

Experimental Investigation of Ambient Temperature Effects on Domestic Refrigerators' Performance and Running Ratio

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Abstract

Background: The domestic refrigerator is one of the most widely used household appliances, and improving its performance can significantly contribute to energy savings and environmental sustainability. Maintaining low and uniform temperatures is essential to prevent food spoilage and inhibit microbial growth. This study experimentally investigates the impact of varying ambient temperatures (15°C, 30°C, and 43°C) on refrigerator performance and running ratio. Three refrigerator samples were tested in a controlled laboratory setting to evaluate their efficiency under different thermal conditions. The results provide insights into how external temperature fluctuations affect operational performance, offering a potential increase in running ratio by 16% when testing the samples in 30 °C compared with testing in 15 °C to maintain the performance, slightly change in running ratio for the tested samples around 2% in 43 °C compared with its result in 30 °C.

Keywords: Top-freezer refrigerator, Running Ratio, Coefficient of Performance (COP).

1. Introduction

A crucial thermodynamic process, refrigeration transfers heat from the refrigerator's inside to the outside, preserving food. To maintain the proper temperatures 0 to 4°C for fresh food and -18 to -24°C for freezers. Home refrigerators use a vapor-compression cycle using environmentally benign refrigerants like R600a. This promotes sustainability and savings by lowering energy consumption and slowing microbial development. Efficiency in a variety of climates is ensured by contemporary features like adaptive defrosting and precise temperature management. The global refrigerator market is expected to increase at a compound annual growth rate (CAGR) of 6.23% from its 2023 valuation of USD 70.33 billion to USD 128.74 billion by 2033 as shown in figure 1(Global Refrigerator Market , 2023). Modular kitchen trends and changing eating patterns are the main drivers of growth. The three primary components of a top-freezer refrigerator are a freezer with an evaporator and defrost system, an insulated cabinet with steel exterior, plastic inside, and foam insulation to reduce heat gain, and a refrigerator section with movable shelves, crispers, and door storage. It works by coordinating the actions of the temperature controls, condenser, and evaporator as shown in Figure 2. The selection of refrigerants for vapor-compression refrigeration systems is critical, as it impacts thermodynamic performance, environmental sustainability, and safety(Haggag et al., 2025).

The Coefficient of Performance (COP) is a critical metric for assessing the efficiency of refrigeration systems, defined as the ratio of refrigeration capacity to the power input necessary for the compressor. Elevated COP values signify more efficient systems, resulting in diminished energy usage and operational expenses. The operational ratio of a fridge, is defined as the duration the compressor operates, is affected by several factors including ambient temperature, frequency of door openings, and load circumstances. Research indicates that refrigerators generally activate and deactivate every thirty to one hour to sustain ideal internal temperatures while reducing energy use.

Domestic refrigeration systems are critical household appliances, accounting for a significant portion of residential electricity consumption. Given their continuous operation, even minor improvements in performance can translate into substantial energy savings. A key factor influencing refrigerator performance is the ambient temperature, which directly affects compressor cycling, internal temperature uniformity, and energy consumption. Azzouz et al. (2009) explored thermal energy storage integration to enhance refrigerator performance, emphasizing how ambient temperature alters cooling efficiency. Similarly, James and James (2010) assessed food cold chains under climate change scenarios, highlighting that rising ambient temperatures challenge refrigeration reliability and food safety.

Saidur et al. (2002) identified ambient temperature as a critical variable impacting the coefficient of performance (COP) and compressor workload. Their findings were echoed by Alsaad and Hammad (1998), who demonstrated that both ambient temperature and power supply frequency significantly influence household refrigerator energy use. Roy and Singh (2015) studied refrigerant alternatives and how their behavior changes under varying thermal conditions. Their analysis of R134a and hydrocarbon blends showed that performance varies considerably with ambient heat loads. Similarly, Sharma and Bansal (2014) evaluated eco-friendly refrigerants like R600a and concluded they perform better than conventional refrigerants in high-temperature environments.

Giroto et al. (2004) conducted a comparative study on energy consumption patterns of domestic refrigerators under different ambient conditions. Their results indicated that energy usage increased linearly with temperature due to longer compressor operation. Yilmaz and Ermis (2012) also found that high ambient temperatures reduced cooling efficiency and extended compressor run-time, further lowering system COP. Furthermore, Hepbasli and Kalinci (2009) reviewed energy and exergy assessments in refrigeration systems. They emphasized that ambient thermal conditions significantly impact exergy losses, leading to overall performance degradation. Abdel-Salam and Mahmoud (2018) performed experimental testing on a top-mount refrigerator, where they analyzed performance parameters across multiple ambient conditions. Their findings showed a steep drop in COP above 35°C ambient temperature, consistent with the results of the current study.

Nekså (2002) focused on R744 (CO₂) systems, illustrating how ambient temperature heavily

influences performance in transcritical cycles. Though different in refrigerant type, the study underlined the universal importance of controlling environmental conditions. Kabir et al. (2010) tested a domestic refrigerator using R600a and found significant energy savings at lower ambient temperatures. Their study supported findings from Ahamed et al. (2011), who also linked compressor power consumption and refrigerant mass flow to environmental conditions. In terms of system modeling, Navarro-Esbrí et al. (2005) simulated domestic refrigerator behavior under dynamic loads. Their model indicated that performance is highly sensitive to fluctuations in ambient air, which affects internal air circulation and evaporator efficiency. More recently, Hassan et al. (2020) performed a detailed computational and experimental investigation of household refrigerator performance under extreme ambient conditions. They emphasized the need for improved insulation and compressor control logic to handle temperature stress, especially in regions with high summer temperatures. Lastly, Khan and Zubair (2017) conducted an exergy-based study of refrigerator components, confirming that ambient temperature is a key factor in determining overall thermodynamic performance.

This study's main goal is to experimentally examine the effects of different ambient temperatures (15°C, 30°C, and 43°C) on the functionality and running ratio of residential refrigerators. The study intends to offer insights into optimizing refrigerator operation for increased energy savings, dependability, and environmental sustainability under actual climatic conditions by assessing temperature distribution, running cycle behavior, and energy efficiency across various thermal environments.

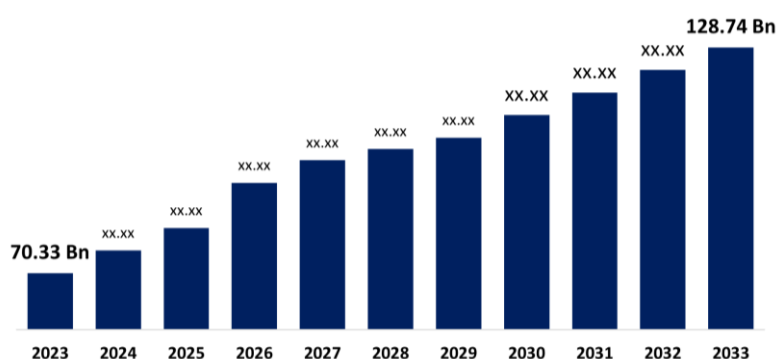


Fig.1; Global Refrigerator Market

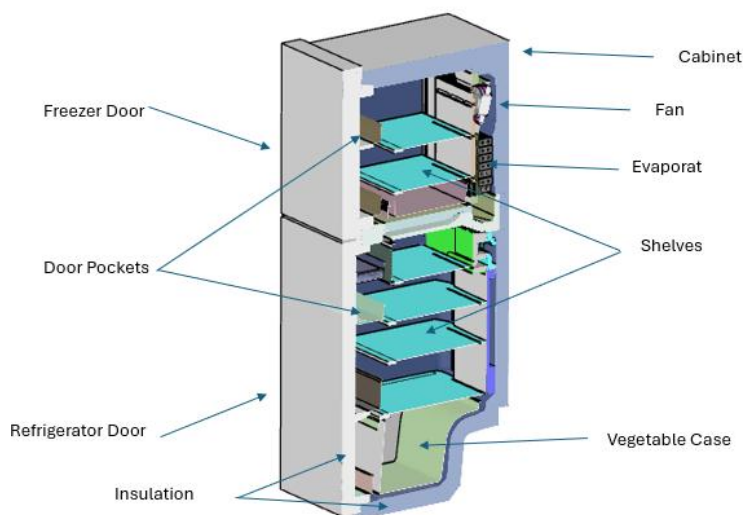


Fig. 2; Refrigerator Top Freezer components

2. Experimental Setup

The existing model is a refrigerator with a top-mounted freezer SJ-GV63G which was stable produced and already on the market. Figure 3 demonstrates the schematic diagram of this model. The upper segment contains the freezer compartment (F-Compartment) featuring a dedicated door (F-door), while the lower section comprises the refrigerator compartment (R-Compartment) that has the corresponding door (R-door). The F-Compartment comprises two shelves, one drawer, and two pockets mounted to the door. The R-Compartment includes three shelves, a fresh case, a vegetable case, and four door pockets. An axial fan is situated in the freezer above the evaporator at a designated angle, enabling air to circulate throughout the F-Compartment and the R-Compartment. The ducting system facilitates the dispersion of air to every shelf, case, drawer, and compartment. The air circulates from the freezer chamber to the refrigerator compartment via a damper.

Figure 4 exhibits the experimental configuration employed in the latest investigation at the refrigerator performance laboratory. Figure 5 illustrates the thermocouple arrangement and the sequence of measurement locations at each phase of the refrigeration system. Six copper-constantan T-type thermocouples are installed in the freezer and refrigerator compartments. These thermocouples are positioned and allocated on shelves and cases to monitor the temperature, as illustrated in Figures 4 and 3. Figure 5(b) depicts the labeling of the shelves.

The thermocouples possess an operating temperature that varies from -50°C to 150°C , with a relative inaccuracy of $\pm 0.5^{\circ}\text{C}$ within typical conditions. A thermocouple is located at the center of the second shelf (F-2). The refrigerator compartment contains one temperature monitoring point per drawer for both the

fresh case and bottom vegetable case (V-Case). Every shelf situated in between contains one thermocouple point, as detailed in Table 2.

The experiment was executed by IEC 62552 requirements within the refrigerator performance laboratory. The laboratory's temperature and relative humidity were established, and the sensors were calibrated as specified in Table 2. The experiment commenced by inserting the test specimen and documenting the temperature continuously. A computerized controller and a human-machine interface managed the device's operating in the testing system, while a high-precision data collector acquired the operational data. Real-time data transmission to a high-performance computer to be processed was feasible; the computer exhibited, archived, generated, and reprinted the test findings.

This study experimentally investigates the impact of varying ambient temperatures (15°C , 30°C , and 43°C) on refrigerator performance and running ratio. Three refrigerator samples were tested in a controlled laboratory setting to evaluate their efficiency under different thermal conditions. The results provide insights into how external temperature fluctuations affect operational performance. The three samples were initially tested at 15°C in a refrigerator performance lab until the compartment temperatures stabilized, as measured by the temperature sensors. Accumulative data was then collected for analysis. Subsequently, the ambient temperature in the testing room was adjusted to 30°C , and the tests were repeated. Finally, the ambient temperature was increased to 43°C , representing the most challenging environmental condition. Temperature measuring thermocouples were distributed with one sensor in the freezer compartment and five temperature sensors in the refrigerator compartment, as shown in Table 2.

The current study utilized normalization for clarity in presenting results, as the temperature differential between the F-compartment and R-compartment was significantly elevated. Consequently, normalization was deemed appropriate for plotting all measurement points in a single figure. The formula for the normalized temperature value is as follows:

$$\Theta = (T - T_{\min}) / (T_{\max} - T_{\min}) \quad (1)$$

T represents the temperature of the measuring surface, $T_{\min}$ denotes the minimum temperature in the present study, and $T_{\max}$ signifies the maximum temperature in the present study.

An uncertainty analysis was conducted for the thermistor-based temperature measurements. The sensor's specified accuracy is $\pm 0.5^{\circ}\text{C}$, which encompasses potential deviations from calibration and environmental factors. Additional error sources include a minimal linearity error of $\pm 0.015^{\circ}\text{C}$ (0.5%) and a resolution limit of 0.05°C . Combining these elements, the total estimated measurement uncertainty is $\pm 0.50^{\circ}\text{C}$ across the operational range of -50.0°C to 150.0°C . This level of uncertainty ensures the data's reliability for the purposes of this thermal analysis.

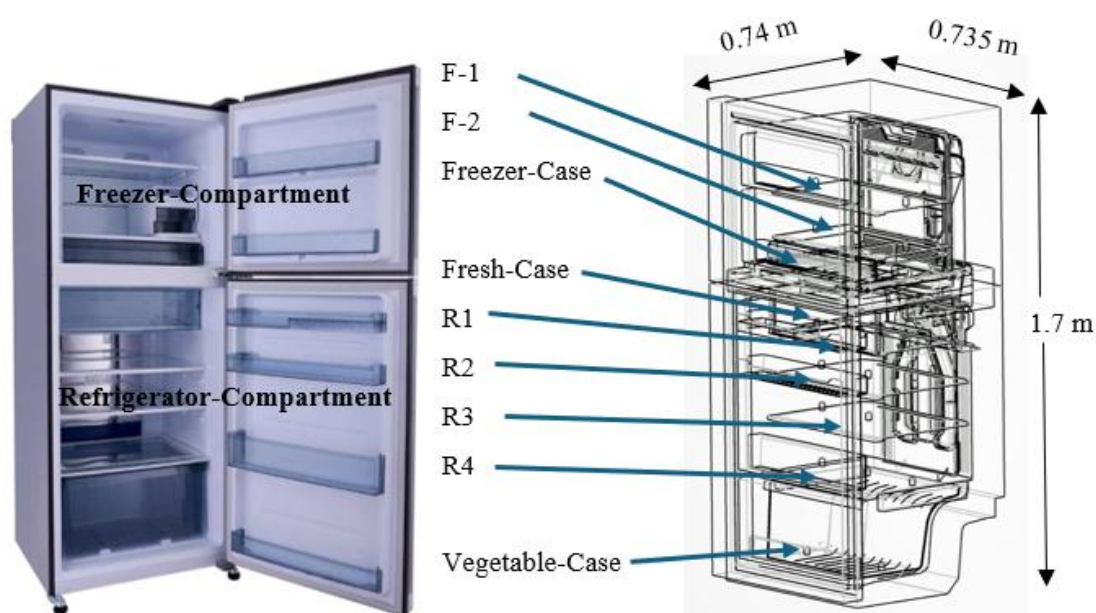


Fig. 3; The schematic diagram of top-freezer refrigerator.



Fig. 4; The experimental setup of Top Freezer refrigerator system.

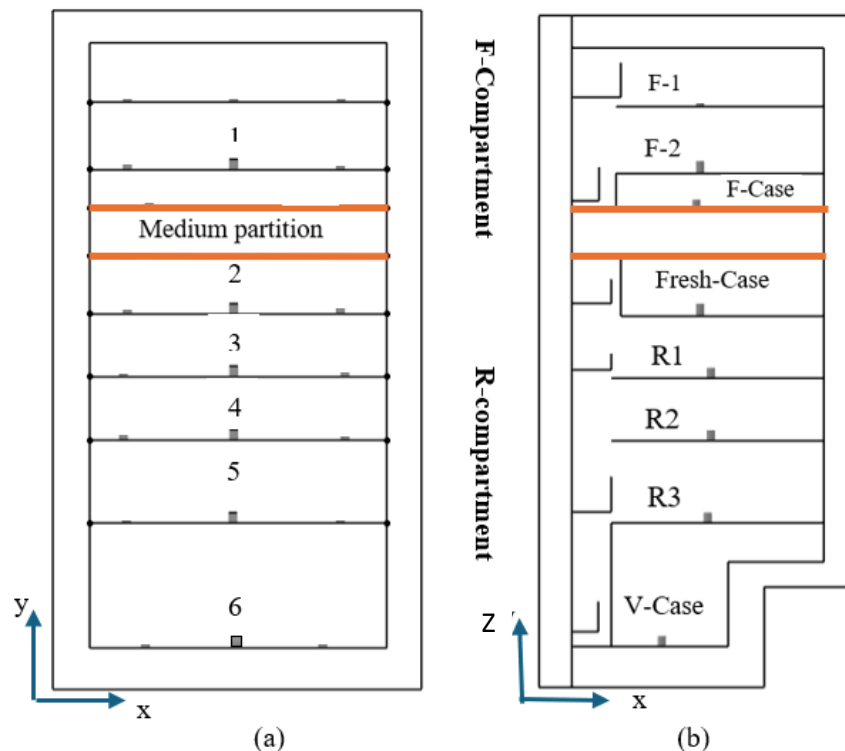


Fig. 5; The temperature measuring points at surfaces of the freezer and refrigerator compartments and the shelf names (a) Front view and positions of thermocouples, (b) Side view and shelf names.

Table 2; The positions of thermocouples at surfaces of the F&R-Compartments.

Compartments	Thermocouple	Shelf position
Freezer Compartment	1	F-2-C
	2	FRESH-CASE-C
Refrigerator Compartment	3	R1-C
	4	R2-C
	5	R3-C
	6	V.CASE-C

3. Results and Discussion

In the current study, sample 1 performance tends to keep the temperature set in Freezer compartment and Refrigerator compartment as shown in Figure 6, the temperature measuring sensor No. 1 in the freezer compartment at 15 °C was lower than at 30 °C and 43 °C. the remaining temperature measuring sensors from no.2 to no.5 was greater in 15 °C than 30

°C and 43 °C and also identical in 30°C and 43°C. Unlike expected the temperature measuring sensor no. 6 was lower in 15°C than 30 °C and 43 °C, the temperature measuring sensor no. 6 location was in vegetable case which nearest one to the compressor, so it was not easy to achieve the target temperature. The running ratio increased by 6% by increasing the environmental condition from 15°C to 30°C and 43°C as shown in figure 7.

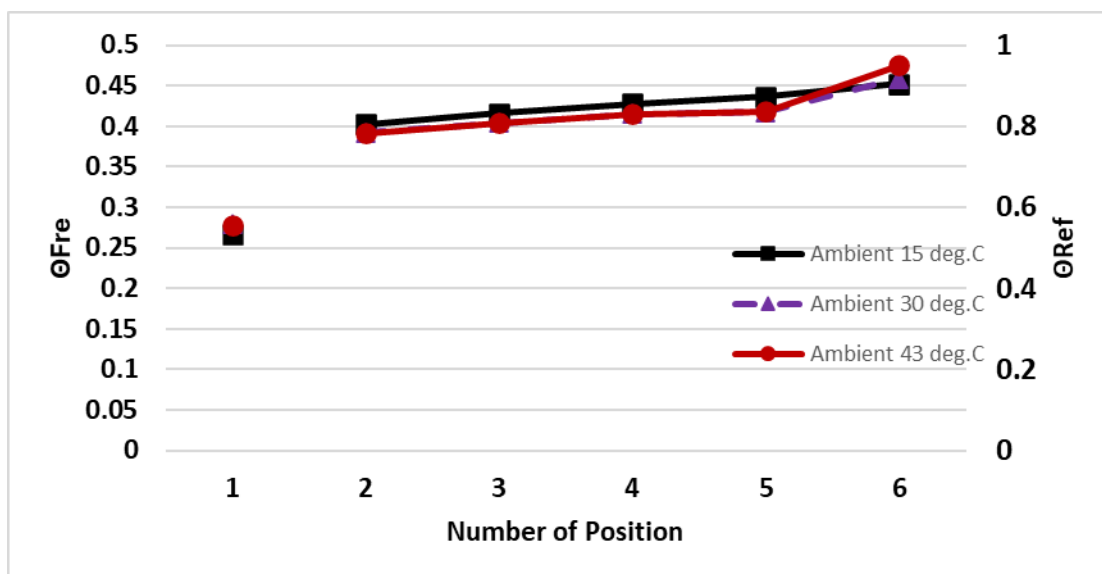


Fig.6; Temperature distribution in different ambient temperatures inside F&R compartments for sample 1

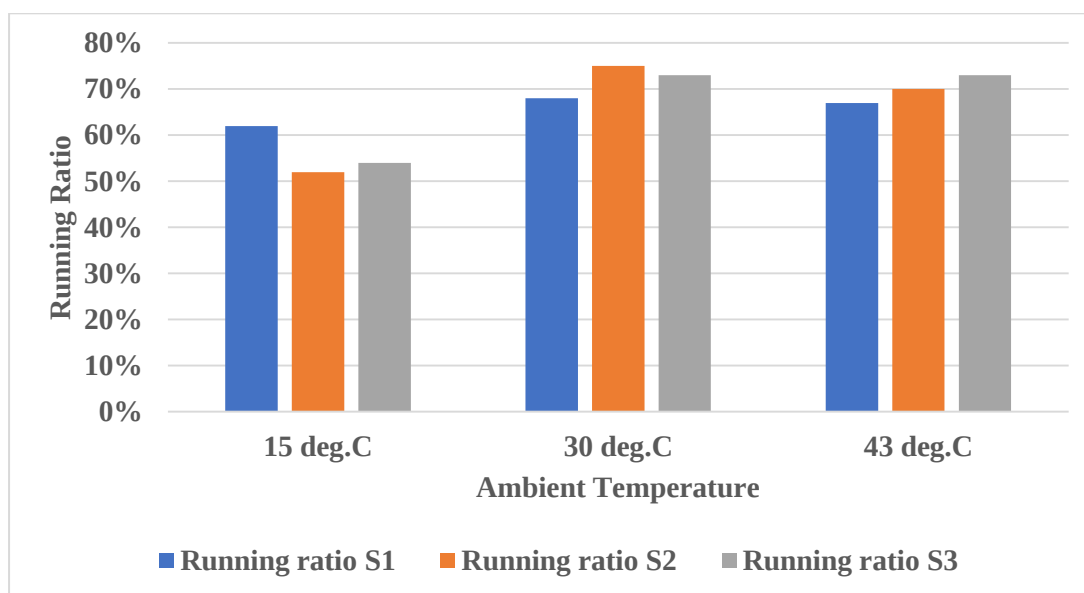


Fig. 7; Runing Ratio

For sample 2, in Freezer compartment the measuring Surface no.1 was lowest at 15°C, in Refrigerator compartment the temperature measuring sensors from no.2 to no.5 decreased by increasing the environmental temperature, but the latest temperature measuring sensor No. 6 increases with the

environmental temperature, similar to the behavior in Sample 1, as shown in figure 8. The running ratio increased by 23% when the environmental temperature was modified from 15°C to 30°C and then decreased by 5% when tested in 43°C compared to 30°C as shown in figure 7.

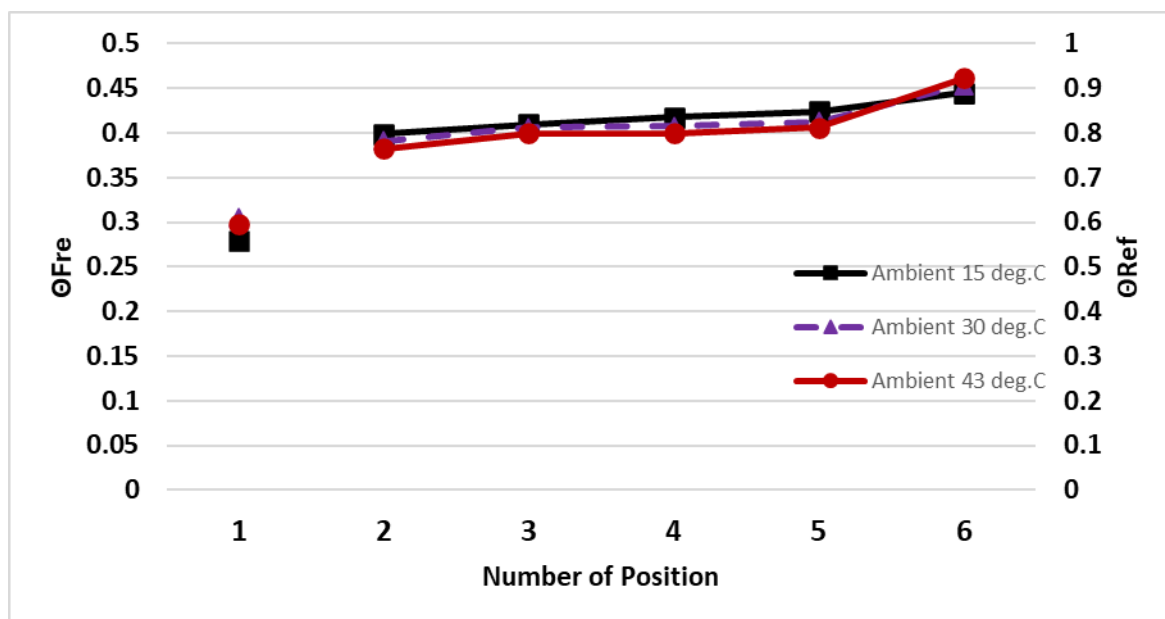


Fig. 8; Temperature distribution in different ambient temperatures inside F&R compartments for sample 2

Like sample 1, sample 3 has the same behavior in Freezer compartment for temperature measuring sensor no.1. and in refrigerator compartment for the no. 2,3,4,5 and 6 as shown in figure 9. The running ratio

increased by 19% when the environmental temperature was changed from 15°C to 30°C. and no change in running when increasing the temperature from 30°C to 43°C as shown in figure 7.

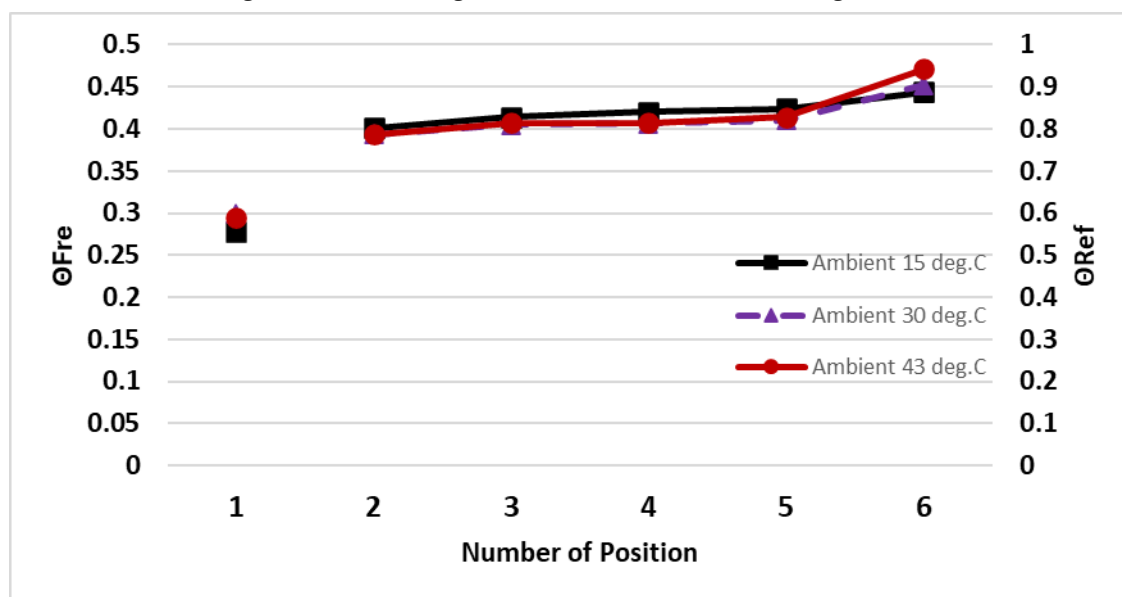


Fig. 9; Temperature distribution in different ambient temperatures inside F&R compartments for sample 3

Figure 10 illustrates the impact of varying ambient temperatures on electric power consumption. It is evident that the peak electric power consumption reached 2500.8 wh/day at an ambient temperature of 43

°C, while the minimum consumption is 1281.6 wh/day at 15 °C. Additionally, the electric power consumption at 30 °C is recorded at 1502.4 wh/day.

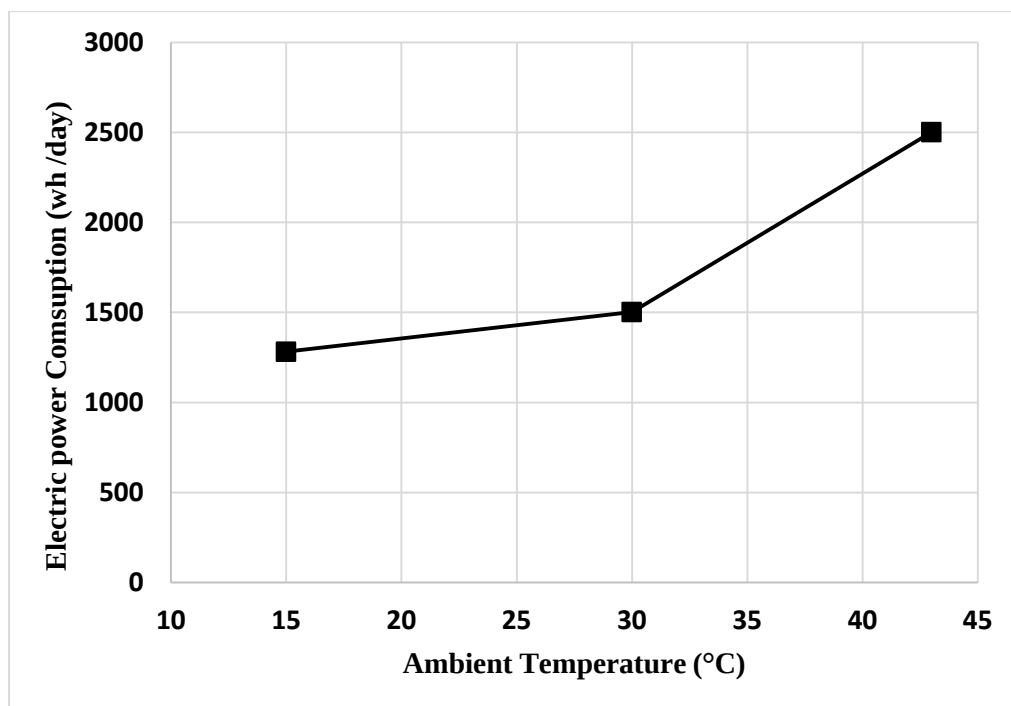


Fig. 10; Electric power Consumption Vs. Ambient Temperature

The refrigerator's coefficient of performance (COP) was evaluated at ambient temperatures of 15°C, 30°C, and 43°C using experimentally measured power consumption and evaporator temperatures Table 3. The

cooling capacity (Q_L) and compressor work (W) were derived from thermodynamic properties of R600a and a mass flow rate of 1.6 g/s as shown in table 4.

Table 3; Evaporator inlet and outlet temperature in different ambient

Ambient Temperature (°C)	Measuring Point	Temperature (°C)
15	Evaporator inlet	-19.73
	Evaporator outlet	-19.13
	Evaporator inlet	-16.63
30	Evaporator outlet	-15.83
	Evaporator inlet	-18.23
43	Evaporator outlet	-17.63

Table 4; The cooling capacity (Q_L) and compressor work (W)

Ambient Temperature (°C)	Cooling Capacity (W)	Compressor work (W)	COP
15	288	53.4	4.58
30	275	62.6	3.74
43	260	104.2	2.12

At 15°C ambient, the system achieved a COP of 4.58, COP declined to 2.12 at 43°C due to a 95% increase in compressor work as shown in figure 11, highlighting thermal stress in high-ambient operation.

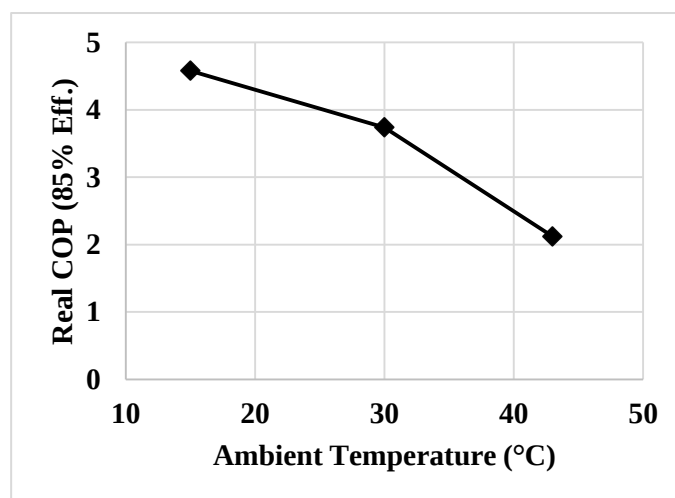


Fig. 11; COPs at different ambient temperatures

4. Conclusion

This study evaluated the thermal performance and energy efficiency of refrigerator systems under varying ambient temperatures (15°C, 30°C, and 43°C). Key findings reveal that:

1. Temperature Distribution: Freezer compartment temperatures (Sensor #1) were consistently lowest at 15°C, with higher ambient conditions (30°C and 43°C). Refrigerator compartment sensors (#2–#5) exhibited inverse trends, with 15°C achieving higher temperatures than 30°C/43°C. Sensor #6 (vegetable case near the compressor) struggled to reach target temperatures due to proximity to heat sources.
2. Running Ratio Dynamics: Sample 1 showed a 6% increase in running ratio from 15°C to 43°C, while Samples 2 and 3 exhibited nonlinear trends (23% and 19% increases at 30°C, respectively). Sample 2's 5% reduction in running ratio at 43°C (vs. 30°C) suggests adaptive defrost activation.
3. Energy and COP Performance: Power consumption surged by 95% at 43°C (2500.8 wh/day) compared to 15°C (1281.6 wh/day), directly impacting COP (4.58 at 15°C vs. 2.12 at 43°C). the COP degradation rate was approximately 0.5% per °C.

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