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Research Article

Comparative Study on Refrigerators Sold in Turkey

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ABSTRACT: As modernization continues, the lifestyle in domestic settings had become more entwined in the usage of gadgets and appliances. Among the appliances, refrigerators have grown to become one of the most useful in food storage in most countries. It has already become among the key features of any kitchen and hence, an integral part of the home appliances market. This paper presents a comparison of some refrigerators commercially sold in Turkey. The parameters included were brand, type of refrigerator, capacity, price and star ratings. Based on the Pearson correlation price was more strongly positively related to capacity $p<0.001$, than to defrosting type $p<0.01$, or to door type $p<0.01$. Free frost types are more likely to be of higher prices than direct cool types. The double door type is more likely to be of higher prices than the single. Furthermore, ANOVA on brand and defrosting type has shown that there is a significant difference among the five brands of refrigerator on defrosting type, $p<0.01$. Post-host testing revealed significant differences between group of BRAND1 and BRAND3, having more of free frost type of defrosting than BRAND5, BRAND4, and BRAND2. However, ANOVA on brand and price and ANOVA on brand and star ratings revealed that there are no differences among the five brands of refrigerators on price and on star rating which means that price and star rating are more dependent on capacity, door type and defrosting type regardless of the brand of the refrigerators.

KEYWORDS: Refrigerator, Star rating, Defrosting type, Door type, Energy efficiency

1. INTRODUCTION

Controlled-temperature storage of refrigerators does not only answer the need of ordinary producers and consumers in domestic settings but also of people in the science industries [1]. Usually in domestic settings, keeping the food in a low-temperature environment can prolong its shelf life. In the science industries, the ability to control the temperature of storage is vital to the storage of a specimen, like vaccines in pharmaceutical settings. Worldwide sales of refrigerator appliances have continuously increased in recent years. According to data [2] from among five groups of appliances, refrigerator appliances ranked second to have the greatest increase in worldwide retail sales with 84.5 bn USD in 2015, to 95 bn USD in 2021.

The quality of performance of refrigeration systems has been identified as one of the important field of research since the consumption of electrical and thermal energies in the residential building sector is growing fast. Refrigeration industry is responsible for 20 % of the total electrical energy consumed around the world [3]. The main idea behind determining the performance of a refrigerator is based on how much work input is needed to transfer the heat from a cold refrigerated space into the warm environment outside [4], [5]. Developing effective technologies at an expensive cost is impossible because competition in the market for these products is challenging and the resulting significant pricing pressure. Manufacturers have therefore turned to various inexpensive ways to increase the energy efficiency of domestic refrigerators [6].

Although the specific materials and full designs of refrigerators may not entirely be known, obvious parameters could be taken into consideration. In this study, some models of refrigerators from five brands commercially sold in Turkey are compared by using these parameters.

2. REVIEW of RELATED LITERATURE

As more people moved into expanding cities and further away from food sources, the need to keep perishable food cold throughout transit and at home increased. Throughout the 19th century, there was an upsurge in the demand for fresh food. Eventually, this has led to the mass production of the refrigerator in 1918 [7].

The purpose of refrigerator's system is to remove heat from its compartment inside. The most popular method in doing this is compression method, wherein refrigerant's heat is removed via evaporation [8]. The refrigerant repeatedly changes phase from liquid to vapor (gas) and back again as shown in Figure 1. These liquid and vapor phase changes are due to changes in pressure and temperature. The components of the refrigerator responsible for this are the compressor and the evaporation valve. In order to move heat-filled refrigerant vapor from the evaporator (a low-pressure location) into the compressor, it must first create suction. A running compressor causes low pressure in the evaporator because it continuously removes refrigerant from it. Also, the compressor compresses the amount of refrigerant that is drawn in during suction, raising the refrigerant's temperature and pressure. Meanwhile, the pressure of the liquid refrigerant entering the evaporator from the metering device drops suddenly. The enormous pressure difference between the metering device and the evaporator decreases the liquid refrigerant's boiling point. When liquid refrigerant enters the evaporator, some of it quickly boils into vapor and absorbs heat since the temperature is so low [5]. Different kinds of materials in the major components and other parts of refrigerator are used by manufacturers for several reasons. Among these is to select suitable materials from an aesthetical and functional perspective. These materials have different characteristics, like different conductivity and specific heat capacities [9].

Meanwhile, the trouble of getting rid of moisture has led to the accumulation of ice on evaporator fins and thus interferes with proper refrigeration. According to the work of Althouse et al. [8], the presence of moisture in the air that circulates through the evaporator coil can lead to the accumulation of ice on the evaporator fins, which interferes with proper refrigeration. They explained that the moisture problem can arise from several sources, including air leaks, improper installation, or failure to adequately remove moisture from the air. In particular, the systems that operate in warm and humid environments are more susceptible to moisture problems. To combat this issue, the authors suggest several approaches, including installing moisture-removing equipment, such as desiccants, in the system. They also recommend regularly checking for air leaks and ensuring proper insulation of the system's components. Failure to address moisture issues can lead to decreased efficiency and increased energy consumption, as well as potentially damaging the system's components. Furthermore, if ice accumulation becomes severe, it can obstruct airflow and lead to system failure. That is, the importance of effective moisture control in refrigeration systems and offer practical solutions for ensuring proper functioning of the system.

The issue of ice accumulation in refrigerators has been a long-standing problem that has affected the efficiency and lifespan of refrigeration systems. However, with the emergence of defrosting type refrigerators, this issue has been significantly mitigated [10]. The automatic defrost feature is designed to regulate the temperature of the refrigerator and prevent the accumulation of ice on the evaporator coils, which improves the overall efficiency of the system. This has made defrosting type refrigerators a popular choice for users who value convenience and efficiency in their kitchen appliances.

Materials used and the design itself [11] of each model contribute to how energy efficient would be the refrigerator. The efficiency is gauged by using star rating standards. According to the Bureau of Energy Efficiency [12], Table 1 and 2 are the star rating guidelines for direct cool and for frost free type of refrigerator, respectively.

Table 1. Star Rating for Direct Cool Refrigerator [12]

Star Rating	CEC Criteria
1 star	$(0.264 \times V_{adj\_tot\_dc} + 221) \leq$ CEC $< (0.33 \times V_{adj\_tot\_dc} + 277)$
2 star	$(0.211 \times V_{adj\_tot\_dc} + 177) \leq$ CEC $< (0.264 \times V_{adj\_tot\_dc} + 221)$
3 star	$(0.169 \times V_{adj\_tot\_dc} + 141) \leq$ CEC $< (0.211 \times V_{adj\_tot\_dc} + 177)$
4 star	$(0.135 \times V_{adj\_tot\_nf} + 113) \leq$ CEC $< (0.169 \times V_{adj\_tot\_dc} + 141)$
5 star	CEC $< (0.146 \times V_{adj\_tot\_dc} + 311$

Notes:
1. CEC stands for Comparative Energy Consumption
2. Total Adjusted Storage Volume for direct cool ($V_{adj\_tot\_dc}$) = fresh food storage volume + 1.31 × freezer storage

Table 2. Star Rating for Fross Free Refrigerator [12]

Star Rating	CEC Criteria
1 star	$(0.286 \times V_{adj\_tot\_nf} + 249) \leq \text{CEC} < (0.357 \times V_{adj\_tot\_nf} + 311)$
2 star	$(0.228 \times V_{adj\_tot\_nf} + 199) \leq \text{CEC} < (0.286 \times V_{adj\_tot\_nf} + 249)$
3 star	$(0.183 \times V_{adj\_tot\_nf} + 159) \leq \text{CEC} < (0.228 \times V_{adj\_tot\_nf} + 199)$
4 star	$(0.146 \times V_{adj\_tot\_nf} + 127) \leq \text{CEC} < (0.183 \times V_{adj\_tot\_nf} + 159)$
5 star	$\text{CEC} < (0.146 \times V_{adj\_tot\_nf} + 311$

Notes: Total Adjusted Storage Volume for no frost ($V_{adj\_tot\_nf}$) = fresh food storage volume + 1.62 × freezer storage

When a refrigerator is turned on, the refrigerant flow cycle continues until the inside compartment reaches a wanted low temperature (set by the user). Its thermostat detects this and turns off the system. Although the inside compartment is insulated and sealed by its door, unwanted heat can still enter and eventually would warm the compartment slowly. This warming up is detected and then refrigerator would automatically turn on again. This repeated cycle of turning on and off of power could also affect the performance of refrigerator. Many researchers nowadays explore the integration of multiple phase change materials (PCMs) into the refrigerator system to address this concern. PCMs are materials that can absorb and release large amounts of energy as they change phase, such as from solid to liquid or liquid to gas.

A study by Ben Taher et al. [13] reveals that the integration of PCMs in the walls of the refrigerator can effectively reduce temperature fluctuations, enhance cooling efficiency, and significantly decrease the overall energy consumption of the refrigerator. Their numerical simulations indicate that the use of multiple PCMs with various melting temperatures is more effective in regulating the temperature inside the refrigerator than using a single PCM.

A research review by Omara et al. [14] provides an overview of the key concepts for improving the performance of refrigerators and freezers by utilizing phase change materials PCMs. The study reveals that the integration of PCMs in the refrigerator walls, doors, and shelves can significantly enhance the energy efficiency, reduce temperature fluctuations, and extend the storage life of perishable goods. The authors also discuss various types of PCMs, such as organic and inorganic, and their different melting temperatures and thermal properties. The review emphasizes that the appropriate selection of PCM type and location is critical for achieving the desired performance enhancement. The most common PCMs used in domestic refrigeration systems are water and eutectic PCMs solutions. They concluded that many research studies have concentrated in incorporation of PCM at the evaporator and compartment but few studies have been carried out at the condenser section. They also concluded that eutectic PCMs demonstrate better system performance than water.

G. Sonnenrein et al. [15] integrated a polymer-bound PCM with a phase change temperature of 9 °C into the compartment of fresh food in a commercial refrigerator to meet the new global refrigerator standard IEC 62552:2015. Their experimental result showed that the cooling capacity improved by 66 % and the temperature rise time rise up to 145 % without negatively impacting energy consumption. This could help manufacturers meet these new standards and improve the overall performance of refrigerators.

Y. Yusufoglu et al. [16] explored the use of phase change materials (PCMs) in household refrigerators to improve their energy efficiency and temperature stability. They conducted experiments on two models of refrigerator using several types of PCMs to determine which combination would have lowest electical power usage. PCM packages were prepared to fit on the evaporator tubes. The study found that using 0.95 kg of PCM could result to 9.4 % energy saving and that increasing the area of condenser could increase the effect of integrated PCM. They concluded that the effectiveness of PCMs in refrigerators is dependent on factors such as the melting temperature of the PCM and the thickness of the PCM layer.

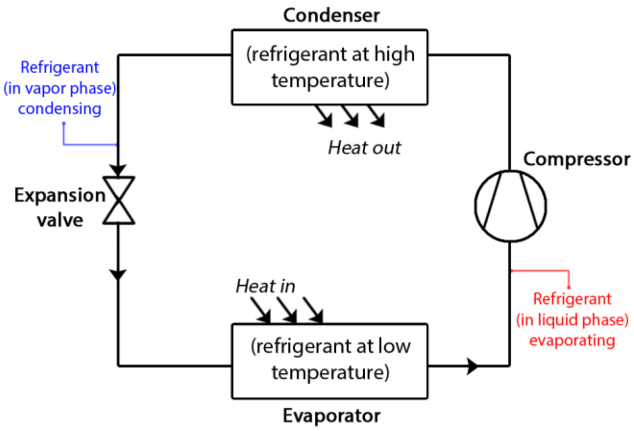

Figure 1. Flow of refrigerant through the major components of a refrigerator.

K. Azzouz et al. [17] conducted numerical simulations of a system with PCM of various designs and operating conditions. Their result has demonstrated that including a PCM leads to an improved conduction of heat from the evaporator to the PCM, as well as the convective heat transfer to the air. This allows a higher evaporating temperature. Nonetheless, response of refrigerator is also dependent on the thermal load. With PCM in the simulated model, coefficient of performance could be improved by 5-15 % which also means increases the energy efficiency of the system.

The research findings hold considerable potential for improving the energy efficiency of refrigerators, which will ultimately result in lower energy costs and reduced environmental impacts.

3. METHODOLOGY

This paper explores the comparison of some refrigerators from five brands, coded as: BRAND1, BRAND2, BRAND3, BRAND4, and BRAND5. The variables considered are brand, capacity, defrosting type, refrigerator door type, and star rating. The capacity of the refrigerator in this study ranges from 190 liters to 450 liters.

The data listed in Table 3 below is gathered from https://gadgets360.com [18]. Figure 2 shows the capacity (L) distribution of considered models. This website can generate a list to compare refrigerators, air coolers, air purifiers, and other electronic devices.

These data were encoded into the Statistical Package for Social Sciences (SPSS). The variables need to be classified as nominal, scale or ordinal in the SPSS. And it is appropriately classified in Table 4 below. For the variable defrosting type, there are only two types, namely: direct cool and frost free which were labeled in SPSS as “1” and “2,” repectively. Similarly, variable door type is of two types, namely: single and double which were also labeled as “1” and “2,” repectively. The variable star rating, it is ordinal with the number 5 rating as the best in performance [19].

Table 3. Data of refrigerators of the five brands

Brand	Capacity (L)	Price (in TL)	Defrosting Type	Door Type	Star Rating
BRAND1	347	8918.8	Frost free	Double	2
BRAND1	290	6817.8	Frost Free	Double	3
BRAND1	263	6157.8	Frost Free	Double	3
BRAND1	367	9017.8	Frost Free	Double	3
BRAND2	335	8797.8	Frost free	Double	3
BRAND2	260	6223.8	Frost free	Double	3
BRAND2	190	3407.8	Direct Cool	Single	5
BRAND2	190	3497.78	Direct Cool	Single	2
BRAND2	235	3957.8	Direct Cool	Single	2
BRAND2	335	8797.8	Frost Free	Double	3
BRAND2	260	5973	Frost Free	Double	3
BRAND3	335	9900	Frost free	Double	2

Table 3. Continued

Brand	Capacity (L)	Price (in TL)	Defrosting Type	Door Type	Star Rating
BRAND3	307	7037.8	Frost Free	Double	3
BRAND3	270	6358	Frost Free	Double	3
BRAND3	450	13755.94	Frost Free	Double	3
BRAND3	282	8360	Frost Free	Double	5
BRAND3	307	6971.8	Frost Free	Double	3
BRAND3	270	5893.8	Frost Free	Double	3
BRAND3	270	6266.48	Frost Free	Double	3
BRAND3	270	6424	Frost Free	Double	3
BRAND3	270	6357.78	Frost Free	Double	3
BRAND4	340	9372	Frost free	Double	3
BRAND4	324	7788	Frost Free	Double	2
BRAND4	192	3212	Direct cool	Single	3
BRAND4	244	5761.8	Frost Free	Double	3
BRAND4	192	2791.8	Direct Cool	Single	1
BRAND4	192	2970	Direct Cool	Single	2
BRAND4	192	3165.8	Direct Cool	Single	3
BRAND4	192	3014	Direct Cool	Single	2
BRAND4	192	3077.8	Direct Cool	Single	3
BRAND5	340	9311.5	Frost free	Double	4
BRAND5	200	3297.8	Direct Cool	Single	4
BRAND5	190	3429.8	Direct Cool	Single	3
BRAND5	245	4727.8	Direct Cool	Single	3
BRAND5	215	4298.8	Direct Cool	Single	4

Ordinary consumers are usually concerned about the price of refrigerators. Hence, analysis of the correlation among the parameters price, capacity, defrosting type and door type of refrigerator is done via the Pearson product-moment correlation test.

Individual One-Way Analysis of Variance (ANOVA) was also used to determine whether or not there are significant differences among the refrigerators in terms of prices, capacity and star rating.

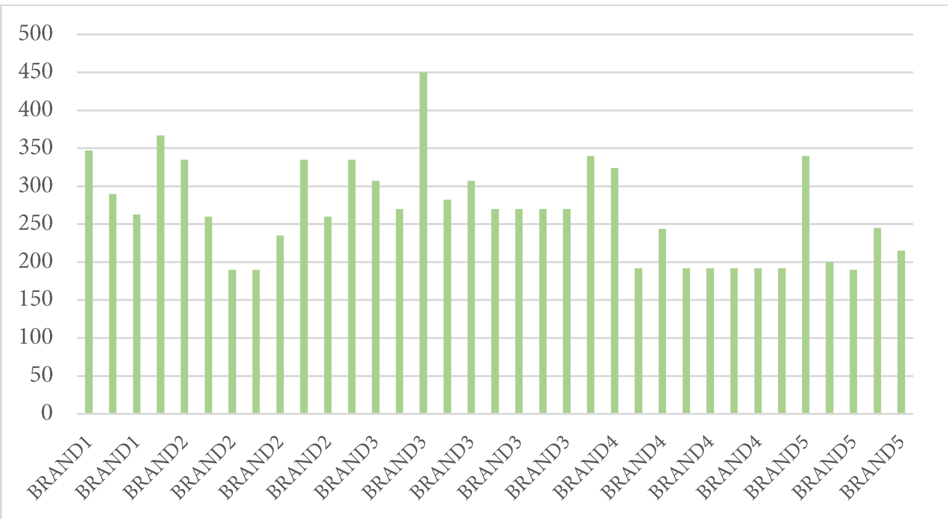

Figure 2. The capacity (L) distribution of considered models from the five brands of refrigerator

Table 4. Classification of variables

Variable	Classification
Brand	Nominal
Capacity	Scale
Price	Scale
Defrosting Type	Nominal
Door Type	Nominal
Star Rating	Ordinal

4. RESULTS

A Pearson product-moment correlation was conducted to examine the relationships between defrosting type and door type of refrigerator. Price was more strongly positively related to capacity, $r(33) = 0.98, p < 0.001$, than to defrosting type, $r(33) = 0.807, p < 0.01$, or to door type, $r(33) = 0.568, p < 0.01$. A complete list is presented in Table 5, a scatter plot of capacity and price is in Figure 3, and a scatter plot of capacity and price per brand is in Figure 4. Figure 5 shows a matrix plot of the four variables. These findings indicate that capacity explains much more of the variability in the price of the refrigerator than does defrosting type. The effect size ($r^2 = 0.96$) for capacity indicate the level of capacity that the brand manufacturer accounted for a large portion (96%) of the variability in the price.

Table 5. Correlation for Price

	Capacity	Defrosting Type	Refrigerator Door Type
Price	0.98**	0.807**	0.568**
Capacity		0.794**	0.583**
Defrosting Type			0.838**
Refigerator Door Type			

Notes: **Correlation is statistically significant at the 0.01 level

There was no significant difference among the five brands of refrigerator on prices, $F(4,30) = 2.923$, $p > 0.05$, $\eta_p^2 = 0.28$. Furthermore, post hoc testing revealed no significant differences among brands BRAND1 ($M = 7728.05$, $SD = 1457.80$), BRAND2 ($M = 5807.97$, $SD = 2330.92$), BRAND3 ($M = 7732.56$, $SD = 2437.13$), BRAND4 ($M = 4572.58$, $SD = 2475.40$), and BRAND5 ($M = 5013.14$, $SD = 2475.73$).

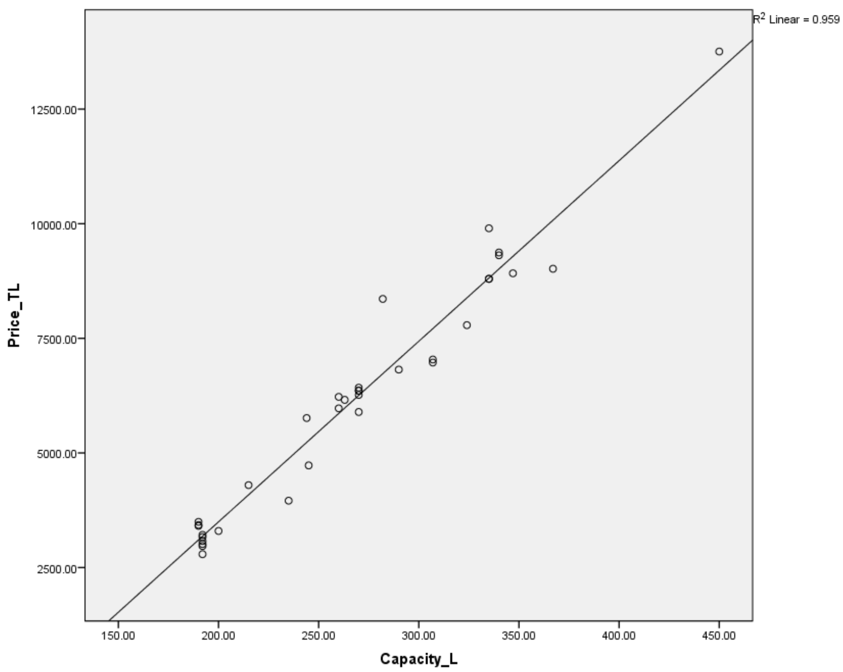

Figure 3. Scatter plot of Price (TL) and Capacity (L)

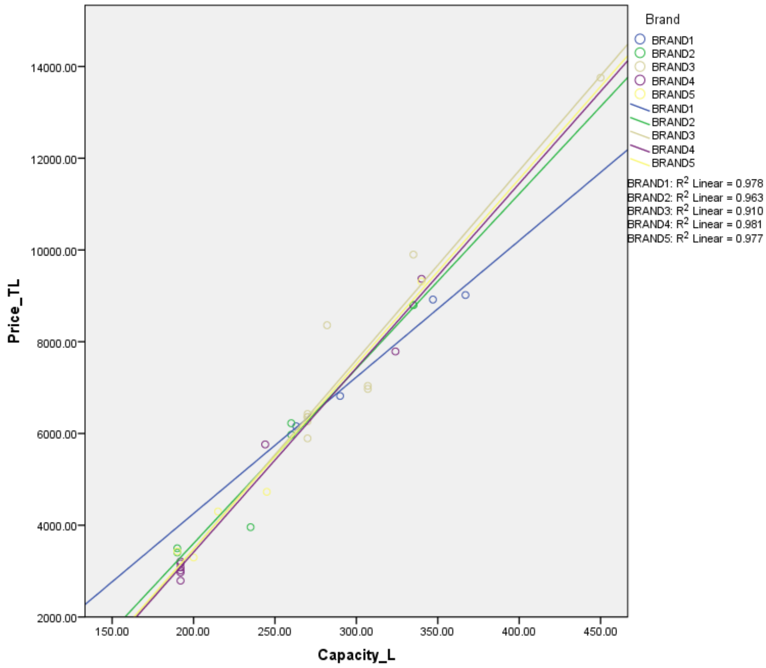

Figure 4. Scatter plot of Price (TL) and Capacity (L) per brand

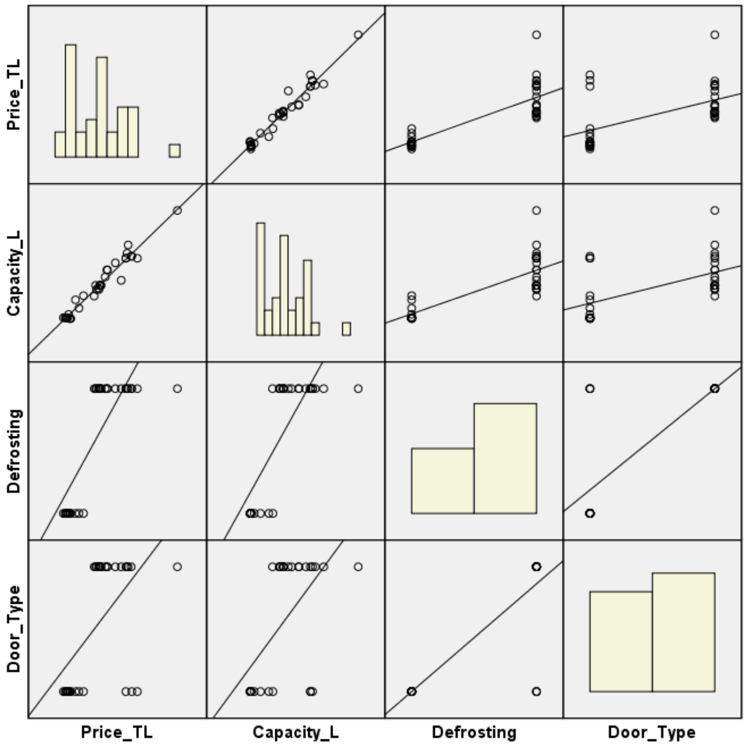

Figure 5. Matrix scatter plot of Price (TL), Capacity (L), Defrosting Type and Door Type.

There is a significant difference among the five brands of refrigerator on defrosting type, $F(4,30) = 22.561$, $p < 0.01$, $\eta_p^2 = 0.45$. Games-Howell post-host testing revealed significant differences between the group of BRAND1 ($M = 2.00$, $SD = 0$), and BRAND3 ($M = 2.0$, $SD = 0$), having more of Free frost type of defrosting than BRAND5 ($M = 1.20$, $SD = 0.5$), BRAND4 ($M = 1.33$, $SD = 0.5$), and BRAND2 ($M = 1.33$, $SD = 0.5$).

There is no significant difference among the five brands of refrigerator on star rating, $F(4,30) = 2.115$, $p < 0.10$, $\eta_p^2 = 0.22$. Furthermore, post host-testing revealed no significant differences among the brands BRAND1 ($M = 2.75$, $SD = 0.5$), BRAND2

($M = 3.00, SD = 1.00$), BRAND3 ($M = 3.10, SD = 0.74$), BRAND4 ($M = 2.44, SD = 0.73$), and BRAND5 ($M = 3.60, SD = 0.55$).

5. CONCLUSION

Therefore, it has been shown that based on Pearson product-moment correlation price was more strongly positively related to capacity, $r(33) = 0.98$, $p < 0.001$, than to defrosting type, $r(33) = 0.807$, $p < 0.01$, or to door type, $r(33) = 0.568$, $p < 0.01$. Since the free frost defrosting type was labeled as 2 and direct cool as 1, this means that the free frost type is more likely to be of higher prices than direct cool. Also, since the double door type was labeled as 2 and single as 1, this means that the double door type is more likely to be of higher prices than single. And this result coincides with what is usually observed in the market.

Furthermore, ANOVA on brand and defrosting type has shown that there is a significant difference among the five brands of refrigerator on defrosting type, $F(4,30) = 22.561$, $p < 0.01$, $\eta_p^2 = 0.45$. Post host-testing revealed significant differences between the group of BRAND1 ($M = 2.00, SD = 0$), and BRAND3 ($M = 2.0, SD = 0$), having more Free frost type of defrosting than BRAND5 ($M = 1.20$, $SD = 0.5$), BRAND4 ($M = 1.33$, $SD = 0.5$), and BRAND2 ($M = 1.33$, $SD = 0.5$). However, ANOVA on brand and price and ANOVA on brand and star rating revealed that there are no differences among the five brands of refrigerator on price and on star rating which means that price and star rating are more dependent on capacity, door type, and defrosting type regardless of the brand of the refrigerators.

6. Declaration of Ethical Standards

The authors declare no conflict of interest.

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