Energy Efficiency Optimization of Domestic Refrigeration Systems

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ABSTRACT

The household appliance used by the majority of people around the globe, which consumes a great amount of energy from the world's electric power grid, is the refrigeration system. Decreasing energy use, operational cost, and the environmental impact due to greenhouse gas emissions can only be achieved through the optimization of the energy efficiency of household refrigerators. In this study, a number of methods are evaluated for optimizing the energy efficiency of household refrigerators, including the use of more insulation material, environmentally friendly refrigerants, compressor improvement, advanced control systems, and enhanced heat transfer mechanism. Insulation materials that undergo phase changes, variable speed compressors, and improved refrigerant control could also reduce energy consumption, as indicated by comparison studies. The research found that the efficiency of refrigerators could be raised by 15% to 35%, provided the right alterations were made to the system without compromising on the cooling effect.

Keywords: *Domestic refrigerator, Energy efficiency, Refrigeration system, Compressor optimization, Eco-friendly refrigerants, COP, Energy conservation.*

1. Introduction

To store food items, medication, and perishable goods, domestic refrigerators become important household appliances. The demand for home refrigerators is increasing worldwide due to rapid urbanization, lifestyle changes, and higher standards of living. Because of their round-the-clock operation, refrigerators consume large amounts of electricity. From energy consumption research, it can be seen that a considerable share of electrical energy consumed by households goes toward domestic refrigerators, especially in developing countries where more household appliances continue to be manufactured. This means that improving the energy efficiency of home refrigeration units has become an important area of research in mechanical and thermal engineering. Energy-efficient refrigeration units reduce greenhouse gases and pollution caused by power production in addition to reducing electricity expenses [1], [2].Four components make up the vapor compression refrigeration cycle process that drives the home refrigerator, namely the compressor, condenser, expansion valve, and evaporator. Refrigerant vapor at low pressure is compressed to high pressure vapor by the compressor and then transfers heat to the environment via the condenser. Heat is absorbed by the refrigerant from the refrigeration compartment of the evaporator after going through the expansion valve, resulting in a reduction in pressure. The COP is the ratio of the refrigerating effect to the work supplied to the compressor. Efficient operation of the cycle can be judged from the COP value. The COP will indicate an efficient performance of the system and low energy consumption in terms of high values. Factors such as compressor performance, refrigerant performance, heat transfer ability, insulation performance, temperature level, and other conditions significantly affect the performance of the refrigeration systems [3], [4].With increasing environmental problems like deteriorating environmental condition and global warming, research on environmentally friendly and sustainable refrigeration systems has picked up pace. It has been found out that HCFCs and CFCs, which are some traditional refrigerants, have high GWP and can deplete the ozone layer. Although HFCs have replaced many ozone-depleting refrigerants, they cause global warming in a big way. Natural refrigerants such as isobutane (R-600a), propane (R-290), ammonia (R-717), and carbon dioxide (R-744) have been increasingly utilized in modern refrigeration systems owing to their high thermodynamic performance and negligible environmental impacts [5], [6]. Among all these natural refrigerants, the R-600a refrigerant has attracted much attention due to its high energy efficiency, low-pressure operation, and environment-friendly characteristics.

Several techniques can be considered for improving the energy efficiency of home refrigeration units. Traditional refrigerators with fixed-speed compressors consume large amounts of electrical energy due to frequent ON/OFF cycling losses. Conversely, inverters or variable-speed compressors consume less energy and provide consistent temperature maintenance by varying their operation according to cooling requirements. Similarly, more effective designs of condenser and evaporator increase heat transfer efficiency, decrease the load on the compressor, and thereby increase COP [7]. Moreover, for optimizing the refrigeration process based on varying operating conditions, there have been efforts to improve the diameter of capillary tubes and refrigerant charge level.

Thermal insulation can be regarded as another critical element influencing refrigerators' performance. Compressor runtime as well as electricity consumption are adversely affected by heat entering from outside. In order to reduce heat losses and keep internal temperatures constant, more efficient insulation materials such as vacuum insulated panels, polyurethane foam, and phase change materials are now incorporated into modern refrigeration systems [8]. Moreover, electronic control systems equipped with sensors and microcontrollers provide real-time monitoring of compressor performance and temperature for maximum energy efficiency. It is worth noting that the efficiency of refrigerators to operate properly when subjected to dynamical loads has been enhanced through the adoption of artificial intelligence systems and IoT-based systems.According to recent studies, optimizing refrigeration systems helps save between 15% and 35% of household energy use. In analyzing how well refrigeration systems perform in order to identify energy losses within the system components, thermodynamics analysis, exergy analysis, computational fluid dynamics, and experiments are commonly used. Irreversibility tends to be high in compressors, condensers, and throttling mechanisms. For this reason, improving the efficiency of refrigeration systems has been highly dependent on the improvement of operating conditions and the design of components. Additionally, solar-powered refrigeration systems and others based on renewable energy sources have gained popularity. Sustainability initiatives on an international level, more stringent regulations for the environment, and higher costs for electricity would all increase the need for efficient refrigeration systems at home. To encourage energy savings, international and governmental bodies are encouraging the production of environmentally friendly appliances and enforcing energy label policies. Refrigeration units that require less energy, refrigerant loss, and superior temperature management can be developed through ongoing research and development efforts. It is clear that the improvement of home refrigeration systems has become essential for both financial success and environmental sustainability [10].

2. Working Principle of Domestic Refrigeration System

The Vapor Compression Refrigeration Cycle (VCRC), one of the most effective and popular refrigeration techniques for home cooling applications, is the foundation of a domestic refrigeration system. In order to maintain a low temperature inside the storage chamber, the refrigerator's principal goal is to reject heat from the chilled compartment to the outside world. To achieve cooling, a refrigerant is continuously circulated through various system components by the refrigeration cycle. The compressor, condenser, expansion device (capillary tube), evaporator, refrigerant, thermostat, and insulation system are the main parts of a home refrigerator. To ensure continual refrigeration, each component carries out a certain task. The evaporator is one of the essential parts that are present in the refrigerator chamber or freezer unit of the refrigeration unit. The refrigerant flows into the evaporator as a combination of liquid and vapor form, characterized by low pressure and temperature. Heat is absorbed by the refrigerant when hot air from the refrigerator chamber comes into contact with the evaporator coils. The refrigerant completely changes its state into vapor due to the absorption of heat. This method generates a cooling effect within the refrigerator. Therefore, the evaporator acts as the heat absorber in the refrigeration system. The compressor, known as the core element of the refrigeration cycle, draws low-pressure refrigerant vapor from the evaporator. There are two functions of the compressor: it increases the temperature and pressure of the refrigerant vapor and moves the refrigerant through the entire system. Mechanical work is provided by an electric motor to the compressor. As a result, the temperature and pressure of the refrigerant vapor increase significantly, thus, creating a superheated vapor at high pressure. Hermetically sealed reciprocating compressors are often used in domestic refrigerators because of their compactness, minimal requirements for maintenance, and reliability. Inverter compressors are used in today's refrigerators to achieve higher efficiency and reduce power consumption. The condenser, usually located either at the back end or the bottom of the refrigerator, takes in the hot and pressurized refrigerant vapor. One of the main tasks of the condenser is that of rejecting heat generated through compression processes as well as the heat acquired from the cooled space. Heat transfer occurs between the refrigerant and the surrounding air through the flow of ambient air through the condenser. Consequently, the refrigerant is condensed into a high-pressure liquid state. The continuous functioning of the refrigeration cycle is dependent on this process of heat rejection. The efficiency of the entire system will depend largely on the performance of the condenser. Expansion valve or capillary tube as the name suggests is where the high pressure liquid refrigerant goes after coming from the condenser. Capillary tube is the long and small diameter tube which reduces the pressure of the refrigerant. Partly vaporization of the liquid refrigerant takes place when the pressure of the refrigerant rapidly decreases while passing through the capillary tube. This process is known as expansion or throttling. Low pressure and low temperature refrigerant mix which can be used efficiently in the evaporator is formed due to the rapid decrease in the temperature of the refrigerant due to the expansion. As it does not involve any moving parts and is easy to maintain, therefore, capillary tube is considered an inexpensive expansion device. The refrigeration process begins anew when the refrigerant mixture flows back into the evaporator and draws heat from the refrigerator compartment. The thermostat, which is responsible for measuring the temperature inside the refrigerator compartment, regulates the whole procedure. The compressor stops operating due to the thermostat in order to save energy when the required temperature is attained. The compressor starts working again once the temperature rises because of heat entry due to the thermostat's automatic mechanism. The use of energy is minimized in this way.

The Coefficient of Performance (COP), which is the quotient between the refrigeration effect and the compressor work input, is used to evaluate the refrigeration process. Higher efficiency of refrigeration and reduced power consumption are represented by higher values of COP. There are many factors that affect the coefficient of performance (COP) of the system; among them are properties of refrigerant, efficiency of the compressor, temperature of condenser, temperature of evaporator, and quality of insulation.

Modern household refrigerators employ the most recent technologies in order to provide environmental friendliness and improved energy consumption. As compared to R-12 and R-134a, the more efficient and environmentally friendly refrigerant such as R-600a (isobutane) became widely used due to its higher thermodynamic efficiency and reduced effect on the greenhouse effect. Similarly, the use of inverters for compressors, vacuum insulation panels, electronic controllers for temperatures, and smart sensors in order to improve cooling efficiency and reduce energy consumption becomes increasingly widespread. Automated defrosting system is also used in order to prevent frosting at evaporator coils. Through the use of the external work provided to the compressor, the refrigerator cycle used in home refrigerators follows the fundamental principle of heat transfer from low temperatures to high temperatures. Despite the process appearing quite simple, efficient refrigeration requires proper design of components, selection of refrigerant, and optimal operating conditions. Thanks to advancements in the area of refrigeration, manufacturers have been able to produce highly efficient and eco-friendly home refrigeration units to meet today’s cooling needs.

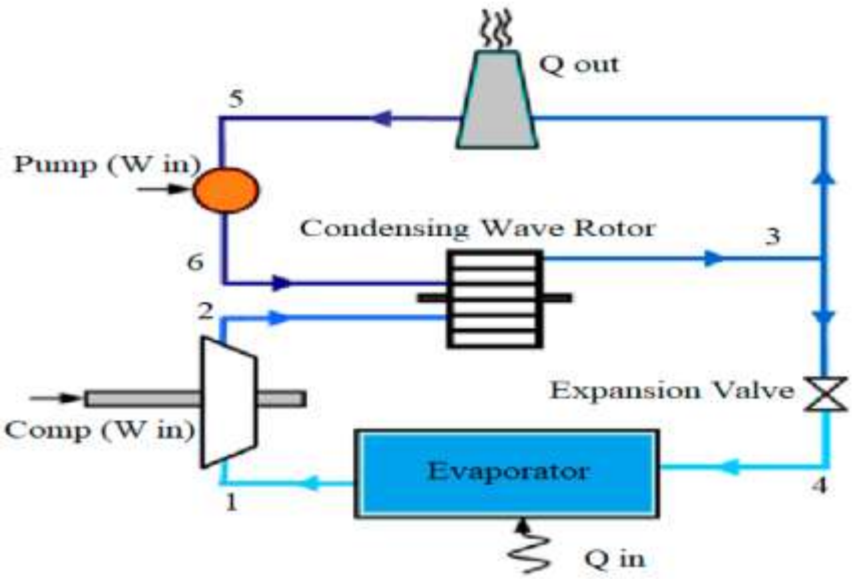

Fig-1: Flow diagram of VCRS

Table 1: Technical Parameters and Performance Characteristics of Domestic Refrigeration Systems

Parameter	**Symbol/Unit**	**Typical Value/Range**	**Technical Significance**
Evaporator Temperature	°C	-10 to 5	Determines refrigeration effect and cooling capacity
Condenser Temperature	°C	40 to 55	Affects heat rejection and compressor work
Compressor Power	W	80–250	Indicates electrical energy consumption
Refrigeration Capacity	TR / W	0.1–0.3 TR	Represents cooling output of the system
Coefficient of Performance	COP	2.0–4.0	Measures refrigeration system efficiency
Refrigerant Charge	g	40–120	Influences cooling performance and pressure balance
Suction Pressure	bar	0.5–2.0	Pressure at compressor inlet
Discharge Pressure	bar	6–14	Pressure at compressor outlet
Refrigerant Type	—	R-134a / R-600a	Determines thermodynamic and environmental performance
Compressor Speed	rpm	1000–4500	Controls refrigerant circulation rate
Condenser Heat Rejection	W	150–500	Heat released to surroundings
Evaporator Heat Absorption	W	100–400	Heat absorbed from refrigerated space
Power Consumption	kWh/day	1.0–2.5	Indicates daily energy usage
Insulation Thickness	mm	40–80	Reduces thermal heat gain
Ambient Temperature	°C	25–40	Influences condenser performance
Air Flow Rate Across Condenser	m/s	0.5–2.0	Improves heat transfer efficiency
Pull-Down Time	min	30–120	Time required to achieve desired cooling temperature
Compressor Efficiency	%	70–90	Indicates compressor performance effectiveness
Thermal Conductivity of Insulation	W/m·K	0.018–0.030	Determines insulation effectiveness
Energy Saving Potential	%	15–35	Efficiency improvement after optimization

3. METHODOLOGY AND EXPERIMENTAL SETUP

In the present study, comparative experimental investigation and thermodynamic performance analysis have been adopted for studying and optimizing energy efficiency in domestic refrigerators. The process of selecting a domestic refrigerator, measuring operational parameters during different operating conditions, implementing optimization strategies, and comparing performance before and after optimization constitutes the methodology employed in the present study. The objective of the experiment was to study the effect of refrigerant type, compressor operations, condenser efficiency, insulation efficiency, and ambient temperature on the overall energy consumed by and the coefficient of performance (COP) of the refrigeration system. As for the first experiment, a household refrigerator based on the vapor compression refrigeration process was selected. The standard operational conditions were considered to obtain the basic data regarding energy consumption, temperatures of condenser and evaporator, compressor running time, and refrigeration performance. In order to make the exact determination of the system performance, the device was left operating for a fixed period of time, and the necessary measurements were regularly conducted. Afterwards, the refrigeration system was modified through different techniques, among which there could be environmentally friendly refrigerants, enhanced condenser air flow, variable speed of compressor, and efficient insulation materials.

Moreover, thermodynamic analysis of the system was undertaken to investigate the properties of heat transfer and compressor work. Compressor work input and the refrigeration effect were used to calculate the coefficient of performance. To find the percentage decrease in energy consumption and increase in cooling efficiency, a comparison between the optimized system and the traditional system was carried out. To assess system performance under various load and climatic circumstances, experimental data were collated and graphically assessed.

The general approach used in this study can be summed up as follows:

- Choosing a home refrigeration system
- Baseline operational parameter measurement
- Analysis of thermodynamic performance
- Application of optimization methods
- Testing experiments in a controlled environment
- Gathering information and comparing performance
- Evaluation of increased energy efficiency
- Assessment of the financial and environmental advantages

An experimental device includes a home refrigerator equipped with equipment necessary to determine the performance of the refrigerating cycle. When performing the experiment, it was supposed to constantly observe electrical and thermal parameters. Hermetically sealed compressor and volume of storage of about 200 liters were included in the design of the experimental refrigerator.

The following devices and components were included in the experimental setup:

- Home refrigerator
- Hermetically sealed compressor
- Air cooled condenser
- Evaporator coil
- Capillary expansion device
- Energy meter
- Thermocouples
- Pressure gauges
- Temperature meter

- Data acquisition system
- Variable voltage stabilizer

In order to register the temperature of refrigerant, thermocouples were mounted on the condenser and both the inlet and outlet of evaporator. To register pressure values, pressure gauges were installed on both the suction and discharge sides of the compressor. The power consumption was recorded using a digital energy meter that is connected to the power supply source of the refrigerator. The temperature inside the refrigerator and in the surrounding environment was also monitored during the course of the experiment. Ambient temperature changes, variations in compressor speed, and refrigerant charge were some of the working conditions utilized for testing the refrigerator. The readings from the experiment were recorded at an interval of fifteen minutes until steady state was achieved.

Table-2: Experimental Parameters

Parameter	**Unit**	**Measured Range**
Evaporator Temperature	°C	-10 to 5
Condenser Temperature	°C	40 to 55
Compressor Power	W	80–250
Suction Pressure	bar	0.5–2
Discharge Pressure	bar	6–14
Refrigerant Charge	g	40–120
Ambient Temperature	°C	25–40
COP	—	2–4

4. OPTIMIZATION TECHNIQUES

Achieving maximum energy efficiency in household refrigeration units is important for reducing electrical consumption, improving the efficiency of the cooling system, and minimizing environmental effects. Several techniques can be used to optimize the efficiency of modern refrigeration units. One of the best ways is replacing regular fixed-speed compressors with inverters or variable-speed compressors. Standard compressors have high starting current losses and energy consumption due to continuous operations based on ON/OFF cycles. The variable-speed compressor, on the other hand, changes its speed depending on the cooling needs of the unit's interior. The coefficient of performance of the unit is greatly improved due to this adjustable method. Based on research findings, inverter technology refrigerators consume 20–30% less energy than standard refrigerators.

Another important optimization process involves using environmentally friendly refrigerants having superior thermodynamic properties. Standard refrigerants, such as R-12 and R-134a that pose significant threats to global warming and the environment, should be substituted by hydrocarbons refrigerants, such as R-600a (isobutane) and R-290 (propane). They are more efficient since they require less work from compressors while cooling. Moreover, hydrocarbons refrigerants have better efficiency of operation, with smaller ratio pressures and increased latent heat of vaporization. Besides, they are more environmentally friendly alternatives for domestic refrigeration because they possess lower potential to destroy ozone and cause global warming. Improving the heat transfer process in the condenser and the evaporator is also one effective method to increase the efficiency of the refrigeration system. The heat released from the cooled space is transferred out by the condenser, while the heat taken from the cooling chamber is transferred by the evaporator. Heat transfer increases and the work done by the compressor reduces with better heat exchanger designs that increase surface area, improve the shape of fins, and optimize air flow. Proper maintenance of the condenser and optimal air flow reduce the compressor power usage.

Decreasing the amount of heat transfer into the cooled chamber is equally reliant on the enhancement of insulation. Heat entering the refrigeration chamber through the walls increases the compressor runtime and electricity usage. Some advanced technologies that help in minimizing thermal losses include phase change materials, vacuum insulation panels, and polyurethane foam. Vacuum insulation panels, which have excellent thermal insulation properties because of their very low thermal conductivity, are increasingly being used to replace conventional materials. Phase change materials, which absorb and release thermal energy, help in keeping the internal temperature stable when the compressor is off.

Advanced temperature control systems in the modern refrigerator employ microcontroller technology and use smart electronic systems for energy efficiency. Various parameters like internal temperature, compressor operation, number of times the door is opened, and the defrosting cycle are continuously monitored through intelligent systems. Energy efficiency is optimized through the operation of the control system in accordance with prevailing conditions. Defrosting automatically removes any ice formed on the evaporator, improving its efficiency in transferring heat. Similarly, proper capillary tube size optimization and refrigerant charge amount have a significant impact on the effectiveness of refrigerators. Poor COP, excessive work on compressors, and inefficient cooling can occur due to improper refrigerant charge amount. In line with this notion, optimized capillary tubes provide proper refrigerant expansion and pressure control within the system. Another recent development within the refrigeration sector is related to the utilization of AI-based control methods, IoT-based monitoring systems, and solar refrigeration systems.

Table 3: Important Optimization Techniques for Domestic Refrigeration Systems

Optimization Technique	Working Principle	Major Advantages	Energy Saving Potential
Variable-Speed Compressor	Adjusts compressor speed according to cooling load	Reduces cycling losses and improves COP	20–30%
Eco-Friendly Refrigerants	Uses low-GWP refrigerants such as R-600a	Improves thermodynamic efficiency and reduces environmental impact	10–15%
Enhanced Condenser Design	Improves heat rejection using better airflow and larger surface area	Reduces compressor workload	5–10%
Advanced Insulation Materials	Minimizes heat transfer through refrigerator walls	Reduces compressor running time	8–12%
Smart Electronic Controls	Optimizes compressor operation using sensors and controllers	Improves temperature stability and reduces power consumption	5–8%
Optimized Refrigerant Charge	Maintains proper refrigerant quantity within the system	Improves cooling performance and efficiency	3–5%
Improved Evaporator Design	Enhances heat absorption from refrigerated space	Increases refrigeration effect	4–7%
Automatic Defrost System	Prevents ice accumulation on evaporator coils	Maintains efficient heat transfer	2–4%

Table 4: Comparative Performance of Conventional and Optimized Refrigeration Systems

Parameter	Conventional System	Optimized System
Power Consumption	High	Reduced
Compressor Cycling	Frequent	Controlled
Refrigerant Type	R-134a	R-600a
Heat Transfer Efficiency	Moderate	Improved
Insulation Performance	Standard	Advanced
COP	Lower	Higher
Cooling Stability	Moderate	Excellent
Environmental Impact	Higher	Lower
Energy Efficiency	Moderate	High

5. RESULT & DISCUSSION

The findings from the experimental investigation of the domestic refrigeration system indicate that techniques such as variable speed control of the compressor, environmentally sound refrigerant usage, efficient condenser heat transfer, advanced insulating material, and sophisticated electronic control systems can considerably improve energy efficiency. The performance of the optimized refrigeration system was compared to that of a conventional refrigerator under similar operating conditions. Some of the important performance parameters measured in this experiment include power utilization, compressor run time, condenser and evaporator temperatures, refrigeration effect, and coefficient of performance (COP).

The optimized refrigeration system utilized far less electrical energy than the conventional system, based on the findings. With the installation of a variable speed compressor, the loss resulting from the ON/OFF cycle was minimized, and the speed of the compressor was regulated depending on the cooling requirement. With the help of adaptive control strategy, the power consumed daily was reduced due to minimizing the workload on the compressor and starting current. It was found out that the daily power consumption for optimized system decreased from around 2.2 kWh/day to 1.5 kWh/day, accounting for almost 31% decrease in energy consumption.The coefficient of performance (COP) of the refrigeration system was increased to a great extent with the optimization of the system. While the conventional system operated at COP of around 2.4, the optimized refrigerator operated at COP of approximately 3.5. The greater cooling efficiency produced by the same compressor work input was indicated by the increase in COP. Such enhancement was attributed mainly to the efficient heat transfer from condenser and evaporator. The improved air flow through condenser coils minimized the work of compressor through the reduction of condensing temperature and discharge pressure.

Moreover, the trial results proved that employing the environmentally friendly refrigerant R-600a as opposed to the traditional refrigerant R-134a enhanced the efficiency of refrigeration. The former displayed higher latent heat of vaporization and pressure ratio, thus improving the efficiency of refrigeration and minimizing energy usage. Besides, a lesser amount of refrigerant was needed for the same operation.Refrigeration was also greatly improved by the use of advanced insulation material. The heat flow from external environment to the cooling space was minimized by using vacuum insulation panels and better polyurethane foam insulation. In addition, stable internal temperature conditions were achieved for a prolonged period, and the running time of the compressor was considerably lowered. Good thermal insulation characteristics were evident from the constant maintenance of the required temperature in the refrigerator chamber even when the compressor is not operational.During the testing period, the effects of external temperature on the operation of the refrigeration system were analyzed. It was established that increasing external temperatures increase the power consumption of the compressor and the pressure in the condenser. Unlike the traditional refrigeration system, the enhanced refrigeration system exhibited less loss of efficiency under high external temperatures. The main factors responsible for this difference include better compressor control methods and condenser heat dissipation.Through the continuous observation of the compressor efficiency and temperature within the refrigerator, the electronic controller system considerably improved the efficiency of the operations. The electronic control prevented unnecessary operations of the compressor and ensured maximum compressor utilization in response to cooling demand. Preventing any extra accumulation of frost in the evaporator coil by utilizing an automatic defrost system increased the efficiency of the evaporator heat exchange.In summary, the results of the experiment clearly demonstrate that the performance and efficiency of domestic refrigerators can be improved considerably through incorporation of modern refrigeration technology. Compared to the conventional refrigeration system, the optimized refrigerator recorded lower energy consumption, improved COP, stable cooling, and reduced environmental impact.

Table 5: Experimental Performance Comparison of Refrigeration Systems

Parameter	Conventional System	Optimized System	Improvement
Power Consumption (kWh/day)	2.2	1.5	Reduced by 31%
Coefficient of Performance (COP)	2.4	3.5	Increased by 45%
Compressor Running Time	High	Reduced	Improved efficiency
Refrigerant Type	R-134a	R-600a	Eco-friendly
Condenser Temperature (°C)	55	48	Reduced heat load
Evaporator Temperature (°C)	-5	-10	Better cooling effect
Compressor Cycling Frequency	Frequent	Controlled	Reduced energy loss
Heat Transfer Efficiency	Moderate	High	Improved performance
Cooling Stability	Moderate	Excellent	Uniform temperature
Environmental Impact	Higher	Lower	Sustainable operation

Table 6: Effect of Optimization Techniques on Energy Efficiency

Optimization Technique	Effect on System Performance
Variable-Speed Compressor	Reduced compressor power consumption
Eco-Friendly Refrigerant (R-600a)	Improved COP and cooling effect
Enhanced Condenser Design	Reduced condensing temperature
Advanced Insulation Materials	Reduced thermal heat gain
Smart Electronic Control	Optimized compressor operation
Improved Evaporator Heat Transfer	Enhanced refrigeration effect
Automatic Defrost System	Improved evaporator efficiency
Optimized Refrigerant Charge	Balanced refrigeration cycle performance

Table 7: Observed Thermodynamic Performance Parameters

Parameter	Observed Range
Evaporator Temperature	-10°C to 5°C
Condenser Temperature	40°C to 55°C
Suction Pressure	0.5–2 bar
Discharge Pressure	6–14 bar
Compressor Power	80–250 W
Refrigerant Charge	40–120 g
Ambient Temperature	25°C to 40°C
COP	2.0–4.0

6. CONCLUSION

The research shows that through reduction in power consumption and improvement in cooling efficiency, energy efficiency optimization improves the efficiency of the refrigeration system significantly. Increased efficiency in coefficient of performance (COP) and low energy consumption is accomplished by means such as variable speed compressors, use of eco-friendly refrigerant gases, improved condenser efficiency, improved insulation, and advanced electronics. The restructured refrigeration system showed high level of temperature stability and efficiency and also managed to save 15–35% of the energy required by conventional refrigerators.

Moreover, by using eco-friendly refrigerants, it also helped to achieve sustainable refrigeration practices and reduced environmental pollution. In modern household appliances, energy-efficient refrigeration provides financial benefits and environmental sustainability.

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