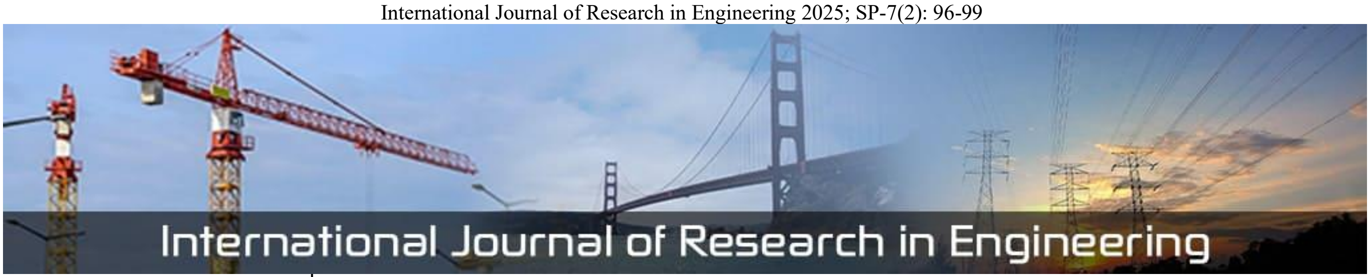

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Recovery of waste heat from domestic refrigerator

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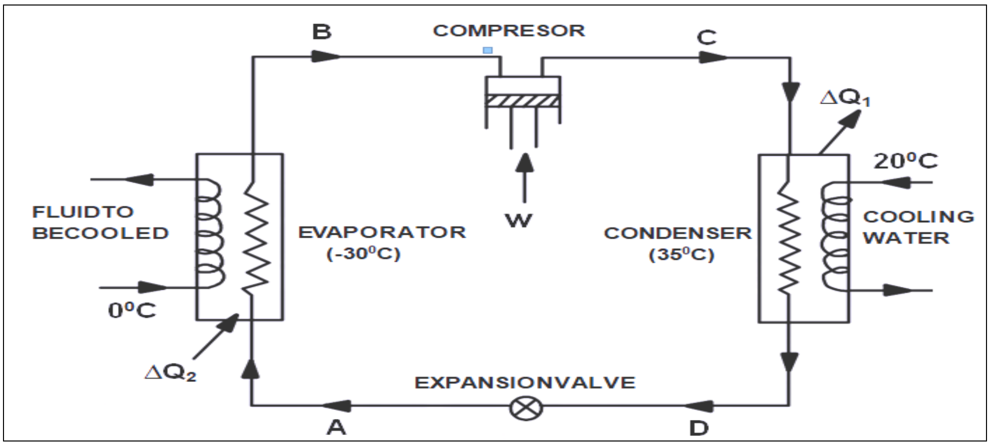
Abstract
Refrigeration is a process where the heat moves from low temperature reservoir to high temperature reservoir. Heat which is rejected by the condenser of a refrigerator is of low quality which means the temperature is low. So in this current project an attempt is made to utilize this waste heat from the condenser of a household refrigerator. Though it is impossible to recover the entire energy lost by the waste heat of the refrigerator, this project aims at minimizing the losses and recovery of maximum heat from the system by using experiment performed as in literature and theoretical heat balancing system. This helped in saving of energy as no electricity was used for heating water. The new system has given better performance than the existing one however with few more modifications a better efficiency from the developed system can be achieved. Also it has contributed to energy saving as well as cost saving as both the utilities (refrigeration and heating) are combined in one system. The maximum temperature of the water obtained after 2 hours of continuous operation was 40°C. This water obtained can be utilized for domestic applications like bathing, laundry, cleaning etc. Heat is energy, so energy saving is one of the key matters from view point of fuel consumption and for the protection of global environment. So it is necessary that a significant and concrete effort should be made for conserving energy through waste heat recovery too. The main objective of this paper is to study "Waste Heat recovery system for domestic refrigerator". An attempt has been made to utilize waste heat from condenser of refrigerator. This heat can be used for number of domestic and industrial purposes. In minimum constructional, maintenance and running cost, this system is much useful for domestic purpose. It is valuable alternative approach to improve overall efficiency and reuse the waste heat. The study has shown that such a system is technically feasible and economically viable.

Keywords: Waste heat recovery, 165 litre domestic refrigerator, air cooled condenser

Introduction
A basic vapour compression refrigeration system consists of four main components:
i) Compressor, ii) Condenser, iii) Expansion valve, iv) Evaporator



In this cycle, the refrigerant undergoes several transformations. Initially, low-pressure, low-temperature vapour is compressed into a high-pressure, high-temperature state. This vapour

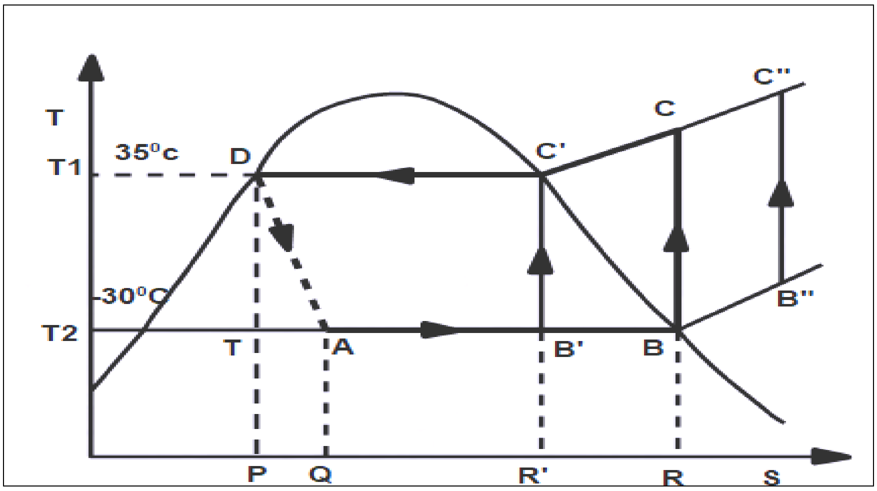
then passes through the condenser, where it releases heat and condenses into a high-pressure liquid. After this, it is throttled through an expansion valve, lowering both its pressure and temperature. The cooled liquid enters the evaporator, where it absorbs heat from the surrounding environment, vaporizes, and the cycle begins anew.
This process involves several energy exchanges.

- The compressor consumes work from an external source.
- The condenser releases heat, primarily in the form of latent heat.
- The evaporator absorbs heat, also as latent heat.
- The expansion process is adiabatic and does not involve any heat exchange.

The cycle operates between two key temperature levels.

- T1 (condenser temperature).
- T2 (evaporator temperature).

Process B-C (B'-C' or B"-C"): Isentropic compression of the vapor from stateB to C. If vapor state is saturated (B), or superheated (B"), the compression is called dry compression. If initial state is wet (B'), the compression is calledwet compression as represented by B'-C'**.**



Each segment of the cycle-compression, heat rejection, expansion, and heat absorption-has a distinct thermodynamic behaviour. Notably, during the heat rejection phase, a portion of the refrigerant becomes superheated, sometimes reaching temperatures 30-40°C above the saturation point. This superheat represents a valuable opportunity for energy recovery.
To make use of this otherwise wasted energy, a heat recovery unit was integrated into the system. This specially designed heat exchanger uses a water-cooled condenser to reclaim heat from the refrigerant and transfer it to water-without the need for additional power. The unit operates on a thermo-siphon principle, eliminating the need for pumps, and uses a double-wall construction to protect potable water from contamination.
This adaptation not only increases the system's overall efficiency but also contributes to sustainable energy use by transforming waste heat into a usable domestic resource.

Theoretical Background of Waste Heat Recovery
Nature of Waste Heat in Refrigeration
According to the second law of thermodynamics, not all input energy can be converted into useful work-some of it inevitably becomes waste heat. In household refrigerators, this waste heat is typically discharged into the room, which can even make indoor conditions less comfortable, especially in summer.
This study proposes a more productive use of that waste heat. By installing a heat recovery unit alongside a standard domestic refrigerator, the expelled heat can be captured and redirected. This unit includes a condensing coil, airflow arrangement, temperature sensors, and a few supporting accessories. Essentially, a compact "hot box" is integrated to absorb and repurpose the refrigerator's discharged heat.

This approach is particularly impactful given the widespread use of refrigerators in homes. The recovered heat-ranging from 35°C to 50°C-is ideal for several daily tasks, such as.

- Preheating water.
- Room heating.
- Laundry and dishwashing.
- Showering or bathing.

Superheating and Recovery Opportunity
The "superheat" (i.e., the difference between the refrigerant's actual and saturation temperatures) often reaches 30-40°C. Rather than letting this thermal energy dissipate into the environment, a water-cooled condenser allows it to be efficiently transferred to a secondary medium-typically water-for household use.

Heat Exchanger Design
This project employs a tube-in-tube heat exchanger for heat recovery, which offers several practical benefits:

- High surface area for effective heat transfer
- Simple and cost-effective construction
- Ease of maintenance
- Compact and reliable design

The inner tube carries the refrigerant, while water flows through the outer tube. This arrangement enables efficient heat exchange, converting otherwise wasted energy into a valuable resource without compromising the performance of the refrigerator.

Heat Balancing
In most domestic refrigerators today, the compressor is the central component driving the cooling cycle. This makes the compressor's discharge line an ideal spot to capture waste

heat.
To determine the effectiveness of heat recovery, a heat balance equation is applied.

Heat lost by the refrigerant = Heat gained by water
$m_{refrigerant} \cdot C_{pr} \cdot \Delta T = m_{water} \cdot C_{pw} \cdot \Delta T_m$

Where.

- **Cpr:** Specific heat of refrigerant.
- **Cpw:** Specific heat of water.

This simple yet powerful energy conservation principle forms the basis for evaluating and optimizing heat recovery. The goal is to ensure that the thermal energy leaving the condenser is efficiently transferred to water with minimal loss, enabling sustainable domestic applications.

Literature Review
Related Studies
Several researchers have explored the idea of recovering waste heat from household refrigerators, validating both its practicality and benefits.

- Patil and Dange (2013) [6] modified a 190-liter refrigerator by submerging the condenser coils in a water tank. While their system was effective in reclaiming heat, it lacked integration and mobility, limiting its usability in everyday settings.
- Chaudhari (2015) [3] conducted experimental analysis showing that between 202W and 410W of heat could be recovered depending on the water flow rate. This confirmed the technical feasibility of such systems.
- J. Sanmati Mirji (2006) [5] introduced a multi-purpose warming device that used waste heat from refrigerators to perform various household tasks like warming food, cooking, cleaning, and even aiding in fermentation (e.g., curd making). The chamber in his setup reached temperatures up to 50°C, with an average of around 40°C. Notably, this innovation did not require any additional power input-just efficient reuse of waste heat.

These studies collectively affirm the concept's validity, showing that with minimal alterations, waste heat from refrigerators can be harnessed effectively for everyday use.

Broader Applications
While this study focuses on domestic refrigerators, the idea of waste heat recovery has broader potential in various sectors, including,

- **Air conditioning systems:** Where excess heat can be redirected for water heating or space heating
- **Industrial chillers:** To recover energy for process heating.
- **Vehicle air conditioning units:** Enabling cabin heating without added fuel consumption.
- **Cold storage facilities:** Which can use rejected heat for adjacent processes like hot water generation.

This growing body of work highlights the adaptability of heat recovery systems, reinforcing their role in promoting energy efficiency across both residential and commercial applications.

Environmental and Economic Implications
Environmental Benefits: Capturing and using waste heat from a refrigerator isn't just an energy-saving strategy-it's an environmentally responsible one. By utilizing this heat for everyday tasks like water heating, the system helps reduce the reliance on electric water heaters. This leads to.

- Lower electricity consumption.
- Reduced greenhouse gas emissions.
- Less strain on power generation infrastructure.
- A meaningful contribution to climate change mitigation.

In a world increasingly focused on sustainability, even small innovations like this can have a large cumulative impact.

Economic Advantages
Aside from environmental gains, the system offers clear financial benefits as well.

- **Low operational costs:** It operates passively, requiring no extra power input.
- **Minimal maintenance:** Its simple design makes upkeep easy and inexpensive.
- **Quick payback:** Depending on local electricity rates and usage, the return on investment can be achieved in under a year.

In essence, this system delivers a rare combination of low cost and high impact-making it ideal for households seeking to cut utility expenses while living more sustainably.

Limitations and Future Scope
Current Limitations
While promising, the current design has some constraints.

- The maximum water temperature achieved is about 40°C, which is adequate for many household tasks but insufficient for high-temperature needs.
- Its performance may dip in cooler ambient conditions.
- The system is still in a prototype phase and lacks commercial standardization.

Future Developments
To improve efficiency and widen applicability, the following enhancements are being considered.

- Phase Change Materials (PCM) for storing heat and delivering it when needed.
- Hybrid designs combining waste heat recovery with solar water heating.
- Smart control systems that manage heat distribution based on real-time demand.
- Advanced materials (e.g., Nano-fluids, enhanced surface tubes) to improve heat transfer efficiency.

With on-going research and innovation, such systems could soon become a common feature in households and commercial refrigeration units alike.

Conclusion
The above study clearly demonstrates that a waste heat recovery system into a domestic refrigerator is technically feasible and also economical while increasing the efficiency of refrigerator. By replacing the standard air-cooled condenser with a custom-built, water-cooled tube-in-tube heat exchanger, it's possible to recover low-grade thermal energy and use it for practical household needs-without adding to energy bills.

It has been observed that the system can raise water temperature by up to 15 °C, reaching around 40 °C, while simultaneously improving the refrigerator's Coefficient of Performance (COP). This dual benefit-better cooling performance and useful heat recovery-makes the solution highly attractive.
As energy costs rise and environmental concerns intensify, such innovations offer a smart and sustainable path forward. With a few more refinements and supportive policies, heat recovery systems could well become standard in future refrigeration technology-helping households conserve energy, reduce costs, and shrink their carbon footprint.

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