6), 628-648.
[5]Varghese, R., Raju, N., Rohit, M., Antony, R. T., & Mathew, T. (2014). Heat Recovery System in Domestic Refrigerator. IEEE Sensors Journal, 2(2), 1-5.
[6]Varghese, R., Raju, N., Rohit, M., Antony, R. T., & Mathew, T. (2014). Heat Recovery System in Domestic Refrigerator. IEEE Sensors Journal, 2(2), 1-5.
[7]Anwaar, A., Prashant, N., Patil, S. B., & Priyanka, G. (2019). Design and Development of a Waste Heat Recovery Unit for Household Refrigerator System. International Research Journal of Engineering and Technology, 6(11)..
[8]Incropera, F. P., DeWitt, D. P., Bergman, T. L., & Lavine, A. S. (1996). Fundamentals of heat and mass transfer (Vol. 6, p. 116). New York: Wiley..
[9]Er.R.K.Rajput, "Heat and Mass Transfer", 4e McGraw Hill Publication 2012.
[10] Yu, A., Su, W., Lin, X., Zhou, N., & Zhao, L. (2020). Thermodynamic analysis on the combination of supercritical carbon dioxide power cycle and transcritical carbon dioxide refrigeration cycle for the waste heat recovery of shipboard. *Energy Conversion and Management*, *221*, 113214.
[11] Yadav, S., Singhal, S., Jasra, Y., & Saxena, R. K. (2020). Determination of Johnson-Cook material model for weldment of mild steel. Materials Today: Proceedings, 28, 1801-1808.
[12] Yadav, S., Kumar, S., & Goyal, M. (2022). PID Tuning and Stability Analysis of Hybrid Controller for Robotic Arm Using ZN, PSO, ACO, and GA.