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Techno-economic feasibility of conventional and eco-friendly refrigerators: A horizontal analysis

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ABSTRACT

The refrigerators have become an inseparable part of the lives of the millions of people around the globe. The cool temperature in the refrigerator slows down the enzyme activity and bacterial reproduction in the food. Protection of environment by eco-fridge is need of the hour. A study was conducted to compare the techno-economic feasibility of conventional and eco-friendly refrigerator in terms of quality of food, Coefficient of Performance (COP) and Performance of System (POS). The food items namely kheer (traditional Indian recipe prepared by milk, sugar and rice), custard and salad were selected for testing. The samples were then evaluated for their organoleptic appeal. Significant difference was found in quality of food kept in both the refrigerators; at 5 and 1 per cent level of significance. Study also revealed that eco-fridge is more efficient and economical appliance than conventional refrigerator in terms of COP attended during no load and full load condition.

Key words: Coefficient of performance, conventional refrigerator, eco-fridge, organoleptic characteristics

INTRODUCTION

Equipments are valued for the work that they can do, as well for the ways in which they reduce time and effort required for many routine tasks. Refrigeration can substantially reduce the rate at which food will deteriorate. Low temperatures slow down the growth of microorganisms and the rate of chemical (including enzymatic) changes in food. These are two of the main causes of food spoilage (https://koolit.co.uk). Different parts of refrigerator may operate at different temperatures. In older style refrigerators, the upper shelves are often slightly colder than the lower shelves. In more modern appliances, the temperature is maintained relatively uniform throughout. The warmest and coldest areas inside the refrigerator are dependent on the types of model (https://www.csiro.au). To promote sustainable consumption, one needs to look at the aspect of sustainable production too. Refrigerators have become an inseparable part of the lives of the millions of people around the globe. Rapid communication and increasing access to commodities plus changes in life style have spurred the need to stock food and beverage in refrigerator for longer. Storage and transportation of medicines is another important area of usage. Also, consumer choices significantly influence the environmental impact of cooling appliances (Kim and Lee, 2023). Small adjustments in usage habits and careful selection of energy-efficient products can result in substantial reductions in energy consumption and greenhouse gas emissions (Rohella and Biswal, 2008). By embracing sustainable cooling practices, individuals need to be updated and play a crucial role in the collective effort to combat climate change and safeguard the environment (TERI, 2023). It is known that reduction in temperature will slow down the processes of decay and spoilage in many foods. The purpose of a freezer is to stop bacterial

growth completely by freezing the water present in the food. Generally, the consumer shopping for new refrigerator look for one that cools food efficiently, maintain temperature evenly and minimizes spoilage. Food occupies the first position in the hierarchical needs of man. The refrigerator is one of those miracles of modern living that totally changed the life style. Prior to refrigeration, the only way to preserve meat was to salt it, and iced beverages in the summer were a real luxury (https://www.danfoss.com).

Kumar (2003) revealed that the cool temperature in the refrigerator slows down the enzymes activity and bacterial reproduction in the food. This preserve food quality, taste, texture and there by keeps food safer for longer time. Gerster (1997) studied that all the early refrigerants like methyl chloride, sulphur-di-oxide, carbon dioxide and ammonia do have disadvantages like flammability, toxicity, time of preservation etc, which restrict their general use. Now-a-days, most common technology recommended in refrigerator is "Hydrocarbon Technology" which protects the ozone layer (GPI, 2025). Also, a number of inventions have prompted the accessibility to varied choices of these eco-fridges. Present study helps to some extent in protecting the environment by usage of eco-fridges (Kumar and Singh, 2024).

MATERIALS AND METHODS

Conventional refrigerator

Any refrigerator that has been produced through old technology i.e. HFC and CFC technology as refrigerants can be called as conventional refrigerator.

Eco-fridge

A popular name of 'Green Fridge' which is according to environment. In which "hydrocarbon technology" is used for both coolant and insulation. The name is given by "Green peace International Association" (Anonymous, 1999). According to a recent AI-generated overview by Google, an eco-friendly refrigerator-often referred to as an 'ecofridge'- is designed to minimize environmental impact and energy consumption. This is achieved through features such as energy-efficient compressors and the use of environmentally safe refrigerants, which enhance cooling performance while reducing waste.

To find out the techno-economic feasibility of conventional and eco-friendly refrigerator, experiments were conducted.

Selection of equipment

Eco-fridge - (Samsung) and conventional fridge (BPL), were selected for the experiment as they were easily available and reachable.

Weighing balance, cups and spoons for measurement of raw material and cooked food products were also used.

Selection of recipe

Kheer, Custard, Salad + green leafy vegetables (Radish, tomato, capsicum, coriander and spinach)

Fig. 1-3. Selected food items for the experiment

The three different food items (Fig. 1, 2 and 3) have been selected for experiment, which were kept in two different refrigerators for at least 48 hours. This was done to check the variation due to effect of appliances.

Sensory evaluation of the cooked food

To evaluate the sensory characteristics of different cooked food items that is kept in two different refrigerators, a panel of six judges were selected using a score card having 9 point Hedonic scale (Sharma et al, 2025).

Coefficient of performance and performance of system

It measures the efficiency of a refrigerator. It is defined as the ratio of the quantity of heat extracted per cycle from the content of the refrigerator to the mechanical work 'w' done by the external agency to do so. It is denoted by:

$$\beta = \frac{Q_2}{w}$$

Smaller the amount of mechanical work done in removing heat Q_2, greater will be the coefficient of performance.

$$\therefore w = Q_1 - Q_2$$

$$\therefore \beta = \frac{Q_2}{Q_1 - Q_2} = \frac{1}{\frac{Q_1}{Q_2} - 1}$$

However : $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$$\therefore \beta = \frac{1}{\frac{T_1}{T_2} - 1} = \frac{T_2}{T_1 - T_2}$$

- In actual practice β varies from 2 to 6.
- Lesser the difference in the temperature of the cooling chamber and the atmosphere, higher is the COP of refrigerator.
- In case of refrigeration, the COP may be much higher than 1. The refrigerator work performance decreases due to formation of too much ice. However, there is practically no change in T_1. This decreases the value of β. However, if the refrigerator is defrosted, T_2 shall increase and thus the value of β. It is necessary to defrost the refrigerator. In actual refrigerator the vapour of some low boiling point liquid (ammonia or freon – 12) act as the working substance. The working substance absorbs a certain quantity of Q_2 from the cold body or sink at lower temperature. $T_2$is called refrigeration effect. In the household refrigerator, the ice- cubes in the freezer compartments and food constitute the cold body (Patel and Rao, 2024).

The COP of the conventional and eco-friendly refrigerator has been measured in three different seasons i.e. March (late winter), June (peak summer) and August (spring) seasons. The measurement included the electricity consumption in terms of electrical potential in volt and current in ampere and simultaneously the prevailing average inside temperature of refrigerator and outside ambient temperature.

These experiments were extended for both type of refrigerator in both condition i.e. no-load and full load conditions. The basic idea behind these measurements is to find out variation in COP in different conditions in different refrigerators. The COP obtained may be useful to predict the performance of refrigerator from the environment point of view. A multimeter comprising voltmeter and ammeter was connected to refrigerator during experiment to find out total electricity consumption (Deshpande, 2024).

RESULTS AND DISCUSSION

To determine the techno-economic feasibility of conventional and eco-friendly refrigerator, experiments were conducted where in each of the three food items were kept in two different refrigerators for 48 hours to determine quality of food (Sarafarazi and Mahawer, 2023). Three food items consisted of kheer, custard and salad. For the sensory study, 9 point Hedonic Scale was used, then, the results were analyzed by using Standard Deviation and T-test.

Table 1. Organoleptic characteristics (Mean ± SD score) of kheer stored in the two refrigerators

Sl. No.	Characteristics	Eco-fridge Mean ± S.D. (SE)	Conventional fridge Mean ± S.D. (S.E.)	Eco-fridge v/s Conventional refrigerator t values
1.	Appearance	8.33 ± 0.469 (0.192)	6.66 ± 0.326 (0.133)	6.637 **
2.	Colour	8.5 ± 0.5 (0.204)	6.83 ± 0.9 (0.368)	3.634 **
3.	Flavour	8.16 ± 0.68 (0.28)	6.33 ± 0.943 (0.386)	3.519**
4.	Texture	8 + 0.479 (0.196)	6.5 ± 0.574 (0.235)	4.504**
5.	Taste	7.66 ± 0.748 (0.306)	6.5 ± 0.957 (0.392)	2.139*
6.	Overall acceptability	8±0.479 (0.196)	6 ± 0.943 (0.386)	4.237**

Level of significance: ** (P<0.01); * - (P<0.05)

Table 1 depicts the mean ± SD (SE) and significance of kheer by the panel members. The results showed that appearance of kheer was significantly different (P<0.01) between both groups (i.e. Eco-fridge and conventional fridge). The results were also same in all the other cases of colour, flavour, texture and over all acceptability. While in the case of kheer, taste was significantly different (P<0.05) between both the groups. Table 2 illustrates the organoleptic characteristics score (mean ± SD) of custard by the panel of judges and their significance differences. The results showed that the appearance, flavor and taste scores of custard were significantly different (P<0.01) between both the group (i.e. Eco-fridge and conventional refrigerator) while in the case of colour and overall acceptability, the scores were significantly different at 5 per cent level, i.e., (P<0.05). There is no significant difference in texture score of custard between both the groups.

Table 2. Organoleptic characteristics (Mean ± S.D. scores) of custard stored in the two refrigerators

Sl. No.	Characteristics	Eco-fridge Mean ± S.D. (S.E.)	Conventional fridge Mean ± SD (S.E.)	Eco-fridge v/s Conventional refrigerator t values
1.	Appearance	8.33±0.46 (0.188)	6.83±0.689 (0.282)	4.065**
2.	Colour	8±0.81 (0.33)	6.33±1.630 (0.668)	2.056*
3.	Flavour	8±0.57 (0.23)	6.83±0.574 (0.235)	3.111**
4.	Texture	8±0.57 (0.23)	6.5±0.741 (0.303)	1.394^{NS}
5.	Taste	7.66±0.47 (0.19)	6.16±0.692 (0.283)	4.03**
6.	Over all acceptability	7.83±0.45 (0.18)	6.66±0.9 (0.368)	2.611*

Level of significance: ** - (P<0.01); * - (P<0.05); NS-Not significant

It is depicted in Table 3 that the organoleptic sensory score (mean ± SD) of salad by the members of panel and their significant effect. The results depicted that the appearance, flavor, texture and overall acceptability scores of salad were significantly different in case of both the groups i.e. (P<0.01). Taste wise there was no significant difference in salad stored in both the refrigerators. However, the colour score varied significantly at 5% level of significance. According to organoleptic evaluation conducted by Sarfarazi and Mahawer (2023), sensory attributes such as taste, flavor, and texture exhibited a progressive decline with increasing ambient storage duration from 0 to 120 days.

Table 3. Organoleptic quality (Mean ± S.D. score) of salad stored in both the refrigerators

Sl. No.	Characteristics	Eco-fridge Mean ± S.D. (S.E.)	Conventional fridge Mean ± SD (SE)	Eco-fridge V/s Conventional refrigerator t values
1.	Appearance	7.66±0.479 (0.196)	4.33±1.6 (0.655)	4.469**
2.	Colour	7.33±0.748 (0.306)	4.66±2.13 (0.87)	2.65*
3.	Flavour	7.33±0.748 (0.306)	3.83±2.19 (0.89)	3.391**
4.	Texture	7.33±0.479 (0.196)	3.83 ± 2.21 (0.90)	3.468**
5.	Taste	6.83±2.414 (0.989)	6.66±2.19 (0.89)	0.16NS
6.	Overall acceptability	7.66±0.479 (0.196)	4.46±1.94 (0.795)	7.766**

Level of significance:** - (P<0.01), * - (P<0.05), NS – Not significant

As the Samsung bio-fresh model claims that the heart of bio-fresh refrigerator is bio-ceramic technology which is used in vegetable compartment. This is a unique property of emitting infra rays which helps retain moisture and keep vegetable fresher and tastier for a longer period. It is true because when the vegetables were kept in both the refrigerators for 48 hours, the vegetables which are kept in bio-fresh refrigerator are more liked by panel members as compared to the vegetables kept in conventional refrigerator. Further, the food item which is kept in bio-fresh refrigerator is more appealing, appetizing and more fresh than the food item kept in conventional refrigerator (TERI, 2025).

Co-efficient of performance

Second experiment was performed to find out coefficient of performance-(COP) of refrigerator. For comparative study of two refrigerators, no load and full load testing of both the refrigerator was done.

The no load testing and full load testing of conventional as well as eco-friendly refrigerator has been made as per procedure mentioned in the materials and methods section. The experiment has been extended in different season's i.e. March (late winter). June (Peak summer) and August (spring season). It has been observed from table no. 4 that the COP of conventional refrigerator during March month comes out to 0.43, where as in the June and August these are 0.38 and 0.42, respectively in no load condition. Further, it was also observed that the power consumption during March, June and August in no load testing condition were 0.77, 0.836 and 0.79 kWh.

During March the outside ambient temperature was less, therefore less electrical work was made to remove required heat from the refrigerator space resulting in maximum COP and less power consumption. However, because of high prevailing temperature in June, the requirement of power for removing heat was more hence less COP was obtained.

Table 4. No load testing of conventional refrigerator (Obs.= 8 hrs)

Sl. No.	Month	Potential (in volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	220	3.5	0.77	23	7	0.43
2.	June	220	3.0	0.836	36	10	0.38
3.	August	220	3.6	0.79	30	9	0.42

Table 5. Full load testing of conventional refrigerator (Obs.= 8 hrs)

Sl. No.	Month	Potential (in Volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	220	3.7	0.814	24	7	0.41
2.	June	220	3.9	0.858	37	10	0.37
3.	August	220	4.1	0.902	35	9	0.40

Table 5 depicted that the COP of conventional refrigerator during full load condition in the month of March, June and August were 0.41, 0.37 and 0.0404, respectively. Further it was also observed that the power consumption during March, June and August were 0.814, 0.878 and 0.902 kWh. It is similar to COP obtained. The COP was further less in case of full load testing. It was an account of more power consumption for keeping moderate temperature inside the refrigerated space.

Table 6 illustrates the COP measurement of eco-friendly refrigerator that comes out to be 0.47, 04 and, 0.44, respectively in the months of March, June and August during no load testing. The consumption of electricity was also in the same proportion as that of COP in respective month.

It was observed from Table 7 that the COP in full load condition were less as compared to no load condition; it were 0.44, 0.38 and, 0.42, respectively for the months of March, June and August.

Table 6. No load testing of eco-friendly refrigerator (Obs.= 8 hrs)

Sl. No.	Month	Potential (in volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	208	2.6	0.66	25	8	0.47
2.	June	208	2.8	0.832	28	8	0.4
3.	August	108	3.0	0.73	26	8	0.44

Table 7. Full load testing of eco-friendly refrigerator (Obs.= 8 hrs)

Sl. No.	Month	Potential (in volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	208	2.7	0.70	26	8	0.44
2.	June	208	3.0	0.835	29	8	0.38
3.	August	208	3.3	0.75	27	8	0.42

Nongthombam (2020) confirms that like ZECC, ecofridge for storing food items involves evaluating their performance based on several key factors such as cooling efficiency, shelf life extension, cost, maintenance, and suitability for different climates and products without affecting our environment. Hence, the conditions are always maintained same. This is also important from refrigeration point of view. Sensory evaluation scores exhibited that samples stored in eco-fridge obtained highest scores in texture, colour, appearance and taste, except in case of flavour, taste and colour of salad. So overall acceptability of samples stored in eco-fridge is more than conventional refrigerator. Similarly, the co-efficient of performance of eco-friendly refrigerator is better as compared to conventional refrigerator in terms of its COP attained during no load and full load condition. Since the COP is more for eco-friendly refrigeraton the heat losses to atmosphere is less in this type of refrigerator. Over all, it was found that eco-fridge performance is better than conventional refrigerator in terms of quality of food and coefficient or performance (Intarcon, 2025). A study by Hoffman et al. (2021) also corroborates and confirms the present study in terms of efficiency of eco-fridge performance.

CONCLUSION

From the study, it was concluded that the performance of eco-friendly refrigerator is better as compared to conventional refrigerator in terms of its COP attained during no load and full load condition. Since, the COP is more for eco-friendly refrigerator, the heat loses to atmosphere is less in this type of refrigerator. This reduces the pollution effect of refrigerating unit. Further, it was also observed that power consumption in eco-friendly refrigerator is varying according to load condition,

similar to that of conventional refrigerator, but the inside average temperature throughout the various seasons is more or less same i.e. 8°C. Overall sensory acceptability score of samples stored in eco-fridge is more than conventional refrigerator. So, eco-fridge is more efficient and economical appliance than conventional refrigerator in terms of quality of food stored and COP attained during no load and full load condition.

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