ISM 6137: Data Analytics Project Report

Energy Consumption for Refrigerator

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Executive Summary

Refrigerators are one of the most commonly used appliances in the household and has the commercial applications too. Refrigerators can account for as much as one-sixth of all electricity used in the average home. With the increase in energy consumption the latest devices are producing, Manufacturers are now concerned with the rise in energy consumption of the Refrigerators and wine chillers.

The aim is to analyze the annual energy consumption of the appliance “Refrigerator” with different attributes. The datasets contain different brand, models, and other attributes of the refrigerator and respective yearly energy consumption (KWh/year). The data has been modelled separately for refrigerators and wine chillers using 5 models and finding the one which explains the data best and also is practically suitable.

The key findings of our analysis suggest that the freezer location and defrost mechanism play an essential role in designing energy efficient refrigerators. This report aims at making some actionable recommendations to the manufacturer who can make an appropriate decision while developing the energy-efficient refrigerator models.

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1. Problem Significance

The appliances we buy can have a significant impact on our electricity bill, and those costs get baked into your fixed expenses for years to come. The annual energy costs range from $43 to $125. (Energy costs are based on a national average of 12.4 cents per kilowatt-hour at the time of testing.) That said, home appliances—and refrigerators in particular—have become much more energy-efficient over the years. The consumer wants to buy a new fridge with the highest energy star, and it depends on the number of factors.

"Federal standards are constantly updated to ensure that refrigerators of certain sizes use ever-lower amounts of energy, and manufacturers constantly introduce new technologies to meet the standards."

In recent year, Consumer is ready to pay extra money for energy efficient refrigerator which helps them in the long-term savings. On the other hand, manufacturer wants to design and manufacture the refrigerators in all the categories of EnerGuide ratings and therefore in an attempt to improve the EnerGuide ratings the manufacturer wants to know which attributes of collected data impacts most to energy consumptions.

The analysis is aimed to find out the attributes which increases the overall energy consumption and will help the manufacturer design and manufacture better refrigerator models by controlling these attributes.

2. Data Source/Preparation

2.1 Data Source

The data is collected from Energy Consumption - Government of Canada. The dataset includes 17 data attributes, and it contains various model number under the brands along with other respective attributes. The data provided in the report needed to be clean accordingly, and we removed redundant values.

The data contains different brands and their respective model according to its different feature and freezer volume. The refrigerators are categorized on the different types of Defrost mechanism: Fully Automatic, Partial, Manual. However, energy consumption is different for every category. The essential attributes in this dataset are the size and the volume consumption of the refrigerator. The position of the freezer is an important aspect as well when it comes to energy consumption.

The dataset contains hierarchical data as it compares different brands and different models. We have considered fixed as well as the random model in our analysis.

Variables	Definition
Refrigerator Details	
NRCan Reference	Unique reference number for each data entry
Model	Model name under the same brand
Brand	Name of the brand
Annual Energy Consumption (kWh/year)	Consumption of energy by a refrigerator brand & model
Type	
Refrigerator	Normal refrigerator with freezer and fridge compartment
Compact refrigerator	A compact refrigerator is a refrigerator that is much smaller than the normal refrigerator.
Celliers domestiques	This type of refrigerators is used for wine chiller and it doesn't contain freezer
Defrost Mechanism	
Defrost Mechanism	The defrost mechanism in a refrigerator heats the cooling element (evaporator coil) for a short period of time and melts the frost that has formed on it. There are three types of defrost Automatic, Manual, Partially Automatic.
Freezer Location	The location of the freezer which could be on top, bottom, side and inside. There are refrigerators without freezer too (No freezer).
Total Volume (liters)	This is a measurement of the volume of the inside portion of the appliance. The capacity shows how much food can be stored inside the refrigerator or freezer.
Size Category on EnerGuide Label	EnerGuide is the official Government of Canada mark associated with the labelling and rating of the energy consumption or energy efficiency of specific products.
Through the Door Ice Service	Whether the freezer door contains the ice dispenser.
Refrigerator Volume (liters)	This is a measurement of the volume of the inside portion of the refrigerator, the capacity shows how much food can be stored inside the refrigerator.
Freezer Volume (liters)	This is a measurement of the volume of the inside portion of the Freezer.

2.2 Data Cleaning:

1. To analyze Annual energy consumption, we examined the data with all the present attributes affecting energy consumption as well as attributes such as ‘Brand’ and ‘Model’ of the refrigerator packages. As the dataset collected from www.Canada.ca states ‘The

datasets provide specific information about the energy consumption of home appliances imported into Canada or shipped between provinces', we removed the row items for each brand where all the attributes carried exactly same values used to explain the energy consumption but had different model numbers. The model number of a brand varies as per make of the product, components used, colors, body type, and other aesthetical & external factors that do not directly affect Annual Energy consumption. (Refer annexure for more details)

2. We normalized records which had Brand names coupled with different product lines or alias company names. E.g. 'LG Signature' was changed to parent brand 'LG.' 'Danby One Plug,' 'Danby Designer' were normalized to parent brand 'Danby.'

3. Under attribute 'Type,' the data contains categories as 'Refrigerator,' 'Compact Refrigerator,' and 'Celliers domestiques' which is French for 'Domestic Chiller,' i.e. 'Wine or Beverage Chiller.' We have segregated the refrigerators and wine chillers and ran the statistical analysis on both the set of data separately. The reason being, wine chillers do not have freezer hence the attributes like 'Freezer Location,' 'Freezer Volume' and new derived attribute 'Ratio of Freezer to Refrigerator volume' is insignificant. Also, the operating temperature for wine coolers is higher compared to a refrigerator. On average wine coolers does not offer temperature above 46F since wines are not to be stored as cold as other beverages or food items that we keep in the refrigerator.

3. Hypotheses

They are the assumptions that are observed when we consider every aspect affecting the energy consumption of the refrigerator unit. Every attribute will either increase the energy consumption or help in decreasing the energy consumption. The β is the energy coefficient that will depict the assumptions of the different attributes. For example, $\beta_{Manual|Automatic}$ will denote the Manual Defrost with respect to the automatic Defrost System.

Defrost Mechanism

$$H1a: \beta_{Manual|Automatic} > 0$$

The Annual Energy consumption of refrigerator having manual Defrost Mechanism is lower than energy consumption of Automatic defrost refrigerators introduce a heating element to the cooled space and therefore the refrigerator uses more energy, whereas manual defrost does not contain automatic heating elements, which reduces overall energy use.

$$H2a: \beta_{Partial\text{-}Automatic|Automatic} > 0$$

The Annual Energy consumption of refrigerator having Partial Automatic Defrost Mechanism is lesser than refrigerator having Automatic Defrost Mechanism but higher than manual Defrost System. In fully Automatic, it generates a heating element to the cooled space that consumes more energy.

Freezer volume

$$H3a: \beta_{Freezer\ Volume} > 0$$

The Annual Energy consumption of refrigerator having a Freezer attached should be more. The bigger the freezer, greater will be the energy consumption in the case. A freezer works by drawing the heat out of the freezer compartment and consumes a more substantial amount of energy.

Refrigerator volume

$$H4a: \beta_{Refrigerator\ Volume} > 0$$

Most of the energy consumed by a refrigerator is used to pump heat out of the cabinet. The Annual Energy consumption of the refrigerator will be high as It depends upon the total volume consumed in the unit.

Freezer location

$$H5a: \beta_{Top\ Freezer|\ No\ Freezer} > 0$$

The Annual Energy consumption of refrigerator having Top Loaded freezer is greater than refrigerator having no freezer keeping all other aspects same.

$$H6a: \beta_{Bottom|No\ Freezer} > 0$$

The Annual Energy consumption of refrigerator having Bottom Loaded freezer is greater than refrigerator having no freezer keeping all other aspects same. The bottom freezer, the freezing starts from the bottom. The cooling needs to be spread across. An internal fan motor is given across the wall of refrigerators to circulate the cooled air to attain the desired temperature in upper parts also, which increases the energy consumption for bottom freezers.

$$H7a: \beta_{Side\text{-}by\text{-}Side|No\ Freezer} > 0$$

The Annual Energy consumption of refrigerator having Side-by-Side Loaded freezer is greater than refrigerator having no freezer keeping all other aspects same. Refrigerators with bottom freezers use 10 to 25 percent more energy than ones with top freezers.

$$H8a: \beta_{inside\ Freezer|No\ Freezer} > 0$$

The Annual Energy consumption of refrigerator having Inside freezer is greater than refrigerator having no freezer keeping all other aspects same.

$$H9a: \beta_{Manual|Automatic} < 0$$

The Annual Energy consumption of wine chillers having manual Defrost Mechanism is lower than energy consumption of Automatic defrost wine chillers introduce a heating element to the cooled space and therefore it uses more energy, whereas manual defrost does not contain automatic heating elements, which reduces overall energy use.

Refrigerator volume of wine chillers

$$H10a: \beta_{Refrigerator\ Volume} > 0$$

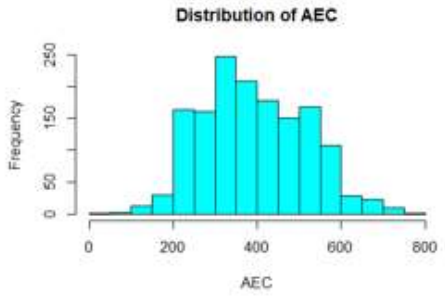
Most of the energy consumed by a refrigerator unit of wine chillers is used to pump heat out of the cabinet. The Annual Energy consumption of the refrigerator unit for wine chillers will be high as It depends upon the total volume consumed in the unit.

$$H11a: \beta_{Manual|Automatic} > 0$$

The Annual Energy consumption of wine chiller having manual Defrost Mechanism is lower than energy consumption of Automatic defrost wine chiller. It introduces a heating element to the cooled space and therefore the refrigerator uses more energy, whereas manual defrost does not contain automatic heating elements, which reduces overall energy use.

4. Descriptive Analysis

The following results were observed, after performing descriptive analysis to find the distribution of Annual Energy Consumption. Fig (1), (2), (3) represent the Distribution of Annual energy consumption for every case.

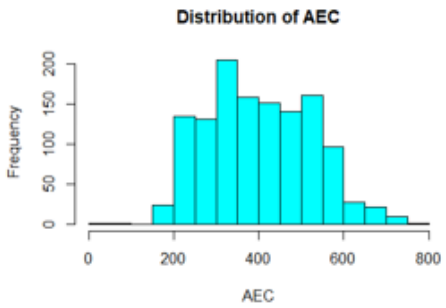


1. Distribution of Annual energy consumption is Normal when check with original dataset

The Mean Value for the distribution:

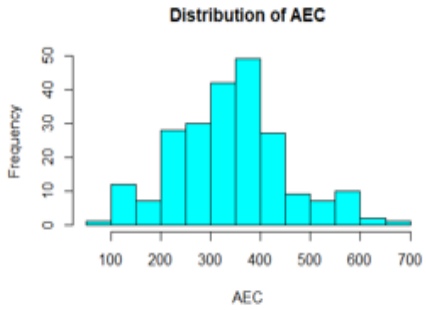
	AEC Mean
Refrigerator. + Wine Chiillers	392.88
Refrigerator and Compact	401.73
Celliers(wine chillers)	343.19

Refrigerator



2. Distribution of Annual energy consumption is near normal when checked for the Compact Refrigerator and Refrigerator Data

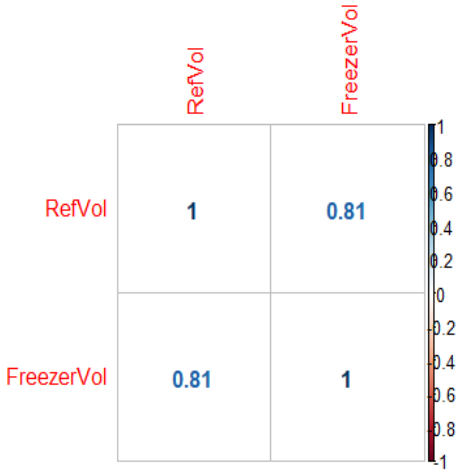
Wine chillers

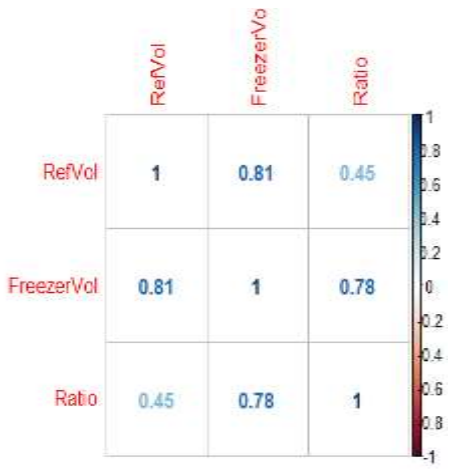


3. Distribution of Annual energy consumption is left skewed in Celliers (wine chillers). Hence we will be applying transforming function to it, to bring the data near to normal.

We are not considering Total Volume as it is a sum of Refrigerator volume and freezer volume which we have already considered. As we can observe in the below correlation plot figure 4(a) refrigerator volumes are highly correlated with freezer volume, we have taken the ratio of (freezer volume)/ (refrigerator volume).

Figure 4(b) shows the correlation between refrigerator volume, freezer volume, and ratio. Celliers does not have freezer volume attribute; hence the ratio is zero in the same.





5. Model

a. Refrigerators

Based on the hypotheses and insights from descriptive analysis, following models were built:
Since the target variable is continuous and we want to analyze the marginal effects of different attributes of a refrigerator on annual energy consumption, we used Linear and Mixed effects models.

Model 1:

AEC = f (Type, Defrost Mechanism, Freezer Location, Ratio)
Where Ratio is (Freezer Volume / Refrigerator Volume)

We have used simple linear regression in order to explain effects of these variables on the AEC. We have not considered the effects of different brands.

Model 2:

AEC = f (Brand (Random effect), Type, Defrost Mechanism, Freezer Location, Ratio)

To account for difference between the brands we have taken random effect into consideration for brands. (The underlined attributes are new addition in the existing model.)

Model 3:

AEC = f (Brand (Random effect), Type, Defrost Mechanism, Freezer Location, Ratio, interaction [freezer volume and Defrost mechanism], Ice through door)

b. Wine Chillers

Model 1:

AEC = f (Defrost Mechanism, Refrigerator Volume)

Model 2:

AEC = f (Brand, Defrost Mechanism, Refrigerator Volume, interaction [Defrost mechanism and Refrigerator Volume])

To account for difference between the brands we have taken random effect into consideration for brands. (The underlined attributes are new addition in the existing model.)

6. Quality Check

Model Comparison Parameters:

1. Adjusted R^2: It is the statistical measure of how much of Annual Energy consumption is explained by the extra explanatory attributes of refrigerator.

2. AIC: Akaike's Information Criterion is an estimator of the relative quality of statistical models for given set of data. AIC provides a mean for model selection. Lower the AIC value better the model.

3. Estimated Coefficients: To check whether the estimated coefficients are stable or not by testing the model on test sample. We are looking for stable estimated coefficients.

Refrigerator				
Model	Description	Adjusted R2	AIC	Estimated Coefficients
Model 1	Simple linear regression to explain AEC	77.65	1417144	Unstable
Model 2	Linear Mixed Model without Interaction terms	-	13127.93	Stable
Model 3	Linear Mixed Model with Interaction terms	-	12700.57	Stable
Wine Chiller				
Model	Description	Adjusted R2	AIC	Estimated Coefficients
Model 1	Simple linear regression to explain AEC	32.62	1077	Unstable
Model 2	Linear Mixed Model with Interaction terms	-	896.11	Stable

Hypothesis	Accepted/Rejected	Significance	Inference
H1	Accepted	yes	The annual energy consumption of refrigerators with manual defrost mechanism is less than refrigerators with automatic defrost mechanism.
H2	Reject	No	The annual energy consumption of refrigerators with partial automatic defrost mechanism is more than refrigerators with automatic defrost mechanism.
H3	Accepted	No	The annual energy consumption increases with the increase in freezer volume.
H4	Accepted	No	The annual energy consumption increases with the increase in refrigerator volume.
H5	Accepted	Yes (according to t value)	The annual energy consumption of refrigerators with freezer location on top is more than refrigerators having no freezers.
H6	Accepted	Yes (according to t value)	The annual energy consumption of refrigerators with freezer location on inside is more than refrigerators having no freezers.
H7	Accepted	Yes (according to t value)	The annual energy consumption of refrigerators with freezer location on bottom is more than refrigerators having no freezers.
H8	Accepted	Yes (according to t value)	The annual energy consumption of refrigerators with freezer location on side is more than refrigerators having no freezers.
H9	Accepted	Yes (according to t value)	The annual energy consumption of wine chillers with manual defrost mechanism is less

			than wine chillers with automatic defrost mechanism.
H10	Accepted	No	The annual energy consumption increases in wine chillers with the increase in refrigerator volume.
H11	Accepted	Yes	The annual energy consumption of wine chiller with manual defrost with respect to automatic defrost mechanism is less

We tested each model on a random sample of the population of data set and checked if the estimated coefficients of the test model are stable with respect to actual model.

7. Recommendations

Based on the statistical analysis performed above, we recommend following things to refrigerator manufacturers

1. Defrost mechanism is a function of Freezer Volume. Automatic defrost is not always the best. Based on analysis, to reduce Annual Energy Consumption, respective manufacturers should implement following defrost mechanisms considering freezer volume. *(Refer Validation sheet in Annexure)

Freezer Volume (Liters)	**Defrost Mechanism Efficiency**
0 – 60.71	Manual > Automatic > Partial Automatic
60.72 - 67	Automatic > Manual > Partial Automatic
67.7 – 73.7	Automatic > Partial > Manual
73.7 and more	Partial > Automatic > Manual

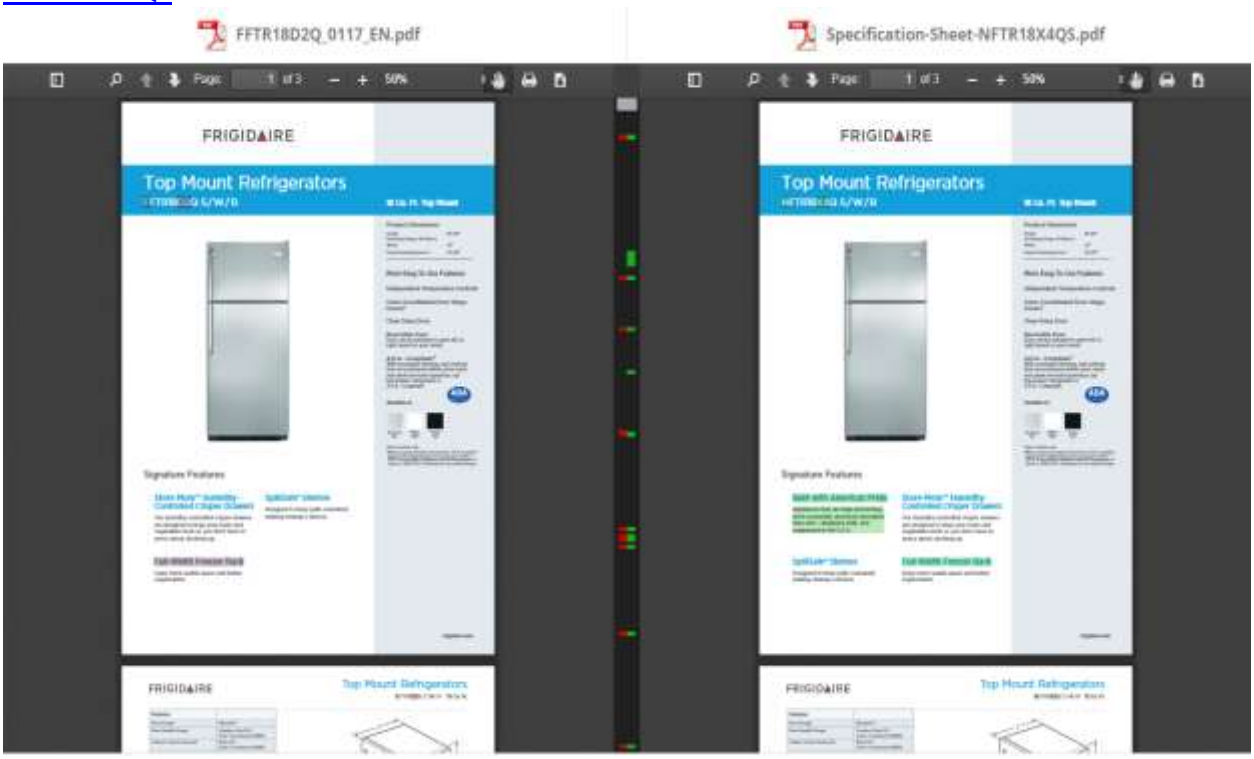
2. Freezer location plays an important role in Annual Energy Consumption. Based on the analysis, Top mounted freezers are more energy efficient than any other types. However, with a bottom freezer, it's a tradeoff between aesthetics and human ergonomics. Bottom freezers are mostly drawer types and provides full visibility of the food items kept in the freezer unlike top freezers which blocks the view and we need to unload the freezer to remove items at the back. The respective manufacturers should take a wise call based on specific model popularity and competitor markets.

3. Wine chiller does not have freezer units. The overall energy consumption is dependent only on refrigerator volume and defrosts mechanism. Based on our analysis, the manual defrost will always be more energy efficient than automatic defrost. Till 95-liter volume, the manual defrost will reduce the baseline energy consumption but after 95-liter

4. volume, it will add up to energy consumption. However, it is still lesser than automatic as stated. The automatic defrost in wine chillers is still prevalent as the difference of Annual Energy Consumption is not more than 12KWh/year at 95-liter volume and it varies as per volume in linear fashion.
   *(Refer Validation sheet in annexure)

8. Annexure

1. Data cleansing with respect to model names and attributes redundancy:
Document comparison of refrigerator of Frigidaire with model no. NFTR18X4Q* and FFTR18D2Q*



2. Validation Sheet

Recommendation validation can be checked via above link.

3.Rcode:

```
install.packages("lme4")
library("lme4")
```

```
ws<- read.csv("C:/Users/Dips/Desktop/ankit SDM/Wine Chiller signature.csv")

#Simple OLS for wine chiller
Sm4<-lm(sqrt(AEC) ~  as.factor(Defrost) +RefVol+as.factor(Defrost)*RefVol, data = ws)
summary(Sm4)  # R2: 32.62

# lmer(random effect of brands) for wine chillers
Sm5m <- lmer(sqrt(AEC) ~ as.factor(Brand)+ as.factor(Defrost)+as.factor(Defrost)*RefVol+
           RefVol+(1|Brand), data = ws)
summary(Sm5m)
AIC(Sm4);AIC(Sm5m)   #1077,896


#-------------------------------------------------------------------------------

r <- read.csv("C:/Users/Dips/Desktop/ankit SDM/Refrigerator data_cleaned signature.csv")

r$FreezerLoc <- relevel(r$FreezerLoc,"No freezer")

# simple OLS
Sm2<-lm(AEC ~ as.factor(Type) + as.factor(Defrost) + as.factor(FreezerLoc)
      + Ratio , data = r)
summary(Sm2)   # R2: 71.53

# lmer without interaction
Sm3m <- lmer(AEC ~ as.factor(Brand)+as.factor(Type) + as.factor(Defrost)
          + as.factor(FreezerLoc)+ Ratio +(1|Brand), data = r)
summary(Sm3m)

# lmer with interaction
im2 <- lmer(AEC ~ as.factor(Brand)+as.factor(Type) + as.factor(Defrost)
     + as.factor(FreezerLoc)+ Ratio+ r$FreezerVol*as.factor(Defrost) +as.factor(DoorIce)
+(1|Brand), data = r)
summary(im2)

AIC(Sm2);AIC(Sm3m);AIC(im2)    #14171,13127,12700

#-----------------------------------------------------------------------------------------
```