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Optimization of Energy Consumption in Parallel Evaporator Refrigeration Units Using Control Algorithms

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ABSTRACT

Mankind had been consuming since their existence. With the improvement of technology, the needs of mankind had increased. The increase in consumption had resulted in a reduction of energy resources. This reduction has caused energy costs to rise, thus giving energy efficiency a more important role in technology. Companies had started developing projects to improve system efficiency. Analyses on commercial refrigerators has shown that increasing and optimizing component efficiency played a very important role in reducing the system's energy consumption. This study was conducted on a parallel cooling system with two different cabinets to determine the effects of various working conditions caused by changes in the performance of system components on energy consumption. The effects of different compressor revolution numbers and valve section opening ratios on the cooling system were investigated. The variables of system energy consumption were nondimensionalized using the Buckingham π theorem. A model was developed using the linear least squares regression algorithm to generalize the relationship between the dimensionless variables and the system's energy consumption.

1. Introduction

Human needs are continuously evolving and increasing over time. To meet these diverse and growing demands, various technologies are being developed across numerous industries. As technological advancements emerge, they bring about new innovations which, in turn, increase the demand for energy. The rising energy demand has led to a depletion of energy resources and a significant escalation in energy costs. Consequently, many countries around the world are conducting research to discover alternative energy sources and to enhance the efficiency of energy utilization. Moreover, in an effort to reduce overall energy consumption, regulations and standards have been introduced to encourage the efficient use of existing energy resources. These standards place a strong emphasis on energy savings and efficiency, further underlining the critical importance and necessity of energy-efficient practices. In addition to energy efficiency, it is also essential that the manufactured products meet user requirements and are easy to operate. Over the years, refrigeration cabinets have been improved both in terms of energy consumption and their

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ability to fulfill human needs. Specifically, in systems where separate compartments within the same cabinet can be maintained at different temperatures using dedicated evaporators (dual-evaporator systems), modifications have been made to the refrigeration cycle to both improve energy efficiency and ensure better preservation of food under optimal conditions.

Various studies in the literature have focused on improving refrigeration systems that utilize dual evaporators, each serving different compartments within the same cabinet, maintained at distinct temperatures. These studies have aimed not only to enhance energy efficiency but also to provide better preservation conditions for stored food by modifying traditional refrigeration cycles. "For example, a series-connected two-evaporator system was analyzed by Chao-Jen and Chin-Chia to investigate performance characteristics [3]."

In a study conducted by Lavanis in 1998, an alternative evaporator refrigeration circuit was investigated. The system employed a single compressor, a single condenser, and a heat exchanger placed on the suction line. A dual-evaporator configuration was utilized in which a solenoid valve directed the refrigerant flow either to the freezer compartment or to the fresh food compartment, depending on cooling demand. A subsequent study by Lavanis adopted a serial connection of the evaporators. Both systems achieved an 8.5% reduction in energy consumption, demonstrating the efficiency benefits of modified dual-evaporator designs.

Won (1994) also studied a dual-evaporator configuration, but each evaporator was supplied by its own dedicated compressor [8]. The system achieved a 3.5% improvement in energy consumption. The use of smaller compressors reduced the thermal impact of the compressors on the surrounding compartments, thereby decreasing overall cabinet heat gain.

In 1995–1996, Kim introduced a configuration referred to as a “tandem system” [11], Kim introduced a configuration referred to as a “tandem system.” In this setup, the refrigerant discharged from the condenser passed through a heat-exchanging pipe in thermal contact with the fresh food compartment evaporator before entering an expansion device and then flowing to the freezer evaporator. After exiting the freezer evaporator, the refrigerant would enter the fresh food evaporator and finally return to the compressor. In this system, the fresh food evaporator functioned as an intercooler. Compared to a similar single-evaporator configuration, this arrangement achieved an 18% reduction in energy consumption. Additionally, refrigerant migration during compressor off-cycles was minimized and better controlled.

Currently, Samsung manufactures refrigerators with dual evaporators, marketed under the name “Twin Cooling System.” Although specific technical details are not publicly available, it is known that the system improves energy efficiency. By physically separating airflow between compartments, the freezer evaporator is not exposed to high-humidity air from the fresh food compartment. This prevents frost formation and reduces the need for defrost heater operation, thereby enhancing overall energy efficiency.

In conclusion, various dual-temperature-cycle configurations have been studied with the goal of improving refrigeration cycle efficiency and reducing energy consumption in household refrigerators. Eveleyn and Francis evaluated the performance of a two-cycle refrigerator/freezer using HFC refrigerants, showing improvements in system efficiency [4].

a) Dual-Loop System:

Two independent refrigeration cycles are used to cool the fresh food and freezer compartments separately, allowing independent control of each.

b) Lorenz-Meutzner Cycle:

This configuration uses a non-azeotropic refrigerant mixture (e.g., 65% R22 / 35% R123 or 80% R22 / 20% R141b) instead of a pure refrigerant, allowing improved thermodynamic efficiency through temperature glide. Kevin, Imam, and Reinhard investigated independent temperature control in refrigerators employing Lorenz–Meutzner and modified Lorenz–Meutzner cycles, contributing to improved compartment-specific performance [9].

c) Two-Stage Compressor System:

This system comprises a serially connected dual-evaporator setup with a two-stage compressor. A phase separator is used to deliver refrigerant at different pressures to each evaporator. The refrigerant exiting the second stage of the compressor partially evaporates in the evaporator, then enters the separator. The vapor phase is directed to the first stage of the compressor while the liquid phase is directed to the freezer evaporator, optimizing performance.

d) Parallel Dual-Evaporator System:

The refrigerant exiting the condenser is divided via control valves into two separate circuits. Each circuit includes a specific evaporator and an expansion device tailored in size and type to match the corresponding compartment (fresh food or freezer). This design enhances the overall efficiency of the system. Lubos et al. focused on optimizing temperature control strategies during the cooling process in multi-zone refrigeration systems, demonstrating significant improvements in thermal regulation [12].

Moreover, multiple studies have focused on addressing specific challenges encountered in dual-evaporator systems, whether configured in series or in parallel, to further reduce the energy consumption of household refrigerators. For instance, Guoliang and Zhili proposed a time-sharing control strategy for parallel two-circuit refrigerator–freezer systems to improve energy efficiency [5].

In addition to experimental approaches, simulation-based studies have provided valuable insight into the dynamic behaviour and performance of refrigeration systems. Guoliang, Chunlu, and Zhili developed component-level dynamic simulations for natural convection bypass two-circuit refrigeration systems, enhancing understanding of their transient behaviour [6]. In a follow-up study, the same authors performed system-level simulations and validated their findings through application-oriented scenarios [7].

Numerous studies have been conducted to improve the performance and energy efficiency of household refrigerators. Ahmet investigated two different performance improvement options for household refrigerators in his graduate study, revealing significant energy-saving potential [1].

This study focuses on a refrigeration system employing parallel-connected dual evaporators. In the system, two separate compartments (a freezer and a fresh food compartment) are cooled by an external refrigeration unit comprising a variable-speed compressor and a condenser. The evaporators of the compartments are connected in parallel, allowing refrigerant to be simultaneously distributed to both evaporators. To control the flow distribution to each evaporator, a proportionally controlled valve is installed at the inlet of each capillary. The effects of changing system parameters—such as the valve opening ratio and compressor speed—on energy consumption were investigated experimentally. Based on the experimental results, a dimensionless correlation was developed to model the system's energy consumption behavior

2. Methodology

The experimental test rig is composed of independently controlled refrigeration compartments and a separate refrigeration unit. The key components of the system are listed below:

- Refrigeration Cabinets: Fresh food compartment (TG) and Freezer compartment (DD)
- Outdoor Unit: Comprising a variable-speed compressor, condenser, and condenser fan
- Proportionally Controlled Valves
- Control Unit
- Measurement and Data Acquisition System

To cool the parallel-connected refrigeration cabinets, an external refrigeration unit (physically separated from the cabinets) is used. The variable-speed compressor within the outdoor unit delivers high-pressure refrigerant to the condenser, where the refrigerant releases its heat to the ambient air. A condenser fan, operating at variable speeds depending on ambient temperature, assists in heat rejection from the condenser.

After condensation, the refrigerant is directed to the refrigeration compartments. The proportional control valves, which operate based on the implemented control algorithm, regulate the refrigerant distribution to each evaporator depending on the cooling demand of each compartment.

Inside the evaporators, the refrigerant absorbs heat from the compartments, causing it to evaporate. The resulting low-pressure vapor then returns to the compressor, completing the cycle.

To ensure balanced flow and uniform response, the supply and return lines to and from the cabinets were designed to have equal lengths but different diameters, optimized for flow dynamics. To prevent frosting along the return line, thermal insulation was applied.

All major components of the refrigeration system—compressor, valves, and condenser fan—are controlled via a central control algorithm, and the entire system is monitored through a computer-based data acquisition interface.

The Engineering Equation Solver (EES) was used to perform thermodynamic modeling and numerical calculations efficiently [10].

Refrigerated Compartments

The experimental investigations were conducted using two separate refrigeration compartments: one fresh food compartment (TG) and one freezer compartment (DD). These compartments differ in both physical dimensions and target temperature ranges.

The fresh food compartment is designed to maintain temperatures suitable for preserving perishable but unfrozen items, while the freezer compartment is intended to store items at deep-freeze temperatures. The structural and thermal properties of the test compartments, including cooling load and thermal conductance, directly influence the refrigeration system's behavior and control strategy.

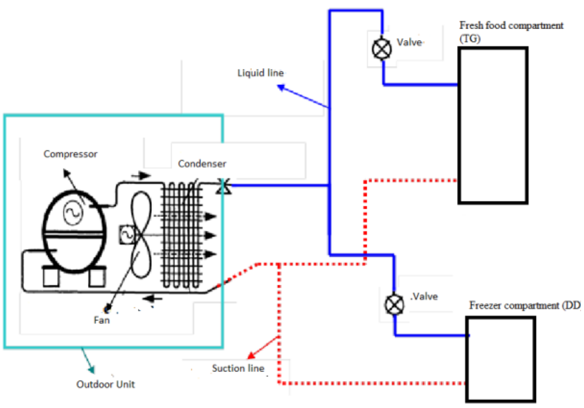

Figure 1. Schematic Representation of the Exper. Setup

The detailed specifications of the compartments used in the experiments are provided in Table 1.

Table 1: Characteristics of the Refrigerated Compartments

Compartment Type	Operating Temperature [°C]	Cooling Volume [L]	Cooling Load Q [W]	Overall Heat Transfer Coefficient UA [W/K]
Fresh Food Compartment (TG)	5	310	22.00	1.100
Freezer Compartment (DD)	–22	110	35.58	0.757

Outdoor Unite

To provide cooling for the independently located refrigeration compartments, a shared outdoor unit was employed. This unit is equipped with a variable-speed compressor, an air-cooled condenser, and a speed-controlled condenser fan, all of which are integrated to dynamically adjust system capacity in response to cooling demands.

The compressor is capable of operating between 1600 and 4500 revolutions per minute (RPM). Its minimum cooling capacity is specified as 101 W, while the maximum cooling capacity reaches 290 W.

Calorimetric test results for the compressor at 3000 RPM, under varying condensation and evaporation temperatures, are presented in Figure 2.

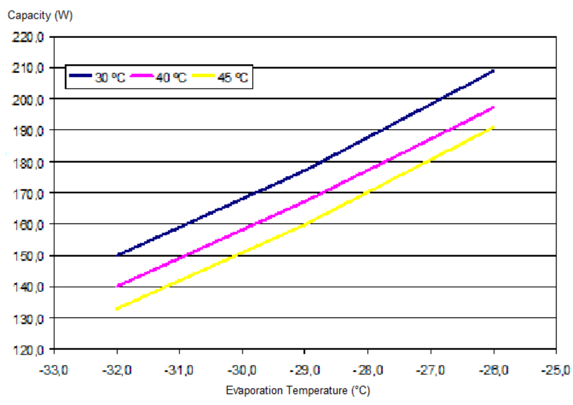

Figure 2. Compressor Capacity Variation as a Function of Rotational Speed

The outdoor unit incorporates a square-shaped coiled-tube condenser, selected for its compact geometry and effective surface area for heat rejection. The condenser is paired with an 8 W axial fan, which enhances air flow across the coil surface, facilitating efficient condensation of the refrigerant under varying load and ambient conditions

Proportional Control Valve

A proportional control valve is a type of flow control device that allows the precise regulation of refrigerant flow based on a continuously variable control signal. Unlike on/off (binary) solenoid valves, proportional valves can modulate their opening degree between 0% and 100%, enabling dynamic adjustment of flow rate in response to cooling demand.

Figure 3. Proportional Control Valve

Figure 3 shows the proportional control valve used in the experimental setup. The valve has one inlet port and two outlet ports. Since each compartment in the setup is equipped with its own dedicated valve, one of the outlet ports was sealed off during testing.

Control Unite

Each refrigeration compartment in the experimental setup is equipped with its own dedicated electronic control board. These boards are interconnected in series and communicate with a central control computer.

Connected to each electronic board are the following components:

- Evaporator temperature sensors
- Air (ambient) sensors
- Compartment user interface/display panel

Similarly, the outdoor unit—which includes the compressor, condenser fan, and crankcase heater—is also managed by a separate control board. This outdoor unit control board is integrated into the same serial communication line as the compartment boards and is fully addressable by the central control computer.

All data collected from the sensors and electronic boards are transmitted to the control computer, where they are processed by the custom control algorithm. Based on the algorithm's logic, the computer sends control signals to activate the necessary components—compressor, proportional valves, and condenser fan—via the respective control boards.

This modular and distributed control architecture enables precise management of each subsystem while ensuring coordinated operation across the entire refrigeration system.

Control System and Algorithm

In the developed parallel cooling experimental setup, all key cooling components—such as the compressor, condenser fan, and proportional expansion valves—are controlled by a custom algorithm. The operational status and parameters of these components are dynamically adjusted based on real-time temperature data from the refrigerated compartments.

Compressor Control:

- Start/stop logic is governed by the internal temperatures of the fresh food (TG) and freezer (DD) compartments.
- Compressor speed is modulated depending on the cooling demand:

If both compartments require cooling, the compressor operates at a higher speed (higher capacity).

If only one compartment requires cooling, the compressor runs at a lower speed to reduce energy consumption.

Proportional Valve Control:

- When both compartments demand cooling, the valve opening ratios are set according to predefined values in the control algorithm.

For example: 75% opening for TG, 25% for DD, or vice versa depending on priority and thermal load.

- If only one compartment requires cooling, the valve serving that compartment is set to fully open (100%), while the other remains closed.

After defining the control parameters—such as compressor speed and valve opening ratios—based on the cooling demand, a dedicated control algorithm was developed and uploaded to the central computer. System operation and regulation were then carried out via the computer interface, enabling precise and responsive management of the refrigeration cycle.

This control approach ensures optimized cooling performance, improved temperature stability, and energy-efficient operation under varying load conditions. Sung Ji and Chan-Chun proposed a patented method for refrigerator control, implemented by LG Electronics, aimed at enhancing system stability and temperature accuracy [14].

Experimental

The experiments conducted on the parallel cooling test setup were carried out in three stages, each designed to evaluate system behavior under different operating strategies and control scenarios.

Stage 1 – Sequential Cooling of Parallel-Connected Compartments

In the first stage, the fresh food (TG) and freezer (DD) compartments, although physically connected in parallel, were cooled sequentially. During periods when both compartments required cooling, priority was given to the fresh food compartment.

The control strategy in this stage was as follows:

- When one compartment was being cooled, its proportional valve was set to 100% open, while the valve for the other compartment remained fully closed.
- Once the first compartment reached its target temperature, the refrigerant flow was switched to the second compartment by fully opening its valve.

This approach ensured that only one compartment received refrigerant flow at a time, while the other remained inactive. To evaluate the influence of compressor speed, three different compressor speeds were tested during this stage. For each speed setting, both compartments were tested under the same compressor RPM to ensure consistency in performance comparison.

Stage 2 – Simultaneous Cooling of Parallel-Connected Compartments

In the second stage, the system was operated to cool both compartments simultaneously. The proportional valves were set to specific opening ratios based on the desired refrigerant distribution between the TG and DD compartments. The compressor speed was adjusted accordingly:

- A higher compressor speed was selected when both compartments were cooled simultaneously, ensuring sufficient cooling capacity.
- When only one compartment required cooling, a lower compressor speed was used to avoid energy waste and overcooling.

The same refrigerant charge used in Stage 1 was maintained in Stage 2 to ensure fair comparison and system consistency. The selected compressor speeds and valve opening ratios used in this phase are presented in Table 2

.

Table 2. Compressor Speeds and Valve Opening Ratios Used in the Experiments

Stage 1: Sequential Cooling Experiments
Compressor speeds: 2000 rpm - 2500 rpm 3000 rpm - 3500 rpm - 4000 rpm - 4500 rpm
Stage 2: Parallel Cooling Experiments
Compressor speeds Both Compartments Active: 3500 rpm - 4000 rpm - 4500 rpm Single Compartment Active: 2000 rpm - 2500 rpm - 3000 rpm
Valve Opening Ratios
Fresh Food Compartment (TG): %75 - %50 - %25 Freezer Compartment (DD): %25 - %50 - %75

Stage 3 – Parallel Cooling with Constant Compressor Speed

In the third stage of the experimental study, the system was again operated to cool both compartments simultaneously. However, unlike the second stage, the compressor speed was fixed—meaning that no adjustments were made depending on whether one or both compartments required cooling.

A constant compressor speed was selected for all tests in this stage, regardless of the active cooling load. The speed values used were the same as those selected in Stage 2 for dual-compartment cooling conditions (i.e., 3500, 4000, and 4500 rpm).

This approach allowed the evaluation of system performance and thermal regulation under fixed-capacity operation, providing a baseline for comparison with variable-speed strategies used in previous stages.

Dimensional Analysis

Dimensional analysis is a method used to identify complex relationships between dependent and independent experimental variables in physical systems. It provides a systematic approach to simplifying equations and identifying relevant dimensionless groups.

Each physical quantity can be expressed in terms of basic dimensions, typically:

- Mass (M)
- Length (L)
- Time (T)

These base dimensions are combined with appropriate exponents to represent the dimensional form of any physical quantity.

The Buckingham Pi Theorem is a fundamental method that forms the basis of dimensional analysis [2]. It states that any physically meaningful equation involving n variables can be reformulated into an equivalent equation involving (n − m) dimensionless parameters, where m is the number of fundamental dimensions (such as mass, length, time) involved in the problem. More importantly, the theorem also provides a systematic procedure for deriving these dimensionless parameters from the original dimensional variables. Let us consider a physical problem that involves n physical quantities.

The dimensional analysis of these physical quantities is presented in Table 3.

Table 3. Physical Quantities Used in the System Energy Consumption Analysis

Quantity	Symbol	Dimension
Temperature	ºC	K
Compressor Speed	t	1/T
Compressor Operation Time	t	T
Energy Consumption	V^2/2, gz	L^2/T ^2
Valve Opening Ratio	-	-

The Π1 and Π2 parameters represent the dimensionless valve opening ratios.

Π1 = Valve opening ratio of the freezer compartment (VTGRZ)

Π2 = Valve opening ratio of the fresh food compartment (VTGF)

Π3 parameter, defined as a dimensionless group representing the relationship between the minimum compressor speed (KD_{min}) and the compressor operation time.

Π3 = KDmin* Tkmpmin

Π4 parameter, defined as a dimensionless group representing the relationship between the maximum compressor speed (KD_{max}) and the compressor operation timeır.

Π4 = KDmax* Tkmpmax

Π5 parameter, defined as a dimensionless group representing the relationship among the fresh food compartment temperature, the freezer compartment temperature, and the ambient temperature.

With the definition of the dimensionless numbers, the energy consumption equation, originally defined in Equation, has been reformulated in terms of five dimensionless parameters. As a result of the non-dimensionalities process, Equation transforms into Equation.

Energy Consumption (ET) = f(Π1, Π2, Π3, Π4, Π5)

In order to establish a relationship between the energy consumption and the derived dimensionless Π parameters, it is necessary to determine the appropriate coefficients for these parameters. Once these coefficients are obtained, an assessment of the energy consumption can be carried out. For this purpose, the regression analysis method was employed.

In order to perform the regression analysis, the Sigma Plot software was utilized [13]. During the analysis, a total of 1,000,000 iterations were conducted in steps of 100, and the solution was achieved within a tolerance range of 0.000001. The coefficients (a_n) obtained as a result of the analysis are presented in Table 4.

Table 4. Regression Coefficients Obtained from the Analysis

a1	a2	a3	a4	a5	a6
0,280	0,079	-0,077	0,034	-3,842	8,844

By substituting the obtained coefficients into Equation, the equation is transformed into the following form

$$ln\,E\,T = 8{,}844x + 0{,}280\,ln\Pi_1\,x + 0{,}079\,ln\Pi_2\,x - 0{,}077\Pi_3 x + 0{,}034\,ln\Pi_4\,x - 3{,}842\,ln\Pi_5$$

The error margin of the model obtained from the analysis is ±1.55%, and the results remain within this range. The comparison between the experimental energy consumption values and the values predicted by the developed model is presented in Figure 4.

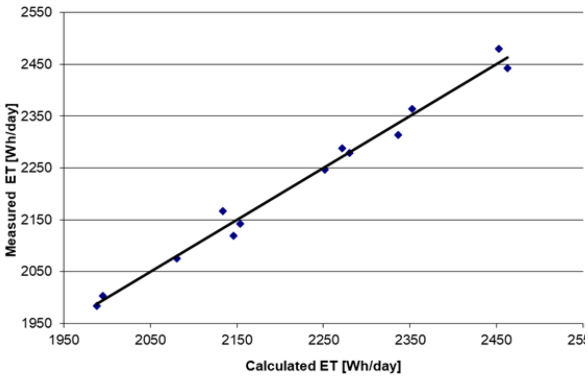

Figure 4. Comparison Between the Energy Consumption Model and Experimental Results

As observed in Figure 4, the data obtained from the model exhibit a sufficiently narrow distribution range.

3. Results and discussion

3.1 Effect of Different Compressor Speeds on System Energy Consumption in Parallel Cooling Operation

Due to the differing heat gains of the compartments used in the parallel cooling system and the increased total cooling demand when both compartments are cooled simultaneously, it was hypothesized that using different compressor speeds for parallel and single-compartment cooling modes could reduce energy consumption. Based on this objective, when the experiments conducted with selected compressor speeds and valve opening ratios were evaluated, it was observed that the energy consumption values varied by approximately 9%. In the experiment where the valve opening ratio was set to 75% for the fresh food compartment (TG) and 25% for the freezer compartment (DD), it was found that energy consumption increased as the compressor speed selected for simultaneous cooling of both compartments increased, whereas it decreased as the compressor speed selected for single-compartment cooling increased (Figure 5).

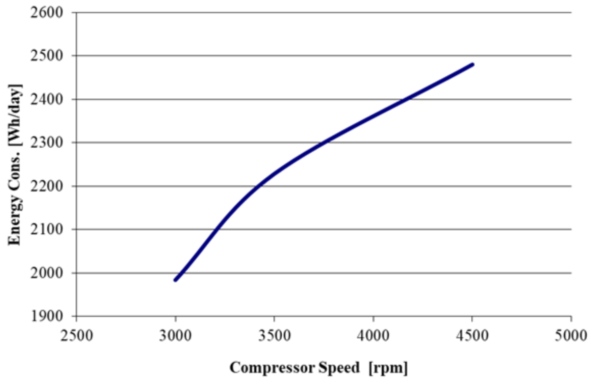

Figure 5. Relationship Between Compressor Speed Variation and Energy Consumption in Simultaneous Cooling Operation

Based on the results of variable-speed and fixed-speed compressor operation, it has been observed that selecting appropriate compressor speeds significantly affects both energy consumption and the compressor duty cycle.

3.2 Effect of Valve Opening Ratio on System Energy Consumption in Parallel Cooling

Since the heat gains and set temperatures of the cabinets used in the study are different, it is known that the cooling rates of the two cabinets will not be the same. As the freezer compartment is set to a lower temperature compared to the fresh food compartment, the refrigerant discharged by the compressor is expected to move toward the freezer's cooling line, resulting in a lower amount of refrigerant reaching the evaporator in the fresh food compartment.

In light of this information, to achieve balanced cooling rates and to prevent wide temperature fluctuations within the compartments, the initial tests in parallel operation were conducted with the fresh food compartment valve opened at 75% and the freezer compartment valve opened at 25%. In the next phase, the valves for both compartments were set to an equal opening ratio of 50%. In the final stage, the valve of the fresh food compartment was adjusted to 25% and that of the freezer compartment to 75%. The graph showing the effect of valve opening ratio variation on energy consumption is presented in Figure 6.

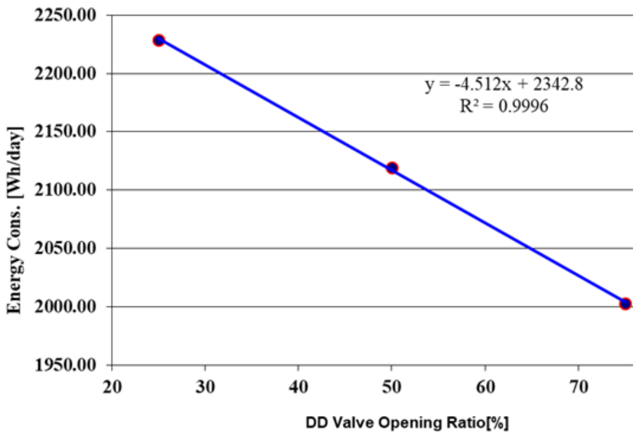

Figure 6. Effect of Valve Opening Ratio Variation on Energy Consumption

As shown in Figure 6, a linear decrease in energy consumption was observed with the increase of the freezer compartment valve opening ratio and the simultaneous decrease of the fresh food compartment valve opening ratio. In the experiments illustrated in the graph, the compressor was operated at 3500 rpm during simultaneous cooling of both compartments, and at 3000 rpm when each compartment was cooled individually. The difference in energy consumption between the best and worst cases was observed to be approximately 11%.

This reduction in energy consumption is attributed to the direction of refrigerant flow. In the parallel cooling scenario where the valve opening ratio was set to 75% for the fresh food compartment and 25% for the freezer compartment, the refrigerant tended to flow toward the colder freezer compartment when both compartments required cooling. Due to the low valve opening in the freezer compartment, the refrigerant took longer to fill the evaporator, which prolonged the cooling time of the compartment. Additionally, as the refrigerant migrated toward the colder freezer section, a reduction in refrigerant mass was observed in the evaporator of the relatively warmer fresh food compartment.

As a result, energy consumption was found to be higher in the configuration where the refrigerant migrated from the warmer to the colder region, causing a delay in cooling for the fresh food compartment and slower evaporator filling in the freezer due to the restricted valve opening.

In contrast, in the case with the lowest energy consumption, the variation of shelf temperatures during simultaneous cooling showed no significant sudden temperature rises. Although the cooling rate of the fresh food compartment varied during parallel operation, this variation did not result in an increase in compartment temperature (Figure 7).

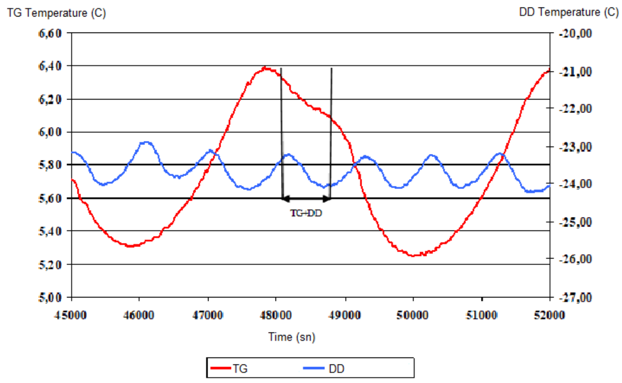

Figure 7. Variation of Compartment Temperatures During Simultaneous Cooling

As shown in the graph in Figure 7, a decrease in the cooling rate of the fresh food compartment occurs during simultaneous (parallel) cooling. During the 7-minute period in which the cooling rate slows down, it was observed that the refrigerant flowing to the evaporator of the fresh food compartment remained sufficient to continue cooling the compartment.

3.3 Effect of Sequential and Parallel Cooling on Energy Consumption

In the experiments where parallel-connected compartments were cooled sequentially, the energy consumption values were found to be close to those of parallel cooling. However, in this type of cooling configuration, it was observed that the temperature fluctuation within the non-cooled compartment increased significantly during its waiting period (see Figure 8).

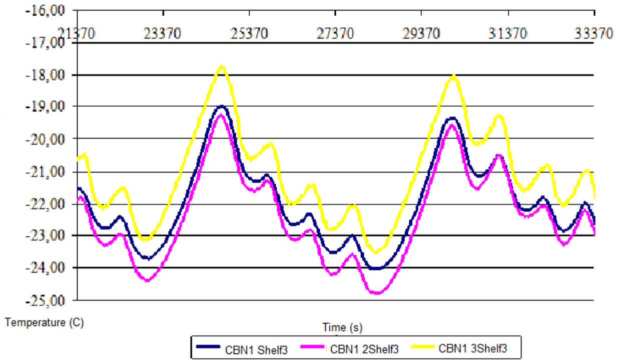

Figure 8. Sequential cooling DD compartment

As shown in Figure 8, during sequential cooling, the shelf temperatures within the freezer (DD) compartment fluctuate within a range of approximately 6 °C. In contrast, under parallel cooling conditions, the temperature variation inside the compartment is limited to a range of about 1 °C.

Although the energy consumption of the best-performing parallel cooling configuration is approximately 1% higher than that of sequential cooling, the significantly improved temperature stability observed in Figure 8 indicates that the parallel cooling strategy is more favourable.

4. Conclusions

The effects of various system components on the energy consumption of a parallel cooling system—where the refrigeration compartments are connected in parallel and can be cooled simultaneously—were experimentally investigated. The major conclusions drawn from the experiments are summarized below:

Increasing the valve opening ratio of the freezer compartment (DD) results in achieving temperatures closer to the setpoints within both compartments. As the valve opening ratio of the freezer compartment increases, total energy consumption decreases.

During simultaneous cooling, increasing the compressor speed leads to a rise in energy consumption.

In cases where only one compartment is cooled, reducing the compressor speed results in increased energy consumption.

For both operating scenarios (individual and simultaneous cooling), using a fixed compressor speed enables the system to maintain the desired compartment temperatures, with energy consumption values comparable to those observed when using variable compressor speeds.

In conclusion, selecting appropriate compressor speeds and valve opening ratios for individual and simultaneous cooling can significantly improve energy efficiency while maintaining the desired compartment temperature levels.

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