Development & Performance Testing of an A-Grade Refrigerator

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF REQUIREMENTS

FOR THE DEGREE OF

MASTER OF ENGINEERING

IN

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BY

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DECLARATION

I declare that the dissertation work entitled "**Development & Performance Testing of an A-Grade Refrigerator**" represents my idea in my own words where other's words that have been included are adequately cited and referenced to the original sources. I also declare that I have adhered to all academic honesty and integrity principles. I have not mis-presented/falsified any idea/data/fact in any submission. I understand that any violation of the above will cause disciplinary action by the institute and can also evoke penal action from the sources that have thus not been adequately cited from whom proper permission has not been when needed.

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Date: July 2022.

CERTIFICATE

This is to certify that the dissertation work entitled "**Development & Performance Testing of an A-Grade Refrigerator**" is an authentic record of work carried out by Syed Md Atifuz Zaman during his engagement as a Master's student from **September 2020 to July 2022**.This project work was carried out under our adiitional guidance in partial fulfilment of the requirements for the award of the degree of "Master of Engineering in Thermal Engineering" at Thapar Institute of Engineering and Technology, Patiala, Punjab during the academic year 2021-2022.

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It is certified that the above information made by the student is correct and true to the best of our knowledge and belief.

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DECLARATION

I, Syed Md. Atifuz Zaman, hereby declare that the Project work entitled "DEVELOPMENT & PERFORMANCE TESTING OF AN A-GRADE REFRIGERATOR" is an authentic record of my own work carried out at LG Electronics India Pvt. Ltd as a part of the Internship/Training that has been done during my final year of M.E.

I declare that I have successfully completed my Industrial Major Project, under the guidance of my industrial mentor,

Mr. Vinoraj Rajendran, from 18th August, 2021 till 31st July, 2022

Signature of the candidate

Syed Md. Atifuz Zaman

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Signature of Industry Mentor

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Date- 23-06-2022

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Abstract

In the present work, two new models of Refrigerators were developed. With every part and design being made new with new additional features, this model was developed with the objective of replacing the previously running models. This was done by surpassing the previously used volumes, achieving higher storage volumes with a proportionately very less increase in Energy consumption.

A detailed procedure of the performance parts selection done in LG Electronics standards is recorded in this work.

Testing for the same were performed in the labs of company following strict standards set by governmental bodies for a particular country.

The project was the development of two 3 Star Refrigerator models of volumes 360L and 340L.

Testing was conducted by our team at the various stages of development. Results obtained were maintained under internal LG limits set previously and also with a 5% margin and were in compliance with BEE and BIS. Machine to machine variation was also checked and kept under limit generated by following Three-Sigma. Volumes and performance results were also compared with other benchmarked companies to ensure healthy competition.

Keywords- Refrigerator, Performance, Testing, Standards, Development.

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Chapter 1
Introduction

LG Electronics is a South-Korean based multinational conglomerate corporation established in 1947. It specializes in Home Appliances, Consumer Electronics and Computer Hardware. It started its manufacturing in India from 1993, and to date, has two subsidiaries/plants in India, at Greater Noida- Uttar Pradesh and at Pune- Maharashtra. The year 2022 marked a milestone of 25 Years of LG Electronics establishment in India. This particular project was entrusted to LGI Greater Noida. Being a part of Refrigerator R&D team, our job was to develop a new model from scratch and deliver it to the customers before peak season arrives.

After a successful period of over 12 years with its running refrigerator model, LG India was entrusted with an A Grade Project in 2021. In its simplest form, an A Grade project is the development of a model, which in every aspect- Design wise and Performance wise, is totally different and newer than its predecessor models. Every minute part comes with a change incorporating an upgraded technology intended for better performance or ease and satisfaction for the customers. A total period of approximately 9 months was taken for our team to complete the project right up till national launch. The models launched were **Frost Free, Top Freezer-Bottom Refrigerator, Convertible, 3 Star domestic models coming with 360 L and 340 L volumes**.

When major testing were over for the base model, we started working on the next upcoming variants for the same by reducing features and making them more cost friendly, bringing us to the next grade of development- the C2 grade. This was done by introducing 2 Star models, Internally Temperature control models instead of External, and the Non-Convertible models which incorporate a totally different and cost efficient technique for cooling. For these C2 grade models, the stipulated time given was 80 days till national launch. There were all total 8 C2 grade models launched all within the April of 2022.

After the completion of C2 grade models, on came the Export models, meant to be exported to foreign countries for sale. These models were basically the Non-Convertible models with some changeovers made to be suitable for foreign climatic conditions. The Export development, as of July 2022, is still under development with tests going on for each country at a time.

All testing were done following standards set from government bodies. For our models which were launched nationally as domestic models, the **Indian Standard IS-15750** was followed which is exclusively for Frost Free Refrigerators. The standard is set by the government body **Bureau of Indian Standards (BIS)** and has been under use since 2006 and will be applicable till the 31st of July, 2022. Apart from this, to launch models in India, it is mandatory to obtain energy based certification which is given by the government body of **Bureau of Energy and Efficiency (BEE)**. The BEE sets the limit of energy consumption, the energy calculated according to the standards set by BIS, and the limit is set according to the volume of the refrigerator and the star rating it is supposed to achieve. For BEE testing, machines are made to undergo energy tests in chambers specifically dedicated for BEE. Once energies are obtained within the set limit, the energy reports are submitted to BEE for certification and allowance to be sold nationwide.

With the IS 15750 approaching to an end to its tenure, the BIS has formulated the new standard as well which is expected to be followed with full effect from the August of 2022. The new **Indian Standard IS-17550** brings forward newer and more accurate methods of calculation of parameters such as energy and other machine performance tests. Tests for the same have also been conducted for accreditation certifying that LGI Greater Noida has labs that can carry out the specified tests as per new standards.

Apart from domestic testing, when testing regarding export models are concerned, there are major changes required in the procedures and many more additional tests are added. The standards change from Indian standards to International standards which are globally accepted, the former itself being a subset of the latter with some modifications suitable for India. The **International Standard IEC-62552** brings forth the conditions of testing with test packages and M-packages, storage and energy tests are different ambient conditions due to climatic differences from India, freezer star ratings which are rather dominantly considered in foreign countries. The countries to which LGI exports include middle eastern countries such as UAE, Qatar, Saudi Arabia, African countries such as Egypt, Kenya, Sudan, Morocco and other countries like Georgia, Iraq and etc.

When it comes to editions of the International Standards, not all countries, as of date, follow the same edition. There are countries which use the 2006th Edition whereas some countries follow the newer 2015th Edition of the same. Countries like Kenya follow their own governmental standard known as the **Kenya Standard KS-2464** which is a subset of the IEC-62552 2015 Edition with some minor changes.

Before we get deeper into this project regarding the performance of our model, given below is a basic classification of the type of refrigerator our model is based on and the other types that are manufactured. This will help in better understanding of context when it comes to testing.

Frost Free Refrigerator- As the name implies, this type of refrigerator comes with a logic of automatically defrosting any form of ice that forms on the evaporator of the machine during prolonged use. This is taken care of without the involvement of customer efforts, thus making it user friendly. Frost Free refrigerators usually come as double door refrigerators with the top as Freezer section and bottom as the Fresh Food or refrigerator section. The defrost logic is explained below stepwise,

* Ice Formation on Evaporator- When the machine's doors are opened during usage, the atmospheric air enter inside the compartments carrying some amounts of moisture depending upon the humidity. This moisture on contact with the evaporator condenses and freezes on it as frost/ice. If not removed, this impacts on the cooling capacity as it hampers heat removal from the compartment.
* Defrosting- Defrosting happens after an interval from the previous defrost. This interval is a time period consisting of two parts- fixed and variable. The fixed part is approximated as 40 hours of the compressor's running time and the variable being approximately 10 hours of the same. This period keeps on decreasing the more frequently machine doors are opened and closed, the minimum time reaching down till 12 hours. When the interval time is over, the sheath heaters (Coiled wired heaters) which are placed right below the evaporator are turned on automatically, melting the frost formed. The heater remains on until the evaporator temperature reaches a temperature of -20°C, the temperature being sensed using sensors attached on the evaporator. The defrost water (ice cold) falls down a drain below the heater which leads right at the bottom to a tray on which a condenser component (drain pipe joint) is placed and thereby evaporates there by taking heat from the condenser. Defrost can also be taken manually by using buttons provided on the PCB.

Apart from just the defrost logic, another significance of frost free refrigerators are its forced cooling technique. These refrigerators are equipped with fan(s) to provide a forced air flow circulation inside the compartments thus making the cooling of a bigger size much easier rather than solely depending on natural convection. The fans are usually placed right in front of the evaporator, sucking cold air from the evaporator side and distributing it to rest compartment via ducts provided in both freezer and fresh food compartment.

The model focused in this project is a Frost Free Refrigerator.

Direct Cool Refrigerators- This type of refrigerator has the highest sales in a country like India where cost matters a lot. Due to its compact design, simple working and cheap prices, this is the most sought after refrigerator contributing up to 60-70% of the total refrigerator sales of LG. These refrigerators basically come with single doors which contain both the freezer and fresh food section. Cooling is done by natural convection from the evaporator. The evaporator in this case, unlike a finned tube, it is a hollow and rectangular. The walls of the eva carry the pipeline for refrigerant and the hollow space can also be used for storage purpose. Air near the evaporator is naturally circulated throughout the whole compartment. As for defrost, these machines have a manual defrost button. On pressing it, defrost takes place and defrost water collects in a tray above the compressor. From the compressor heat, the water evaporates. Defrost does not takes place automatically but it is suggested for such refrigerators that at least once every week, the machine should undergo defrost. As of now, the testing of domestic DC machines are governed by the **IS-1476**. This standard expires after 31st July, 2022 and then it will be succeeded by the IS-17550 (same as FF refrigerators).

1.1. Project Road Map

The Project Road Map is set prior to the starting of any project as it gives us a bird's eye view of the entire project process. Set as per the company, our Road Map is given below,

- ✓ Product Development Request- A request is generated in the company server system which incorporates the idea generated from the combined results of market survey and R&D ideas. The new project is introduced and timelines are set for the same in the system.
- ✓ Concept Planning- A concept of the product is planned and designed in CAD software based on the ideas and the requirements of customers from market survey.

- ✓ Product Planning- The CAD model is then analysed, either by generating a prototype and performing practical tests on it or by running CFD based simulations on it, both leading to the feasibility decision of the product. Within this, a number of activities as followed are covered
  - BOM is made, with every part and child part material getting finalized.
  - New Part List and Changed Part Lists are made and finalized.
  - Design review is made based on part failure method and tests are prescribed accordingly.
  - Modifications and upgrading of tools, modifications in production line are made.
  - Critical dimensions are inspected to ensure best fitment of parts.
  - Performance tests are performed with an objective of obtaining results with 10% safety margin.
  - Design Standard is released in which all Product Test, Performance, Safety parameters, Noise, Drop, Transportation is mentioned with their specs also specified.
- ✓ Design Verification- After confirmation of design reviews, line modifications and tooling modifications, Quality Team gives R&D the approval to start testing. Simultaneously, Cost input is done in the system. Production team and quality check teams are given the production guidelines. All of this is followed by the production of samples on the production line. Issues found in this stage are tackled in the DV2 event where countermeasures are taken. After the success of every test, the event is closed and the project moves on to its next event.
- ✓ Process Verification- In this event, the production team and manufacturing team inspect for issues faced in line, line quality, and product scanning.
- ✓ Pre-Mass Production- The project is finally handed over to the production team where they ensure the product's quality for the final time to decide whether it's acceptable for Mass Production.
- ✓ Mass Production- This event is carried out according to the sales requirement and from this point, Field Inspection team comes into play to ensure product performance for customers.

1.2. Key Features

The new features included in this model are as follows-

* Increased Volume i.e. 360L & 340L
* Wi-Fi Connectivity through mobile for remote temperature control
* Smart Diagnostic System to alert machine behaviour
* Externally Temperature control Digital Display
* Express Freeze for faster cooling when required
* AI driven performance which analyses customer's usage pattern and adapts accordingly providing more cooling when customer uses more frequently, and lesser when refrigerator is undisturbed.
* Expresses errors digitally, if found, during performance issue, making it easier for servicing when required.
* Flat Freezer and Fresh food compartment Duct Design to increase storage volume
* Movable Ice making assembly
* Fresh Food air return near air outlet for complete circulation of air
* Hygiene Fresh LED Lights to purify the used air inside
* Modified Drain Tube for defrost water outlet to avoid outside air entry through it

The Running/Existing Features incorporated from the previous models are as follows-

* Smart Inverter Compressor, which can change frequency depending on the load of the machine and the required temperatures required.
* Frost Free Refrigerator
* Charcoal Deodorizer at air return paths for extracting unwanted odour
* Door Cooling duct

This work shows the mathematical approach to the thermal load determination of the model and the various performance tests undergone (the tests carried out in LG Electronics, Greater Noida Plant) with their procedures and standards mentioned and their results stated.

Chapter 2
Literature Review

The following standards, materials and research papers were used and followed in completing this work and thus have been mentioned. Being a development based project completed in an industry, mostly Indian and International standards were followed. Internal materials from LG Electronics were studied for calculations and selection of performance components and topics exclusively made for the model developed.

2.1. Indian Standards

IS 15750

This is the Indian Standard for Household Refrigerators set by the governmental body BIS back in 2006. It is a subset of the International Standard IEC 62552 2006^{th} edition. Every test- performance based, material based, endurance based and safety based- that has been performed was done under the regulations set by this standard which is only applicable in India and was set as per Indian climatic conditions (Tropical Class). It specifies the essential characteristics of a Frost Free refrigerator only and not in any refrigerator which does not incorporate internal forced air circulation.

IS 17550

This is the new Indian Standard for Household Refrigerators set by the same governmental body BIS in 2021 which is to be followed in India from the 1^{st} of August, 2022 after the term for the previous IS 15750 ends. It is a subset of the International Standard IEC 62552 2015^{th} edition. This standard specifies newer and more accurate methods of calculations for energy, and updated setups for material endurance tests. The regulations are, similarly, only applicable in Indian climate class (Tropical Class) and is to be applicable for both Frost Free and Direct Cooled refrigerators.

IS-302-1

This is the Indian Standard for Safety of Household and similar Electrical Appliances, published by the BIS and deals with electrical appliances safety used in household. It basically covers hazards which can possibly be created from electrical appliances.

IS 10617:2018

This is the Indian Standard for Hermetic Compressors-Specifications. In this standard, the safety and performance requirements for hermetic compressors operating on VCRS is covered suitable for all low, medium and high temperature operations.

2.2. International Standards

IEC 62552 (2006th edition)

The International Standard for Household Refrigerators was published by the IEC Technical Committee 59. It covers the testing procedures, specs and setups for both Frost Free and Direct Cooled refrigerators. Being an International Standard, it specifies tests which are performed worldwide and so it covers climatic conditions of all types. It specifies tests like Storage temperature, Freezing capacity, Temperature Rise and Energy tests with the use of test packages and M-Packages which simulate the behaviour of meat. Since in India, meat storage not being a dominant demand, the use of such packages and their particular tests is omitted in the Indian Standards. Already being superseded, it is still followed in numerous countries with the likes of most middle-eastern countries and Asian countries. The subset, IS 15750, was also followed till this year's July in India.

IEC 62552 (2015th edition)

This standard supersedes the 2006th edition and brings forth originally the methods and procedures of testing mentioned in the IS 17550. It covers the testing procedures, specs and setups for both Frost Free and Direct Cooled refrigerators.

2.3. Internal Materials

Cycle Design and Simulation

An internally provided training material for cycle engineers explaining how the cycle components are selected by calculations and how tests for the same are conducted which validate the calculations. It covers the calculation process of thermal load, the cycle parts calculation process, and then their performance verification test.

Product Standard

Product standard is made for each model individually and so was made for our models. It contains every detail of the model regarding dimensions, volumes, additional features and existing features modified. It contains every details of the machines incorporated except testing details.

Design Standard

Design standard is similarly made for each model individually. It contains in it, every detail of the tests the model needs to undergo during its development. Details of tests include basically the durations, the procedures and the specs within which it should be obtained. The product and design standards used were exclusively and only for the models developed in this project.

2.4. Research Papers

Erik Björk et al, (2006), in his work represents the results obtained from a domestic refrigerator which is tested by varying the expansion devices, the refrigerant amount and the ambient temperature. Its relevance was found in comparing its results with the test results obtained from or model in the ambient variation test and charge determination test. From the work, it was declared that until and unless there is a significant change in the charge quantity, the system performance is unaffected because of the compensation done by the accumulator. The performance was also found unaffected by varying the expansion device.

Christian J. L. Hernes et al, (2015), in his work carried out a thermodynamic analysis of a refrigeration system incorporating a liquid to suction heat exchanger to report a potential reduction in the charge quantity that can be used. His work found out the improvement in evaporator capacity when an LSHX is deployed. It reduces the amount of refrigerant in the condenser and the compressor shell. The reduction of vapour quantity inside the refrigerant also resulted in a reduction of the quantity irrespective of the refrigerant used and the working conditions.

P.A. Domanski et al, (1994), in his work presented the use of a Liquid Suction Heat Exchange in a refrigeration system. The work showed that the benefits of an LSHX is dependable on operating conditions and the fluid properties used as refrigerant. Fluids having a better performance in basic cycle have minimal effect on performance when an LSHX is deployed, whereas a significant improvement in COP is detected from fluids which gave relatively poor performance in basic cycles.

L. A. Pridgeon et al, (1924), in his work presented the difficulties and failures experienced during the designing of an evaporator. The work gives an explanation for the discrepancies faced and a scope for future improvement in procedures for calculations required in such designs. The paper is based on overall heat transfer coefficients as results which come from a vast variety of workers with enormous differences in their methods and conclusions.

Dmitriyev et al, (1984), in his work carried out a charge determination test for refrigerators using a tubed capillary for expansion. His work concluded that the amount of refrigerant mostly depended on the evaporator and condenser volumes. Also it was found that ambient air had negligible effects and was not a significant factor for determining charge quantity.

Laguerre et al, (2002), in his work mentions about the survey of a variety of refrigerators he carried out in France. His conclusions were that any form of commonness was found in refrigerators of similar type. A combination of factors had effects on the overall performance of the machine.

Belman-Flores et al, (2015), in his work represents the various impacts on domestic refrigerators. The impacts were based on thermal stratification, machine control systems, harmless refrigerants and thermal isolations. The motive of this work was to find alternatives to high energy consumption and uses of environment deteriorating refrigerants.

Gupta et al, (2007), in his work modelled a domestic frost free refrigerator and performed a thermo-fluidic analysis on the same. Discrepancies were found only between the analytical results and experimental results. Unaccounted heat transfer and lack of accurate air flow data were found the reasons behind the discrepancies.

Chapter 3
Selection of Components

There are various steps needed to be followed in the heat load calculation for determination of the dimensions and capacity of machine performance parts as it is the first step and the most critical field in the context of developing a new model from scratch. In theoretical practice, it is preferable to obtain the desired results from a set of pre-determined or pre-manufactured parts. But in practical scenario, it starts from back calculation after already knowing the results we need to obtain and the manufacturing the required parts for the same. The desired results from which the calculation starts are obtained from standards and simulation software for Heat Load calculation. The performance parts selected for both the 360 L and 340 L models were same.
The steps are followed as below,

3.1. Volume Determination

The Volume as decided for this model by considering the Voice of Customers and R&D ideas was 360L and 340L. Since the machine is a Double door machine with compartments dedicated one for Freezer Section and another for Fresh Food Section, the volume also gets divided in the following manner,

<u>Freezer</u>-

- 79L (common volume in both machines)
- Has a glass shelf in between which divides the compartment into 2 equally sized subsections, top & bottom.
- An ice making assembly which consists of an ice tray, ice drop box and a movable holder to hold the former two in position. The whole assembly can slide on the shelf horizontally from left to right and vice versa.
- 2 equally sized Door Baskets

<u>Fresh Food Compartment</u>-

- 256L & 236L
- Divided into 5 subsections
- A Pull-Out Tray (or a chiller) at the very top, which is the coldest area in the Fresh Food compartment.

* A Vegetable storage box at the very bottom
* 2 shelves in the middle of the compartment providing 3 more subsections
* 4 unequally sized door baskets

3.2. Dimensions

The Dimensions of the machine as set is given as follows,

Considering, Thickness of doors= 100 mm

Gross/Net Volume= 360 L & 340 L

Storage Volume= 335 L & 315 L

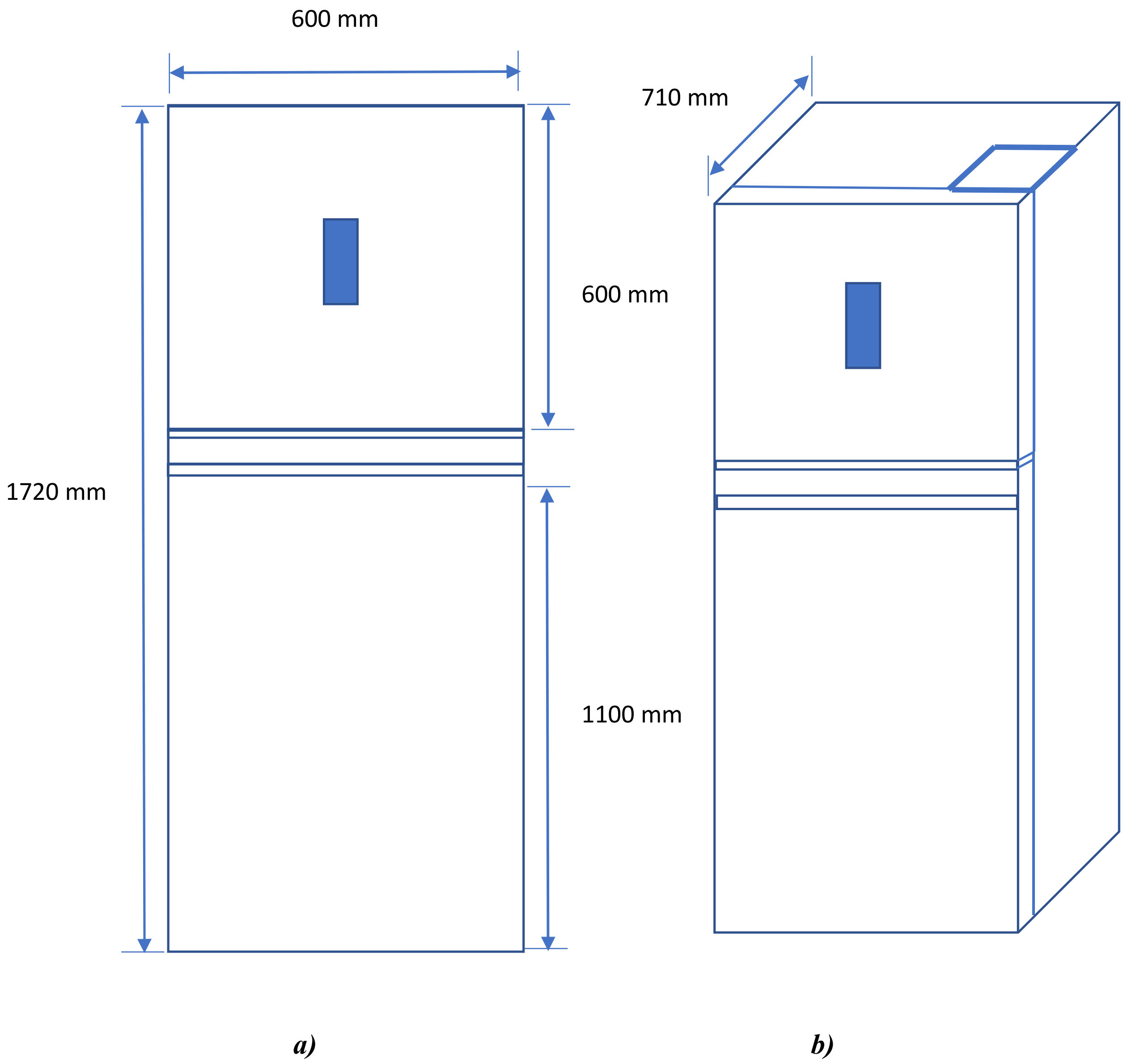


Figure 3.1 a) Front View, b) 3D View of the model with dimensions

3.3. Heat Load Determination

A Refrigerator is basically a machine which maintains a cold temperature inside by constantly removing heat from the goods stored in it and the heat transmitting inside from outside. A machine, according to its volume, must have its own Heat Load determined. The load varies throughout the day, so an average load is calculated over a period and simulated throughout the day.

The Heat Load is divided into several categories- i) Transmission Load, ii) Product/Goods Load, iii) Internal Equipment Load, iv) Defrost Heater Load, v) Infiltration/Exchange Load

3.3.1. <u>Transmission Load</u>- This is the heat transferred from outside atmosphere towards the inside of the refrigerator through the insulated walls of the refrigerator. Its mode of transfer is conduction and convection occurring in the following order,

* Convection from outer atmosphere to the Cabinet Outer Wall
* Conduction through Cabinet Wall to PU Foam
* Conduction through PU Foam to Inner Liner
* Conduction through Inner Liner to Inner cold space
* Convection from Inner Liner to Inner cold space

This load in *W* is calculated from the given formula,

$$Q = U \times A \times (T_{out} - T_{inside}) \qquad (1)$$

Where, U= Overall Heat Transfer Coefficient (W/m^2K),

A= Cross Sectional Area of Wall (m^2)

T_{out} & T_{inside}= Temperatures Outside and Inside of the Refrigerator (˚C)

The value of U differs when different compartments are considered.

3.3.2. <u>Product/Goods Load</u>- This is the heat transferred from products that are brought inside the refrigerator from and at a higher temperature than what is maintained inside. This is a load which depends on the usage of the refrigerator and cannot be determined exactly unlike transmission load. But this load accounts for up to 50-60% of the total. It can be calculated in Watts from the given formula,

$$Q = \frac{m \times C_p \times (T_{product} - T_{inside})}{1000} \quad (2)$$

3.3.3. Internal Equipment Load- The refrigerator comes with some internal accessories which can generate minute amounts of heat which eventually do reflect on the annual energy consumption. For example, LED lights inside the fresh food compartment, hygiene LEDs for purification, fan motors for air circulation inside freezer. This can be simply formulated as,

$$Q = \text{No. of lamps } (1) \times \text{Wattage of Main LED} \quad (3)$$

$$Q = \text{No. of lamps } (2) \times \text{Wattage of Hygiene LED} \times \text{ON Duration } (10 \text{ mins fixed/hr}) \quad (4)$$

$$Q = \text{No. of Fans } (2) \times \text{Heat released per second} \times \text{Running Duration (Depends on Set Temperature)} \quad (5)$$

3.3.4. Defrost Heater Load- Defrost Heater turns on after a certain period of time depending on the number of times and the duration for the doors are opened during normal operation and is not a continuous heat addition. According to the logic, they remain on until the evaporator temperature goes above -16˚C. This is typically achieved in an approximate duration of 20 minutes operating with a wattage of 150 W. Therefore,

$$Q = 140 \text{ W} \sim 150 \text{ W} \quad (6)$$

3.3.5. Infiltration/Exchange Load- This is the load which comes in when the doors of the refrigerator are opened during normal usage, and has an impact of up to 1-10% of the total load. This can be formulated as,

$$Q = \text{No. of volume changes per day} \times \text{Volume} \times \text{Heat entering per cc of air} \times (T_{out} - T_{inside}) \quad (7)$$

3.4. Compressor Selection

After the thermal load calculation is performed and the required load is determined, a compressor is selected for the same which can efficiently remove the load, in any applicable conditions and with a factor of safety considering 20% according to LGE Standards.

The compressor selection is done by carrying out tests on various compressors which can deliver the required performance. Testing is firstly carried out in Calorimeter units which gives us, as output, the freezing capacity, input power and the EER (Energy Efficiency Ratio). But the results obtained from a calorimeter are not exact as what is obtained when a compressor is run in an actual refrigerator. This is due to many reasons such as compressor inlet (suction) conditions vary, the inclusion and exclusion of the super-heated d sub-cooled parts in a cycle, factors of refrigerator volume and its load based on usage and ambient variations and so on. So, the second step is to run the compressors in the refrigerator to retrieve actual data. A comparison is then made and a Calorimeter Correlation Factor is deduced.

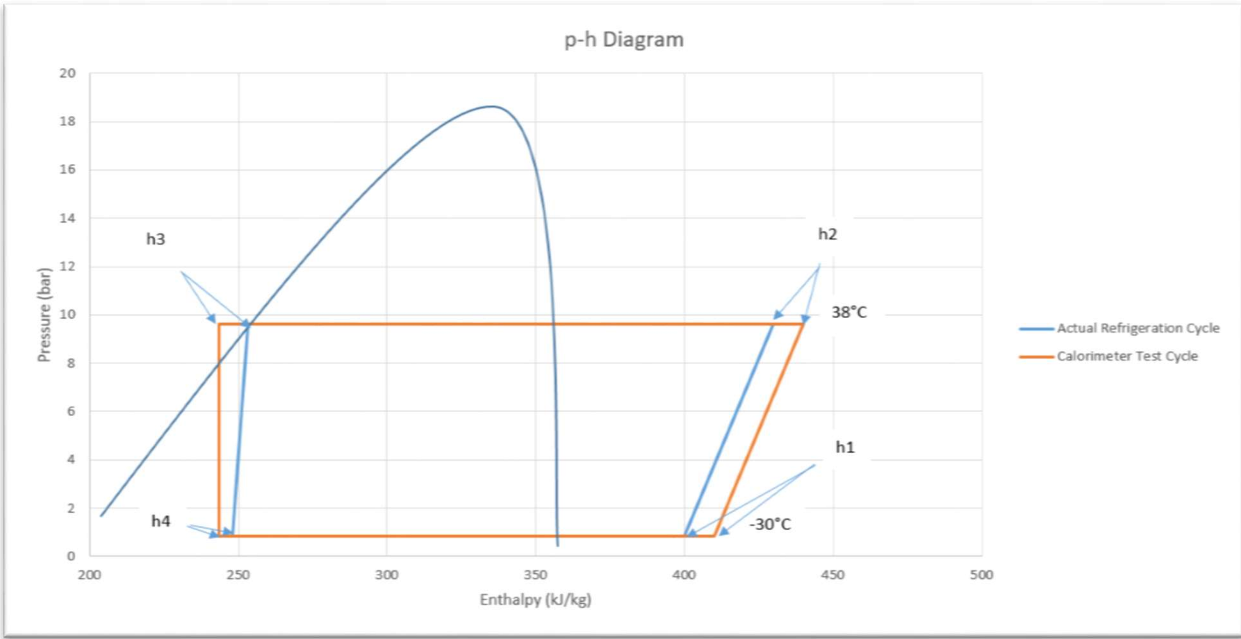


Figure 3.2 p-h diagram of VCRS cycle in Actual machine vs. Calorimeter Tester

The process is given as follows,

3.4.1. Calorimeter Testing- The compressor is attached to a refrigerating unit (not an actual refrigerator) and its performance is checked. The calorimeter is connected to the unit and measures the refrigerating effect using the 9 Point Data method. It is calculated from the following formula,

$$Q_{cal} = \text{Refrigerant mass flow rate (m)} \times (h_4 - h_1) \tag{8}$$

As Q_{cal} can be directly obtained from the test unit, and the enthalpy difference can be obtained from the operating temperatures, we can find out the mass flow of the refrigerant. Using the same mass flow, we can calculate the energy input to the compressor.

$$m = \frac{Q_{cal}}{(h_4 - h_1)} \tag{9}$$

$$Q_{Comp} = m \times (h_2 - h_1) \tag{10}$$

$$EER = \frac{\text{Heat Load Removed}}{\text{Energy Consumption of Compressor}} \tag{11}$$

This way we calculate the freezing capacity, input power, and the EER of the compressor.

3.4.2. Calorimeter Correlation Factor- The performance of the calorimeter for the compressor unit is different from the actual freezing capacity and input power obtained when running on an actual refrigerator. For compressor selection, it is very much obvious that actual data is required. To calculate the same from the Calorimeter data, a Calorimeter Correlation Factor is deduced as in eq. (12). The CCF gives us the effective refrigeration capacity using the 9 point data calculation.

$$CCF = \frac{m\Delta h_{actual}}{m\Delta h_{calorimeter}} \quad (12)$$

3.4.3. <u>9 Point Data</u>- This is the method of calculating the most optimized parameters of the compressor at 9 different conditions using the calorimeter unit. The parameters calculated are the Freezing Capacity, Input Power and EER. The conditions are set for the Condenser and the Evaporator at 9 points as figure 3.3. shown below,

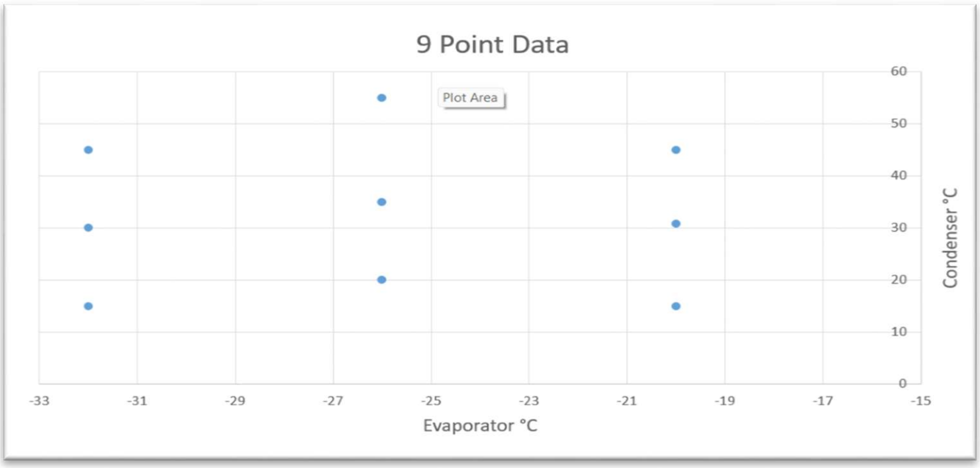


Figure 3.3 Graphical representation of 9 Point Data

3.4.4. <u>9 Point Data Results</u>- The results obtained of a compressor are shown below,

S.no.	Evaporator	Condenser	Freezing Capacity	Input Power	EER
1	-32	15	**163.3**	**83.3**	**6.691**
2	-32	30	**174.4**	**104.8**	**5.678**
3	-32	45	**163.1**	**114.7**	**4.854**
4	-26	20	**224.2**	**93**	**8.229**
5	-26	35	**235.6**	**122.4**	**6.568**
6	-26	55	**215.9**	**143.5**	**5.135**
7	-20	15	**276**	**80.7**	**11.671**
8	-20	30.7	**301.3**	**124.9**	**8.23**
9	-20	45	**304.3**	**158.4**	**6.557**

Table 3.1 9 Point Data Results

It is possible to change the measurement conditions as well as the number of conditions according to the purpose of the measurement.

* After required results are obtained, the thermal load is plotted overlapping with the compressor's freezing capacity (figure 3.4.).
* The point of intersection between the two lines becomes the point where maximum capacity is achieved when a particular compressor is attached to the refrigerator.
* The compressor that produces a temperature equal to or more preferably lower than the design standard temperature (Compressor A, graph below) is selected. Its thermal load changes from Q_{cal} to Q_{Ref}. All specifications of other cycle parts are done according Q_{Ref}.
* Other compressors which give higher temperatures than the standard temperatures (Compressor B, graph below) are unable to deliver the required cooling performance.

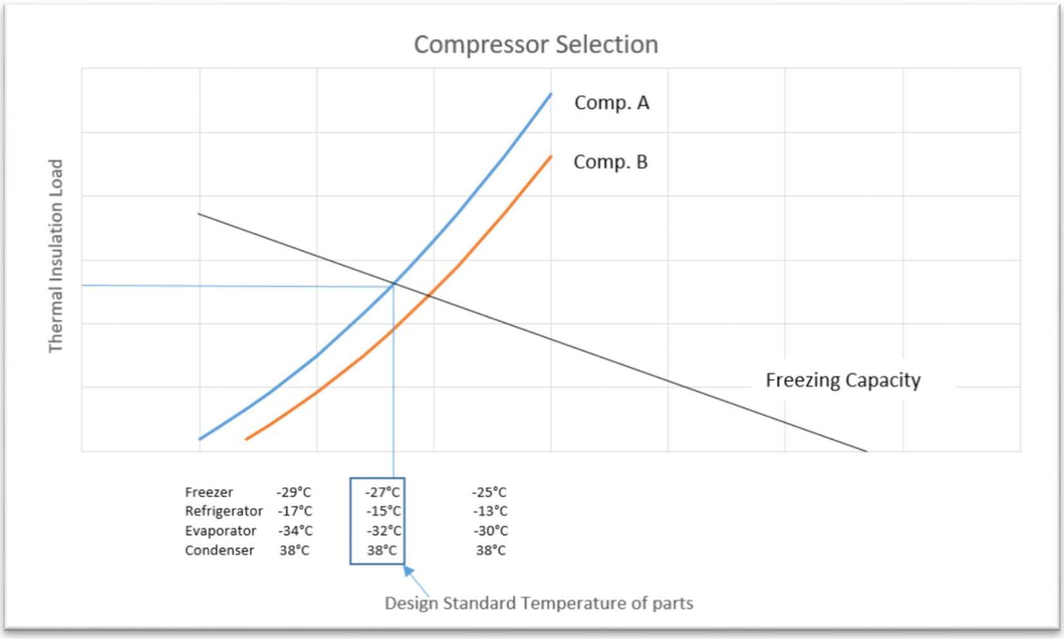


Figure 3.4 Graphical representation of Thermal Load intersecting Compressor Freezing Capacity

3.5. Evaporator Selection

For the calculation of evaporator selection, there are some basic parameters which must be determined,

* Air volume of Freezer/Fresh Food Compartment (CMM_f, CMM_r), properties of air

* Shape of the Heat exchanger: Width, Depth, Flow area S (=width x depth)
* Number of levels, pipe diameter, unit fin area, number of fins for each level
* Temperature of Freezer and Fresh Room

3.5.1. Vaporizing Heat Q_e- This is the heat the refrigerant inside the evaporator extracts from the air inside the refrigerator to vaporize into gaseous form. It is a function of the air properties and is given as,

$$Q_e = (m \times C_p)_a \times (T_{ai} - T_e) \times \varepsilon \tag{13}$$

where, $(m.C_p)_a$= mass and C_p of air in kg/s and J/kg˚C respectively

T_{ai}= Temperature of air coming towards/into the evaporator in ˚C

T_e= Temperature of evaporator in ˚C

ε= Effectiveness of heat exchanger (in our case, evaporator)

3.5.2. Effectiveness of Evaporator- Effectiveness is the ratio of actual heat transferred to the maximum possible heat transfer. It is also calculated using the specifications of the evaporator, air flow rate and material properties,

$$\varepsilon = 1 - \exp\left\{\frac{-(UA)_e}{(m \times C_p)_a}\right\} \tag{14}$$

$$= \frac{(T_{ai} - T_{ao})}{(T_{ai} - T_e)} \tag{15}$$

where, U_e= Overall HT Coefficient in W/m^2 ˚C

A_e= Surface Area of Evaporator in m^2

T_{ao}= Temperature of air going out/away from the evaporator in ˚C

3.5.3. Temperature of air coming towards/into the evaporator (T_{ai})- This is calculated from the temperatures of F compartment, R Compartment and air flow ratio as follows,

$$T_{ai} = \left\{ \frac{[(T_f + 0.5) \times CMM_f] + [(T_r + 2.0) \times CMM_r]}{CMM_f + CMM_r} \right\} \quad (16)$$

where, T_f= Temperature of Freezer in ˚C = -28 ˚C approximately

T_r= Temperature of Fresh Room Compartment in ˚C = -17 ˚C (extremely cold due to pull-down mode)

CMM_f= 0.8, CMM_r= 0.2, from our model

0.5, 2.0= Constants derived experiences gained from experimentation

3.5.4. Overall Heat Transfer Coefficient (U_e)- This is calculated as a function of air velocity in the evaporator as follows, (Empirical equation of refrigerator's fin tube type evaporator),

$$U_e = 27.2 \times V_{air}^{0.56} \quad (17)$$

where, V_{air}= Velocity of air in m/s

3.5.5. Area determination of Evaporator A_e- Considering values approximated for our model from various other tests, from eq. 13, ε can be found out.
From this, we can calculate the value of Evaporator area using eq. 14

3.6. Condenser Selection

The condenser in our model is divided into 4 sections in the following order, i) Drain pipe joint, ii) Back Plate condenser, iii) Left Side Plate condenser, and, iv) Framework condenser.

3.6.1. Condensing Load Q_{tc}- This is the heat load on the condenser which needs to be rejected at a high pressure to the outside air. It consists of the sum of the thermal load (Q_R) and the additional heat added to the refrigerant during compression (N).

$$Q_{tc} = Q_R + N \quad (18)$$

3.6.2. Condenser Integer C_k- This is defined as the ratio of the condensing load and the thermal load,

$$C_k = \frac{Q_{tc}}{Q_R} \tag{19}$$

The relation between the condenser integer and the compressor capacity is given as,

$$C_k = 1 + \frac{N}{Q_R} \tag{20}$$

Therefore, condenser integer is decided by the thermal insulation load Q_R at a given temperature and the quantity of heat received by refrigerant during compressor.

3.6.3. Total Heat of Condenser- Heat transfer from condenser takes place by a temperature difference between that of refrigerant and the outside air. The temperature distribution in the condenser can be shown generally as the graph (figure 3.5.) below,

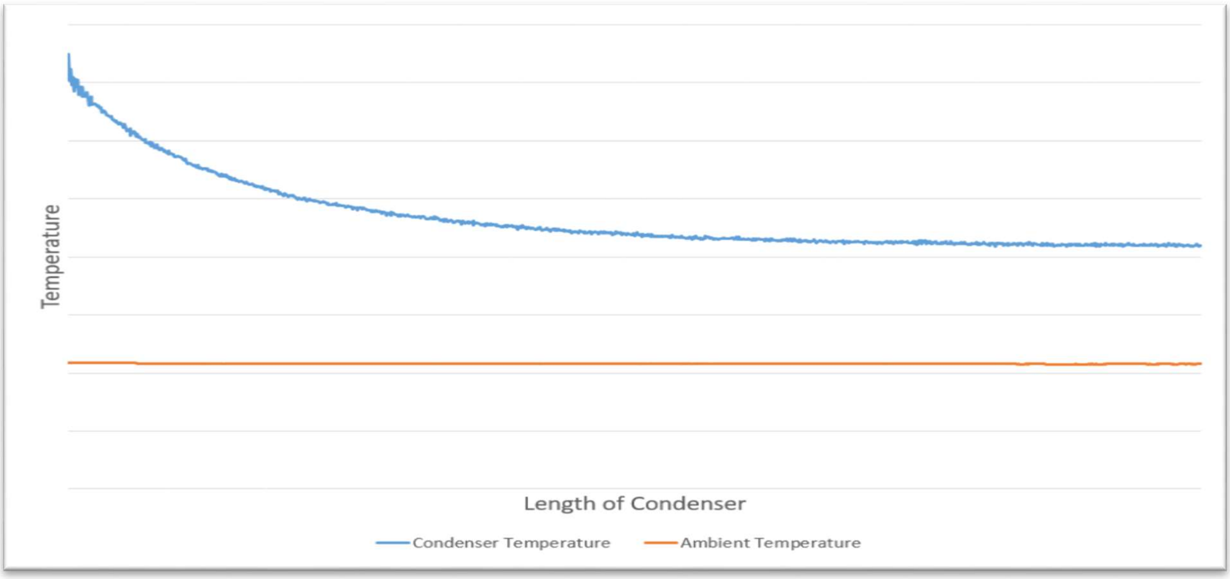


Figure 3.5 Temperature Distribution of Refrigerant along condenser length

Total Heat in Condenser $Q_C = K.L.\Delta T_m$

where, K= HT Coefficient

L= Condenser Length

ΔT_m= Logarithmic Mean Temperature Difference

3.6.3.1. Logarithmic Mean Temperature Difference between the air and the refrigerator at inlet and outlet of the condenser is expressed as follows,

$$\Delta T_m = \frac{(t_{in} - RT) - (t_{out} - RT)}{\ln \frac{t_{in} - RT}{t_{out} - RT}} \quad (21)$$

where, t_{in}= Inlet temperature of the condenser section

t_{out}= Outlet Temperature of the condenser section

RT= Room Temperature

Now, since we know that the condenser is divided into 4 sections, similarly the ΔT_m is calculated in 4 different sections separately. Also, the heat transfer inside condenser takes place at 2 stages, i.e. firstly superheated refrigerant gas is brought down to saturation temperature by sensible cooling, and then latent heat rejection for phase change of refrigerant.

Sensible cooling region- This heat transfer takes place completely in the first three sections of the condenser, i.e. Drain pipe joint, BP condenser, LSP condenser. So the equation for LMTD is used to calculate the ΔT_m in these sections separately as $\Delta T_{m,\,drain}$, $\Delta T_{m,\,BP}$, $\Delta T_{m,\,LSP}$.

Latent heat rejection region- This heat transfer begins inside the framework condenser and is basically the phase change part. Thus, the inlet and outlet have very close temperatures approximately, the outlet being equal to the room temperature, which gives us $\Delta T_{m,\,frame} = (t_{in} - RT)$.

Therefore, the total condensing load Q_{tc} can also be given as,

$$Q_{tc} = Q_{drain} + Q_{BP} + Q_{LSP} + Q_{frame} \quad (22)$$

$$= K_1L_1\Delta T_{m,\ drain} + K_2L_2\Delta T_{m,\ BP} + K_3L_3\Delta T_{m,\ LSP} + K_4L_4\Delta T_{m,\ frame} \quad (23)$$

3.7. **Capillary Selection**

The capillary is selected based on its operating point conditions which in turn depends on the compressor performance and the evaporator heat transfer satisfaction. The operating point is decided from the intersection of the compressor performance curve and the capillary tube performance curve (points 1, 2, 3), both drawn in a plot of mass flow rate against the suction pressure as shown in figure 3.6. If the operating point at a given condition does not satisfies the evaporator heat transfer, it implies that either a shortage or an oversupply of refrigerant has occurred due to cycle imbalance.

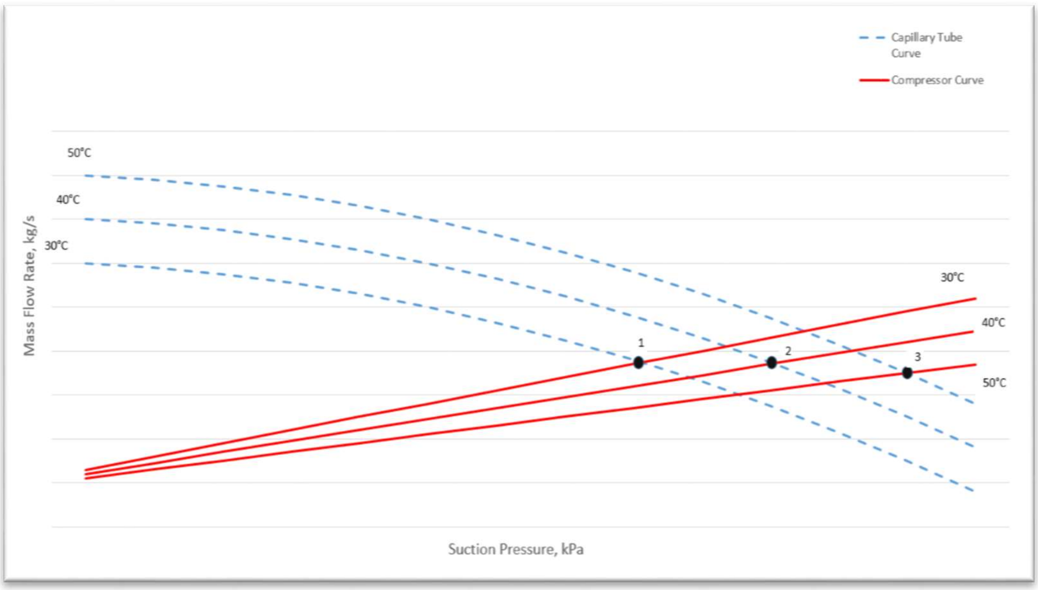


Figure 3.6 Plots of Capillary Tube performance and Compressor performance

For a new refrigeration cycle, the capillary diameter and length should be selected such as the compressor and the capillary have a balance point at the required vaporizing temperature of evaporator. The final length selection process is a trial and error method mostly. Initially, a tube with longer length is installed which leads to a balance point much lower than the vaporizing temperature. The length of the tube is then gradually reduced until it reaches the required balance point.

3.7.1. Analytical Calculation-

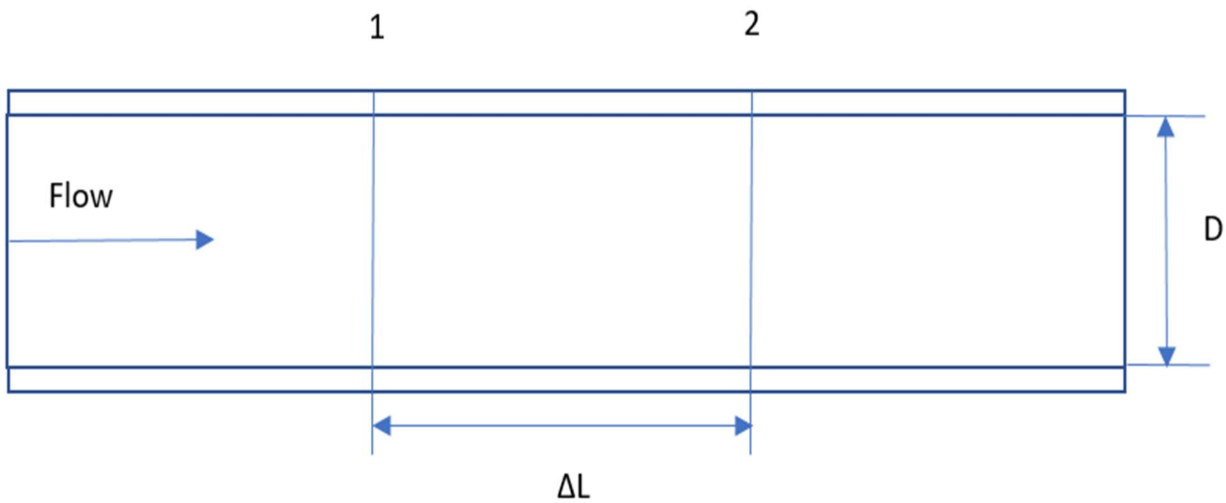


Figure 3.7 Refrigerant flow through a Capillary Micro-Length

Let us consider the following terms and symbols for the upcoming calculations,

Symbol	Term	Unit	Symbol	Term	Unit
A	Cross Section	m^2	v	Specific Volume	m^3/kg
D	Inner Diameter	m	v_f	Sat. liq. Spec. vol.	m^3/kg
f	Friction Coefficient	Dimensionless	v_g	Sat. vap. Spec. vol.	m^3/kg
h	Enthalpy	kJ/kg	V	Refrigerant Vel.	m/s
h_f	Sat. liq. enthalpy	kJ/kg	ω	Circulation amt.	kg/s
h_g	Sat. vap. enthalpy	kJ/kg	X	Humidity	
ΔL	Micro Length	m	μ	Viscosity Coefficient	Pa s
P	Pressure	Pa	μ_f	Sat. liq. Visc. Coeff.	Pa s
Re	Reynolds Number		μ_g	Sat. vap. Visc. Coeff.	Pa s

Table 3.2 Nomenclature for Capillary Selection Calculation

The equations applied to the capillary tube is decided by point 1 and 2 in the figure 3.7 and is given as follows,

Continuity Equation-

$$G = \frac{V_1.A}{v_1} = \frac{V_2.A}{v_2} \tag{24}$$

$$\frac{G}{A} = \frac{V_1}{v_1} = \frac{V_2}{v_2} \tag{25}$$

Conservation of Energy-

$$1000h_1 + \frac{V_1^2}{2} = 1000h_2 + \frac{V_2^2}{2} \tag{26}$$

Conservation of Momentum-

- The pressure difference is given as,

$$(P_1 - P_2) = f\frac{\Delta L}{D}.\frac{V_2}{2v} = \omega(V_2 - V_1) \tag{27}$$

- As refrigerant passes through the capillary tube, its pressure keeps falling gradually and humidity/vapour content increases. Therefore,

$$h = h_f + X(h_g - h_f) \tag{28}$$

$$v = v_f + X(v_g - v_f) \tag{29}$$

- For expressing the frictional coefficient, it gets complicated for a 2 phase flow, so it is approximated first and then the results are compared with experimental results in order to check accuracy. So, for our case where Re value is in a low range of turbulent area, the frictional coefficient can be expressed as,

$$f = \frac{0.33}{Re^{0.25}} = \frac{0.33}{\left(\frac{V.D}{\mu v}\right)^{0.25}} \tag{30}$$

- Viscosity Coefficient of a 2 phase flow at a given position inside the tube is a function of humidity X,

$$\mu = \mu_f + X(\mu_g - \mu_f) \tag{31}$$

* This will lead to two different frictional coefficients at point 1 and 2, therefore, an average f is taken of f_1 and f_2.

Calculation of Micro length- If refrigerant flow rate at one point is known (say, inlet), the remaining values of points 1 & 2 can be determined in the following order for a temperature decided arbitrarily for the two points,

1. Refrigerant flow rate calculation- The flow rate (mR) varies slightly according to the selected compressor and the same is determined using the following technique.

* Calculation is done using the compressor calorimeter test data, and the test results are obtained under design conditions of discharge and suction pressure.
* From calorimeter, we get the refrigeration effect (Q_{cal}), and from the set temperatures at evaporator inlet and outlet we can find out the enthalpies.
* We also know that Q_{cal}= mR x Δh
* mR= Q_{cal} / Δh
* On obtaining refrigerant flow rate, the remaining parameters at points 1 & 2 can be calculated.
* Now, from the energy equation, we can get,

$$h_2 + \frac{V_2^2}{2}\left(\frac{\omega}{A}\right)^2 = h_1 + \frac{V_1^2}{2} \tag{32}$$

So only unknown parameter left is X (humidity). On solving the equation, we get X in a quadratic equation form.

* After getting value of X, we can obtain h, v values at points 1 & 2.
* Average Frictional coefficient is calculated for an increment in length by calculating Re number at point 2 using viscosity coefficient and friction coefficient.
* Lastly, ΔL is calculated from the momentum conservation equation.

Chapter 4
Overview of Refrigerator Performance

This chapter focuses on how a refrigerator performs and how the refrigerator cycle is followed. This will give a quick and brief overview on the performance which will be helpful while explaining the testing side of the refrigerator. As of now, all cycle parts and their calculations being explained, what is left is the explanation of the cycle that is followed. This can be best explained from the following figure 4.1.,

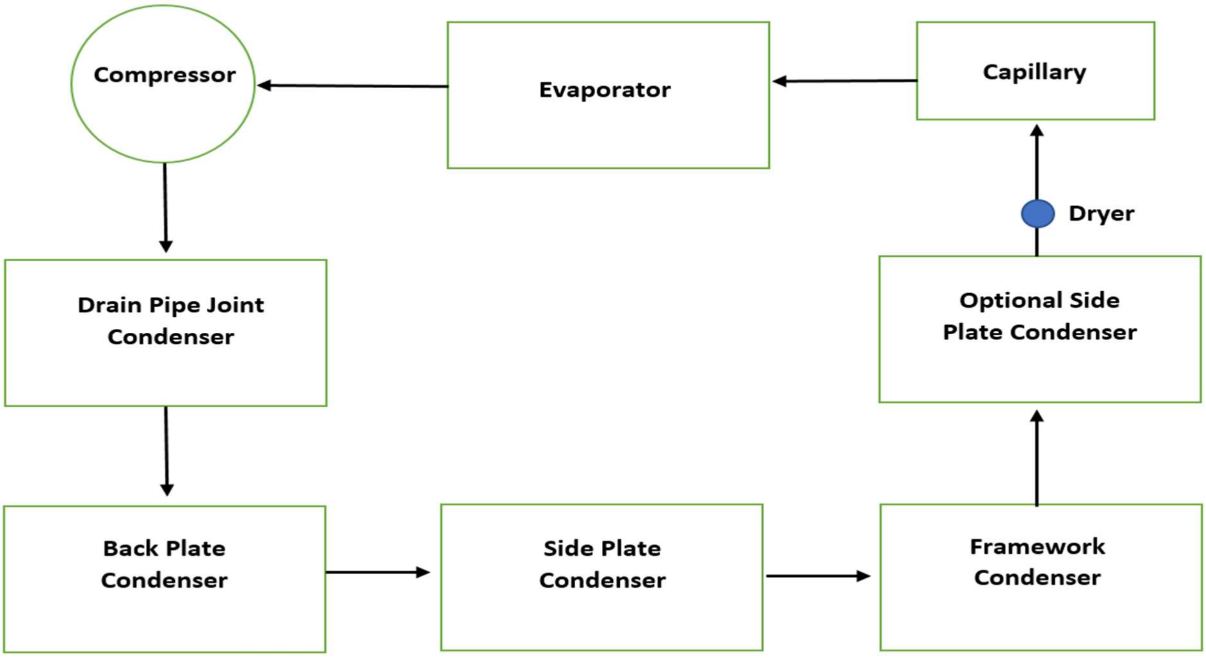


Figure 4.1 Flowchart of Refrigerant flow through the cycle parts

4.1. Working Cycle

The working can be explained as follows,

- When machine is manufactured on line, the required amount of gaseous refrigerant is filled inside the compressor. When the compressor runs, it compresses the gas increasing its pressure and temperature and discharges it to the condenser.
- The condenser, as mentioned earlier, is divided into 4 components.
    i. Firstly, the refrigerant is discharged into the drain pipe joint condenser. This is a heat exchanger designed like a coil. It is placed on a drain tray. The drain tray is where the melted water from defrost drops into. The water being

ice cold, assists in heat exchange with the drain pipe condenser by taking away its heat and evaporates itself. The refrigerant undergoes sensible cooling in this section.

ii. Next, the refrigerant moves into the Back Plate Condenser. This is attached and pasted on the back plate of the machine. Natural convection from surrounding air is the mode of heat exchange and this section also contributes in the sensible cooling of the refrigerant.

iii. From back plate, refrigerant goes to the side plate condenser which, in our model, is present at the left side from the front view. Also contributes in sensible cooling

iv. From side plate, it goes to the framework condenser. This is situated on the front side of the refrigerator along the framework. Here, the phase change of the refrigerant takes place.

- After condenser, the refrigerant flows through the dryer. The dryer is a small component which has a filter within. Its function is to absorb any moisture or impurities which anyhow might have entered inside the cycle.
- From dryer, it moves into the thin capillary. The capillary drops the pressure and does the main cooling of the refrigerant, taking it to temperatures below -25°C. The capillary is brazed with the suction which is the most important point because this is where Liquid to Suction Heat Exchange (LSHX) takes place. Referring figure 4.2.

  LSHX- Liquid refrigerant at the exit of condenser is of the same temperature as the ambient. It is at saturated liquid state (point 3). And suction is the pipeline that joins evaporator outlet to the compressor inlet. The inlet at suction is nearly saturated vapour at very low temperature (point 6). So the concept of LSHX is to braze the capillary to the suction which promotes a counter flow heat exchange between the two (3-4 is brazed with 6-1). This provides sub-cooling inside capillary and also keeps extracting heat all the way up to evaporator inlet, thus greatly increasing the refrigeration effect. Inside the suction, from inlet the nearly saturated vapour refrigerant starts extracting heat from the capillary right down till the compressor inlet, which means the refrigerant gets superheated. This superheating eliminates any form of risk of liquid refrigerant entering into the compressor, which if unchecked, can cause serious damage to the compressor. Relying solely on capillary's pressure drop phenomena and the suction's natural heat convection with surrounding is not sufficient for a refrigerating system.

* From capillary, refrigerant enters the evaporator where the heat is extracted from the compartments. Phase change of refrigerant takes place from liquid to gas.
* From evaporator, refrigerant passes through the suction which leads right down to the compressor, the refrigerant being at the same temperature as the capillary inlet/ambient due to LSHX.

In this way, the cycle continues as long as the compressor is running. The running of the compressor, its duration, cut off and start up is decided by the achievement of temperatures inside the compartment and is explained ahead.

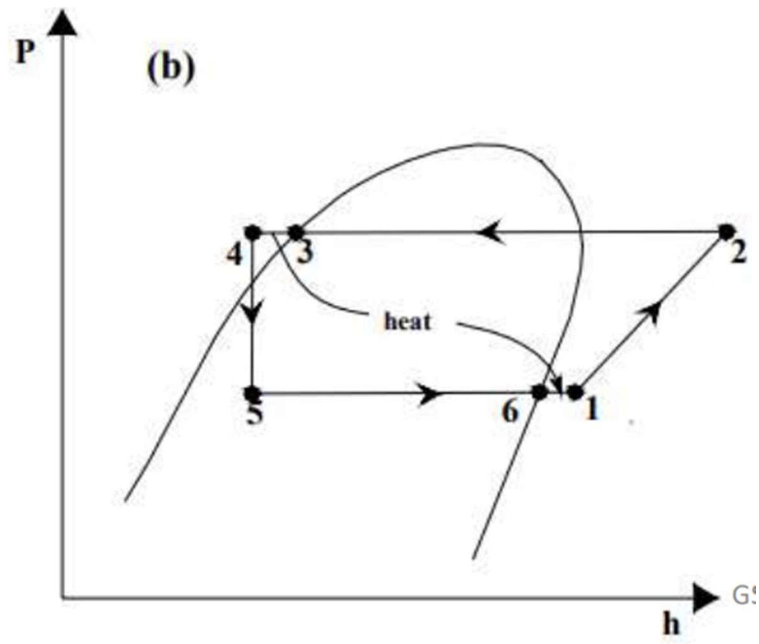


Figure 4.2 LSHX function through p-h diagram

4.2. Compressor Cycle

The compressor runs as long as the set temperature is not obtained inside compartments. Once obtained, it cuts off and stops further cooling. It starts again when temperatures again fall below set temperature. The same goes with the fan motors which are used for the forced convection. The machine is incorporated with two fans, F fan dedicated for the freezer, R fan dedicated for the fresh room. The machine is called an F fan controlled machine. This is because, a fan also turns off once its respective compartment temperature is obtained. So since fresh room temperatures are obtained first, the R fan turns off in the middle of a cycle while the F fan and the compressor keep running for Freezer temperature achievement. Once achieved, the F fan is turned off, which gives signal to the compressor to turn off.

This whole operating procedure takes place in a period which is called the ON time period of the compressor, the length of which is decided by factors like the set temperatures, ambient temperatures and load inside compartments. The ON time is followed by the OFF time period. In this period, compressor and fans are off and the temperatures inside compartments start rising. Once high enough, the ON time starts again. One ON period followed by one OFF period together constitutes one complete cycle of the compressor.

This can be presented better from a graph (figure 4.3.).

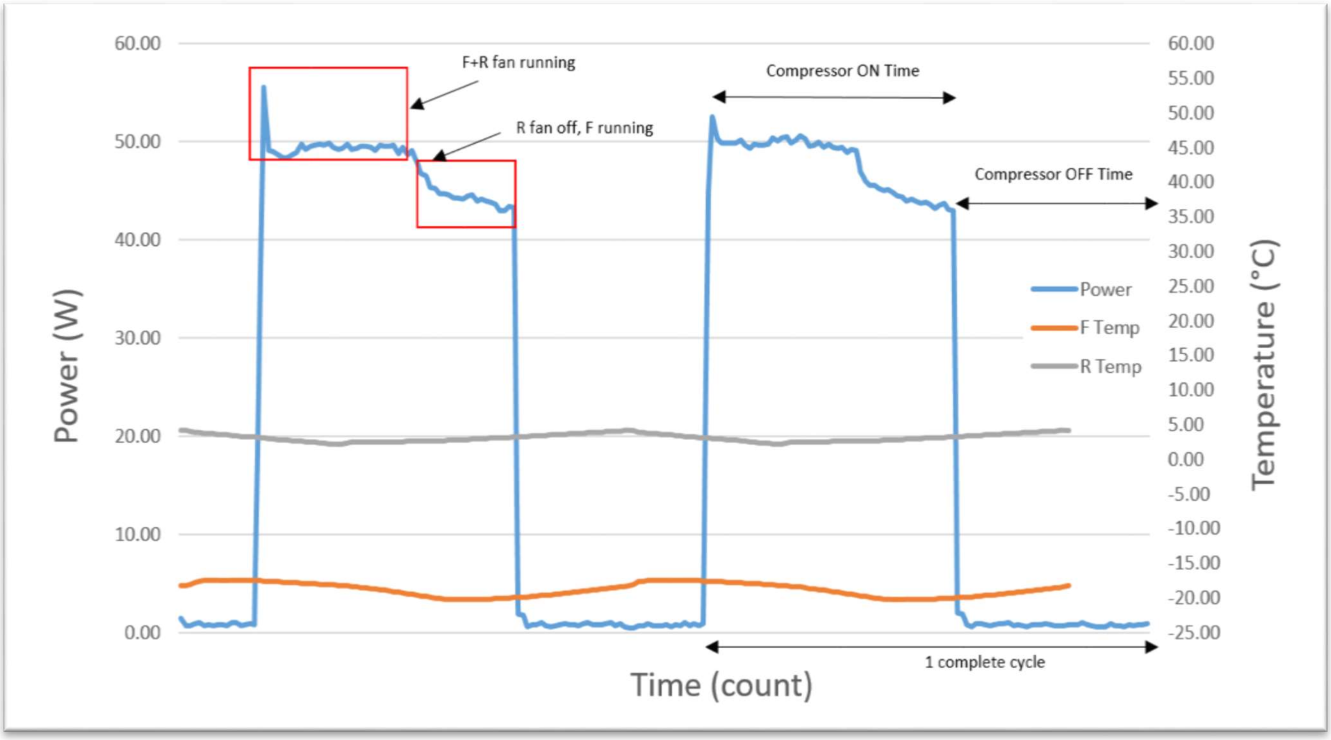


Figure 4.3 Graphical representation of a Compressor's power cycles and Compartment Temperatures

As the fans turn off for each compartment, it is evident that the temperatures rise until a point after which the fans turn on (along with compressor) and temperatures start coming down again. But not every time normal cycles are obtained. There are abnormal or irregular cycles which take place also during normal operation. This is shown in the **figure** below,

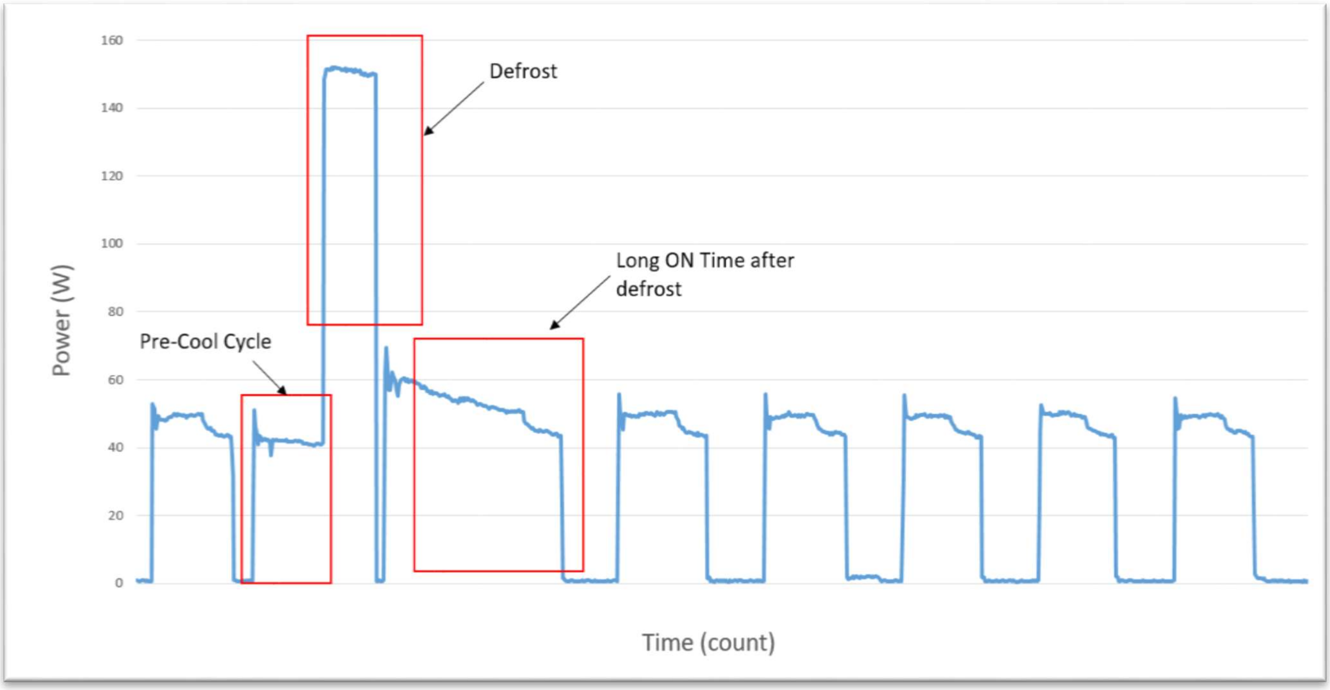


Figure 4.4 Types of Abnormal cycles

Pre-Cool Cycle- Pre-cool cycle is a deliberate cycle which takes place according to the PCB logic. In this cycle, the fans and compressor are kept on right before defrost is about to happen. This means defrost takes place in an ON time period (the compressor and fans turning off the moment sheath heater turns on). This is done to keep the cold air as far away as possible from the evaporator during defrost or else the cold air slows down the evaporator to reach sheath heater cut off temperature.

Long ON Time after defrost- After defrost, the compartments remain at a higher temperature, so it takes longer than usual for the compressor to bring the compartments back to set temperatures.

4.3. Variable Frequency Smart Inverter Compressor

The compressor which is used in this model is a smart inverter compressor. The importance of the inverter is that the compressor can adjust/vary its frequency according to the load on the machine. This means when high cooling is required, compressor runs at higher frequency, and this extra energy consumption can be compensated when the load is low, making the compressor run at low frequency, thus saving energy.

4.4. Machine Control Classification

Convertible and Non-Convertible. There are basically two kinds of control systems a machine can have. First is in which both Freezer and Fresh food compartments have individual and independent controls. Second is in which one of the compartment temperature is dependent on the other compartment temperature.

4.4.1. First Case- The machine has two independent control systems. This is achieved by dedicating one fan for each compartment, incorporating a total of two fans in our model. A fan switches off when its respective compartment has obtained set temperature. In this way, both compartments can be controlled independently, thereby allowing the machine to obtain 3 different temperature settings (also known as notches). The notches are explained from table 4.1. given below,

	Cold/Cold notch	Cold/Warm notch	Warm/Warm notch
Freezer Compartment (°C)	-15 to -17	-15 to -17	-13 to -15
Fresh Food Compartment (°C)	1 to 3	3 to 5	3 to 5

Table 4.1 Temperature Specs for all notches

Energy test results for such models are obtained after running all three notches. From all notches, the energy is calculated using 3 Point Interpolation onto a target temperature.

4.4.2. Second Case- In this case, one of the machine compartment temperature is dependent on the other. Mostly, the freezer temperature stays dependent on the fresh food temperature. The freezer cannot be directly controlled, any change in fresh food temperature setting will have an effect on the freezer. Such a machine does not has the convertible feature and it can obtain only two notches, Cold/Cold and Warm/Warm. Cross notching is not possible. For such machines, the energy can be obtained in two notches only and its calculation is done by 2 Point interpolation.

4.5. Interpolation

Interpolation is the method of calculating a specific value of a parameter, at a given target point, using values at other nearby points, provided all fall in a line or inside an area. In our case, the target point is our target temperature, Freezer at -15°C and Fresh Room at 3°C. On this target temperature, we are required to calculate our annual energy. This is done by interpolation, using the energies obtained at different notches (Cold/Cold, Cold/Warm, Warm/Warm).

2 Point Interpolation- This is done by running the machine through 2 notches, Cold/Cold and Warm/Warm. Firstly, an interpolation factor is calculated from the temperatures of Fresh food compartment (can be freezer also).

$$f = \frac{(T_{target} - T_{CC})}{(T_{WW} - T_{CC})} \tag{33}$$

Where,

f= Interpolation factor

T_{target}= Target Temperature for a particular compartment

T_{CC}= Temperature of compartment at Cold/Cold Notch

T_{WW}= Temperature of compartment at Warm/Warm Notch

This interpolation factor can then be used to calculate any value at the target temperature, provided the same value is available at the two test points (notches).

$$E_{target} = E_{WW} + f \times (E_{CC} - E_{WW}) \tag{34}$$

The non-convertible variant of this model follows the same method for calculation. This type of interpolation is also known as linear interpolation as the two points and the target value all fall in a straight line.

3 Point Interpolation- For this, the machine runs through all 3 notches. After obtaining energies, a validation is done to check the validity of interpolation. This is done by checking whether the target temperature lies inside the area enclosed between the 3 points, as shown in the figure 4.5 below. If not, the interpolation becomes invalid and test is continued until suitable temperatures are obtained.

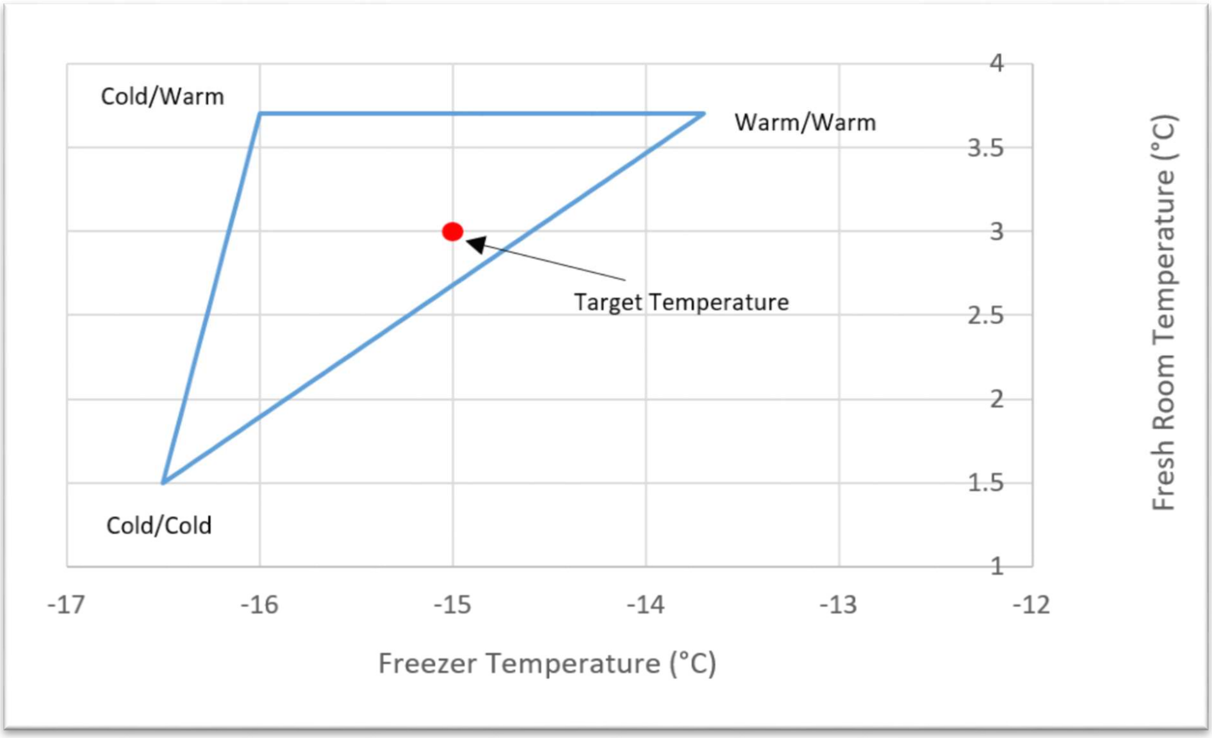


Figure 4.5 Graphical representation of Validity check for 3 point Interpolation

Validity is confirmed if target temperature is found inside the area. After this, a series of linear interpolation is performed. Referring figure 4.5. above, from any point 1 (say Cold/Warm) a line is drawn through Target temperature and intersects the line from the other two points 2 and 3 (Cold/Cold, Warm/Warm). This gives us a 4^{th} point temperature. The energy at the fourth point can be calculated by linear interpolation between points 2 and 3. From here, considering point 4 and point 1, interpolation is done with regard to the Target temperature. This gives us the interpolated energy at the target temperature.

Chapter 5
Testing Procedures and Calculations

All forms of testing for this model was carried out in Chambers established in LG Electronics, Greater Noida itself. A total of 14 chambers were used, each being tuned to the required conditions accurately, the same being verified through computerised monitoring systems. The total number of machines per chamber, according to locations specified, were 3-4. Thermocouple sensors are attached inside the machine compartments, and on the cycle parts and these temperatures are fed to the monitoring system. The placement of machines on their locations, placement of thermocouples and test procedures are all specified by the IS-15750. There were various tests performed and each test contributes in validation of a certain field in the machine’s development. Each field is specified below,

* Basic Performance Check
* Governmental Regulations Check
* Customer Satisfaction Check
* Safety and Liability Check
* Design and Material Strength Check
* Others

5.1. Basic Performance Check

These tests are basically performed at the most initial stage whenever a machine is manufactured, that is to check whether the performance is smooth and disturbance free, any form of leakage, electrical parts are checked, temperatures are checked and so on. There were various tests which covered these and are explained as follows,

5.1.1. Pull-Down Test- This test is the very first test on each machine that is manufactured for testing purpose. The objective of this test is to check the functionality of compressor, the cooling and cooling speed, cycle part temperatures at stable and peak operating conditions, and the maximum current input. It is an approximately 24 hours long test which contains a 6-8 hour long ambient soaking of the machine.

Installation- A total of 3-4 machines were used for this test. Machines were placed on a wooden pallet/elevation from the floor by approximately 0.3 m. Vertical wooden plates were placed parallel to each side of the cabinet except the front door side. This is to restrict air circulation and simulate a situation of machine placement in a congested area. Clearance on rear side from wooden plate was 100 mm. Left & Right side clearance were 300 mm each.

Ambient Conditions- The interior ambient condition of the chamber is maintained at 43°C and at a relative humidity of 45% to 75%. The machine undergoes a soaking of the ambient conditions before starting. This is done by keeping the machine doors open for at least 6 hours and letting the space inside to reach an equilibrium with the ambient. When this is obtained, machine doors are closed and is started at Pull-Down mode. The input voltage/frequency was kept 230V/50Hz.

Sensor Locations- Sensors used for this test are of two types. First type, is the basic thermocouple, used to measure the air temperature of a compartment. They are covered by a small copper cylindrical body of height not more than 2 cm. Second type, is the naked wired sensor, which are directly kept in contact with parts whose temperatures are to be measured. Given below, figure 5.1. shows first type sensor placement (Fh/Rh stands for Freezer/Refrigerator height). Second type sensors are attached to all the cycle parts at inlets and outlets.

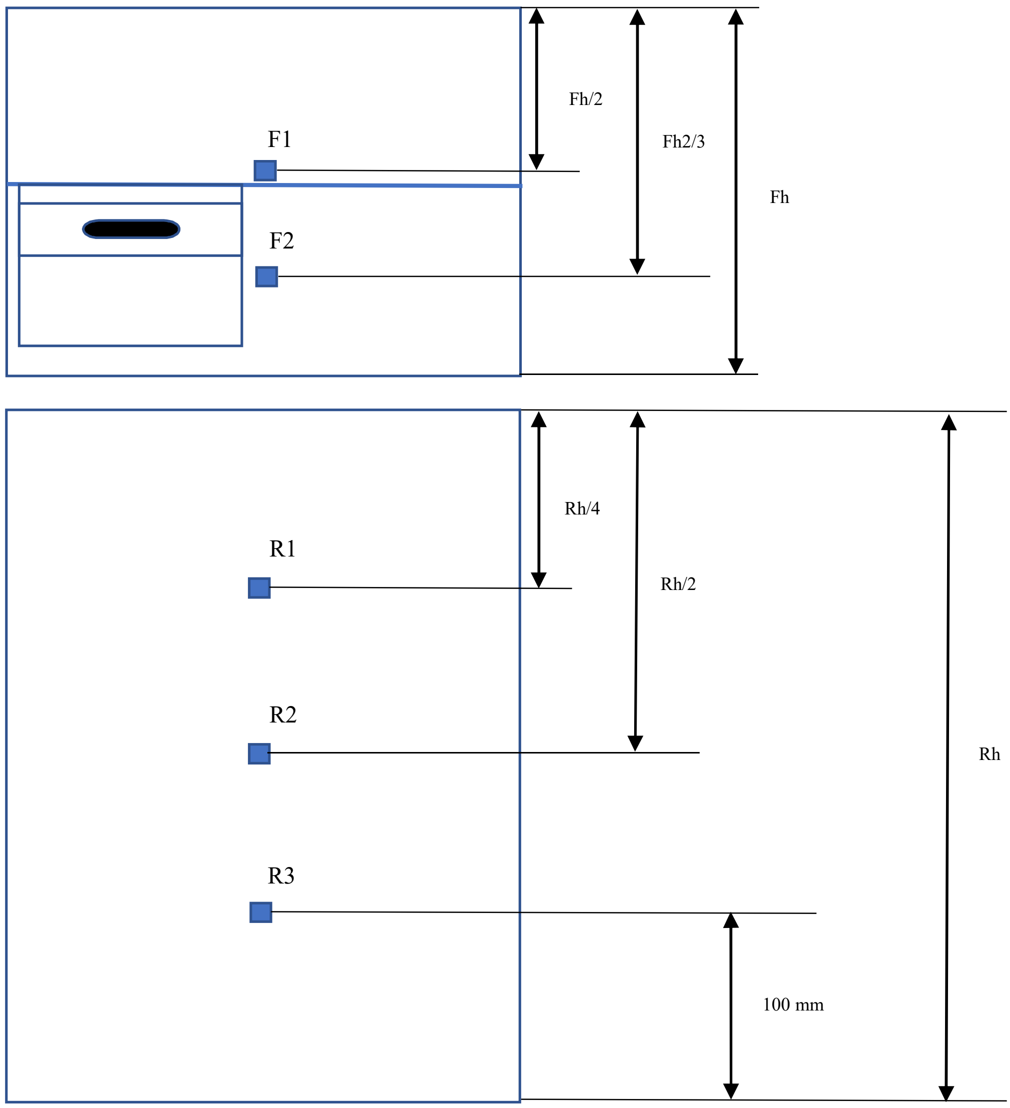


Figure 5.1 Sensor Placement for Pull-Down test

Machine Performance- The machine, as mentioned earlier, is made to run in the Pull-Down mode. In this mode, a by-pass logic is activated, which means every PCB logic related to sensors, compressor and fans ON/OFF due to set temperatures is by-passed and the compressor and fan motors keep running without stopping providing continuous cooling. The machine operates at its full potential and compartment temperatures go to extreme cold conditions. The machine starts with a high load due to initial conditions at 43°C and therefore a high consumption of energy is seen at beginning. This is followed by the stabilisation of the machine as power comes down until it reaches a point beyond which it becomes nearly constant.

Results- The data obtained is shown graphically as figure 5.2. and 5.3. given below,

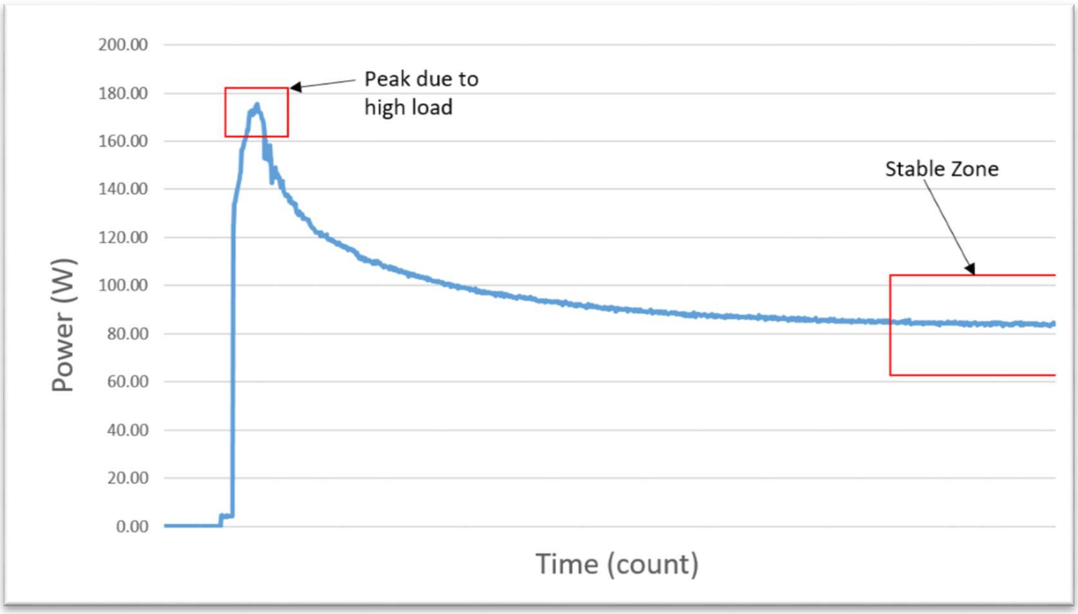


Figure 5.2 Power graph of Pull-Down test

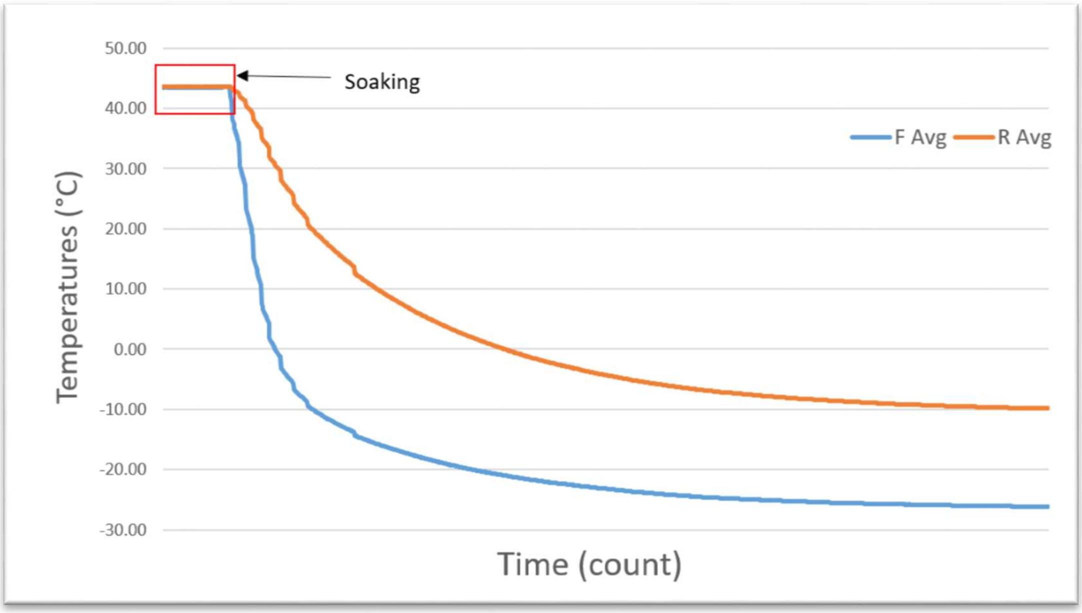


Figure 5.3 Compartment Average Temperature graphs of Pull-Down Test

The graphs for all cycle temperatures were of the same form as the power graph (figure 5.2.). At stable region, the following readings were obtained from the 360L model(an average from what was obtained during DV & PV testing) against their mentioned specs,

Parameter	Unit	Spec	Reading
Eva In	°C	-	-33
Eva Out	°C	-	-32
Eva In-Eva Out (Gliding)	°C	≤ 3°C	1
F Avg	°C	≤ -18°C	-27
R Avg	°C	≤ 4°C	-12
Suction Stable	°C	RT ± 3°C	43~44
Drier Stable	°C	50 ± 5°C	50~51
Condenser Gliding	°C	≤ 5°C	1~2
Power Stable	W	-	80 (360L), 77 (340L)
F Cooling Speed	min	-	110 (43 to -13 °C)
R Cooling Speed	min	-	140 (43 to 8 °C)
Peak Current	A	-	1.1

Table 5.1 Pull-Down Test Results

Discussion- From the above readings, it was concluded that all parameters were within spec. Evaporator and condenser gliding was minimal, compartment temperatures were obtained by large margins, suction temperature found OK confirming no liquid refrigerant goes into compressor. Power at stable region and the cooling speeds are found for benchmarking purpose and the peak current is mentioned for design of electrical circuits with factor of safety over the peak current. This is to ensure product liability.

5.1.2. Charge Determination Test- This test determines the optimum quantity of refrigerant charge that should be used for the machine and is a one-time test performed at the initial stages of development. This test is basically done fully experimentally in a hit & trial method. At the beginning of the test, the machines are deliberately overcharged and made to run. The refrigerant is gradually taken out 1 gram at a time and the machine is tested at every reduced quantity of refrigerant. The test keeps going on until the machine is declared under charged. The point at which the most optimum performance is achieved is set as the optimum charge quantity.

Installation- Machines were placed in the chamber at 25°C without wooden pallets. Use of Service dryers were used. Service dryers come with a lid opening system, which when attached to a gas removal jig, is used to take out refrigerant from the machine accurately according to requirements. The jig is basically a container filled with water completely. Inside the container is an upside down beaker, also filled completely with water. The beaker wall has holes on the bottom region and top surface of the beaker is connected by a pipe & valve system to the service dryer. Refer figure 5.4. below,

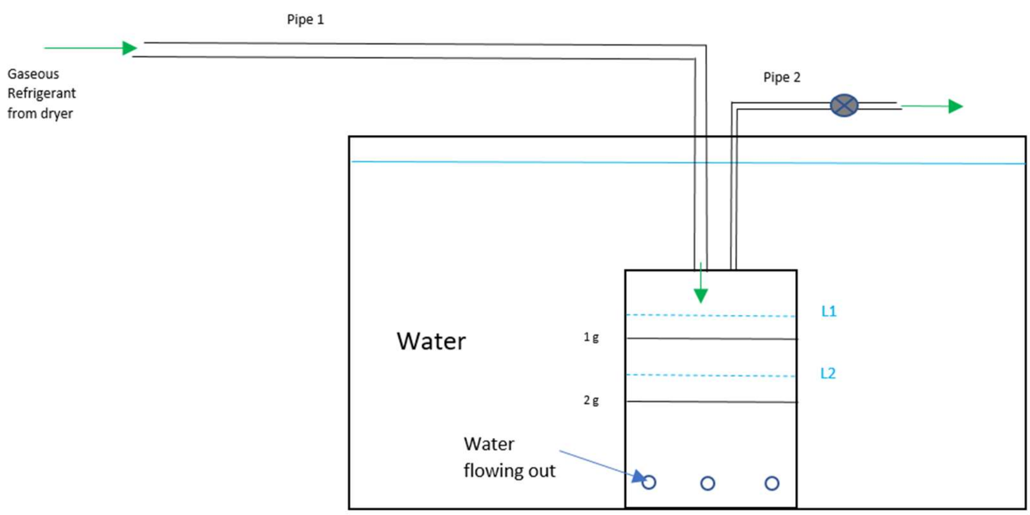


Figure 5.4 Gas Removal Jig

Jig Working Principle- Referring the figure 5.4. above, at initial conditions, the beaker inside is completely filled with water. All valves on Pipes 1 & 2 are tightly shut. When the valve attached to the service dryer is opened minutely and very slowly, to avoid any violent gas leakage, the gas enters the beaker inside through Pipe 1. It presses down the level of water (to L1). The water from the beaker moves out from the holes in the bottom. The level of water moves down from L1 to L2. For measuring the amount of gas removed, markings are made on the beaker (1 g, 2 g) which tells us the grams of gas that has been removed. Once the required amount of gas is removed, the service dryer valve is closed immediately. Readings are taken and the valve attached on Pipe 2 is opened to let the gas out. When gas flows out, water from the container fills inside the beaker through the holes due to atmospheric pressure. Valve on Pipe 2 is shut after all gas is removed and beaker is again filled with water completely.

Sensor Locations- The sensors were placed in the exact same manner as the Pull-Down test.

Machine Performance- The machine was made to run in Pull-Down mode. Initially, the machine was overcharged at 74 g of gas. Gas was gradually taken out 1 g at a time, and at every amount of gas, the machine ran between 6-8 hours to have sufficient stable data.

Results & Discussion- Performance readings were taken for an amount of gas (X g) after 8 hours just before taking out gas to obtain next amount of gas (X-1 g). The important readings which decided the amount of gas to be finalised were,

- Power
- Suction Temperature
- Discharge Temperature
- Evaporator Gliding
- Condenser Gliding

Shown below (figure 5.5.) is the power graph. Two cases have been particularly shown here. The rest being hidden to make the graph compact.

- Case 1 shows when the machine is over-charged and gas is removed. It results in a slight drop of power consumption. The reason behind this is the excess charge which causes a higher power consumption. The load on the compressor increases because of increased gas. Overcharge also leads to an increased sub-cooling. So when this overcharged increased sub-cooled refrigerant goes into the evaporator, the superheat becomes minimal or happens very close to the evaporator outlet. This in turn might just result in liquid refrigerant entering the compressor or what is called as a cold suction line. This becomes detrimental for the refrigeration system.

- Case 2 shows the machine in under- charged condition with the gas being removed. It is observed that the power consumption increases after this point. This happens because the refrigerant is out of the condenser too soon resulting in minimal sub-cooling. This leads to higher evaporator inlet temperature. Higher evaporator inlet temperature leads to a lesser refrigeration effect. This will obtain cooling slower than usual and will result in compressor running for longer periods to obtain set temperatures. Thus increase in power consumption. Also, a higher evaporator inlet temperature will result in faster and more superheat of refrigerant, therefore a hot suction line. This in turn increases the entire cycle average temperature bringing down the efficiency of the refrigerator.

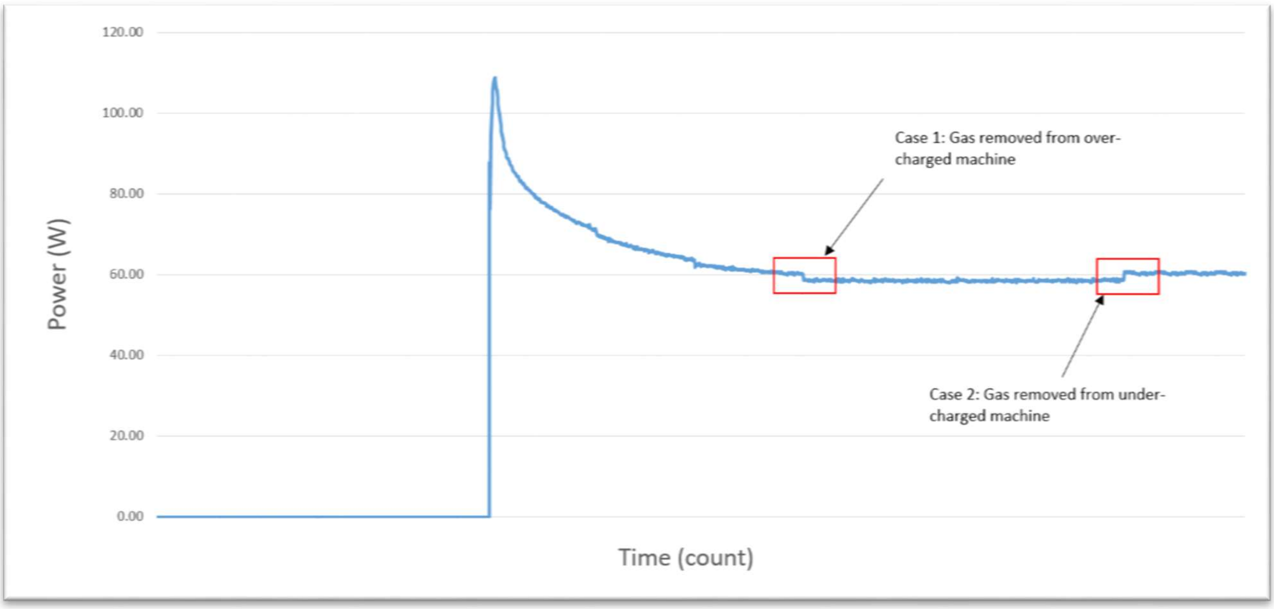


Figure 5.5 Power graph in Pull-Down mode during charge removal

It was seen in our models, that at 66 grams of refrigerant, the machine yielded the most optimum performance,

- Power was close to minimum.

* Suction temperatures were found within pull-down spec, i.e., RT ± 3°C
* Evaporator and condenser gliding, most importantly, was found minimum at this point.

These points ensured and concluded 66 g as the optimum charge quantity.

5.1.3. High Ambient Load Test (HALT)- This test is to ensure the proper functioning of compressor at high temperatures simulating the conditions of an extreme climate.

Installation/Ambient Conditions- Machines were placed inside the chamber on wooden pallets. The ambient was set at 45°C, RH at 70-90% and the machine was made to run normally with set temperatures at medium.

Procedure- The machine was allowed to run for some hours and then the machine was switched off and on multiple times with irregular intervals. After every switching on of the machine, it was allowed to run for some time. This was to ensure a proper start-up of the compressor even at the highest of ambient temperatures.

Criteria- The criteria for the passing of this test is to check how many times the compressor trips after start-up. The allowed number of times is 2. If the tripping goes beyond, it is declared that the compressor is not fit for the machine at high temperatures.

Results- In our case, it was observed that the machine **did not trip** even at the high ambient, declaring the compressor fit for the machine.

5.2. Regulations Check

These tests are required for the approval from Government bodies, the approval being required for launching the machines for sales nationwide. The tests are given below,

5.2.1. Energy Consumption Test- This test is the most important test of all as it decides the energy that is to be declared for the machine, which then according to the volume and energy required declares the star rating of the machine. This test is performed at multiple stages during the development of the model to ensure the energy calculated is always under the declared value. Firstly, for the registration of the model in the BEE, it is required to undergo an energy test in chambers which are exclusively dedicated for NABL. After this, internal testing is performed at PP, DV, and PV. Till PV, the testing is majorly handled by R&D. After PV, quality control teams are given the responsibility to randomly pick machines, which are now running on production line, and conduct the required tests on them.

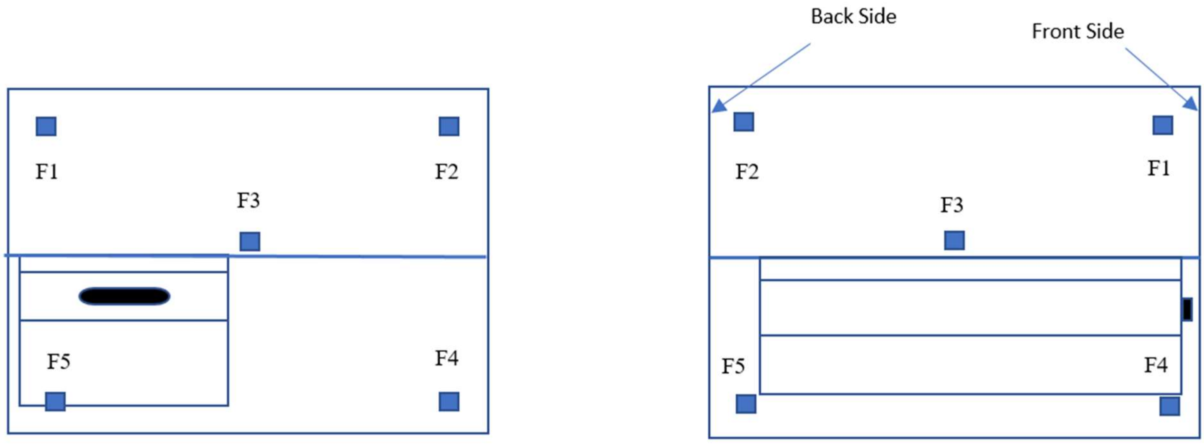
Duration- Since the model being an FF model, energies consumed in defrosts is also considered. On counting this, the test takes place for a full defrost cycle (72 hours), which means the start is marked from an initial defrost, and the ending is after 72 hours of the initial defrost. If defrost happens to come, anyhow, before 72 hours, the test is concluded just before the second defrost.

Number of machines required- For BEE testing, the number of machines required is 3. For internal testing purpose, the mandatory number of machines required is 4. This is to check and ensure the machine to machine energy variation is kept minimal.

Installation- The machines were installed on the wooden pallets, the same way as Pull-Down test.

Ambient Conditions- The ambient conditions set were 32°C and an RH of 65%, simulating the average climatic conditions of India. The input voltage/frequency was kept 230V/50Hz.

Sensor Locations- For the fresh food compartment, the sensors are placed in the same way as Pull-Down test, refer figure 5.1. of Pull-Down sensor R compartment. Additional sensors are placed in the chiller and the vegetable box. The placement of Freezer sensors is different for energy tests and is shown below



a) *b)*

Figure 5.6 Sensor Placement in Freezer for Energy Test a) Front View, b) Side View

The sensors which are at the 4 corners maintain a gap of 50 mm from any surrounding walls including the ceiling and floor of the freezer. Sensor F3 is at the centre of the compartment.

Machine Performance- The machine was made to run in normal cycles until temperatures were obtained and the average power of the latest few cycles was under limit. Any adjustments to the temperature controls were made to obtain the temperatures provided power was kept at optimum.

Procedure- After obtaining stability, temperatures and power under limit, an initial defrost was taken (either naturally or manually). The test starts from this initial defrost and ended after 72 hours was completed. Any adjustments to the temperature controls or opening of machine doors or chamber doors was not allowed after the initial defrost. Readings were taken daily to check temperatures and power. A daily check was maintained by taking average of the latest stable 5 cycles and simulate it throughout the year to calculate yearly energy consumption. This becomes just a simulated value, whereas the actual value is obtained more accurately only after the full test.

Calculation- The calculation of yearly/annual energy consumption is done considering defrost. We get the value of energy already consumed just before start of defrost and the same after the completion of 72 hours from the Refrigerator Monitor software. The difference is taken to calculate energy consumed from defrost to completion. This is simulated throughout the year and we get the final value.

$$\text{Energy(kWh/yr)} = \frac{(E_2 - E_1) \times 60 \times 24 \times 0.365}{4320} \tag{35}$$

E_1 = Energy already consumed before final defrost (Wh)
E_2 = Energy consumed up till completion of 72 hours (Wh)
60 = Converts hours to minutes
24 = For energy per day
0.365 = For kWh per year
4320 = Duration of test in minutes (72 hours)

The average temperatures of Freezer and Refrigerator is also calculated for the same period and checked whether it is below the target temperature.
For daily checking, the simulated energy formula is as follows,

$$\text{Simulated Energy (kWh/yr)} = P \times 24 \times 0.365 \times 1.04 \tag{36}$$

P = Average power of latest stable 5 cycles
1.04 = 4% defrost factor, because the 5 cycles does not contain defrost within it

Criteria- The judgement criteria has two directions. It starts with running the machine in the first and highest load condition, also known as the Cold/Cold notch. An energy limit is set by BEE according to the refrigerator volume and the star rating set for the same. From this limit, an additional limit is internally set as per LGE standards keeping a margin of 5%. So at first priority, the temperatures and energies are checked and kept under limit. Apart from temperatures and energies, within those 4 machines that are being tested, the machine to machine energy variation is checked and a limit for the same is set. Energy reports are declared OK when the results are obtained within limits.

The 2nd direction arises when the results are not obtained within limits, i.e. when either energies are above internal limits or machine to machine variation is above limit or both. On such occasion, the test proceeds into the next two notches- Cold/Warm and Warm/Warm notches. On running the next two notches, it is observed in an obvious manner that the energy and variation comes down significantly. The test is declared OK when results are achieved. A final energy and temperature values is calculated at the target temperature from the three notches using 3-point interpolation. Every notch is performed similarly to the first notch.

BEE Limit Setting- This limit is set for every machine sold in India according to the volume and the star rating to which it belongs. It is calculated from an empirical formula formulated by the BEE itself. The volume is considered as the adjusted volume which is given as,

$$\text{Adj. Volume} = \text{Fresh Room Volume} + (\text{Adj. Volume Factor} \times \text{Freezer Volume}) \tag{37}$$

where, the factor is given as,

$$\text{Adj. Volume Factor} = \frac{(\text{Room Temp} - \text{Freezer Temp})}{(\text{Room Temp} - \text{Fresh Room Temp})} \tag{38}$$

In India, the standard room temperature is set as 32°C because of its tropical climate type. The compartment temperatures are the target temperatures and are -15 and 3 for freezer and fresh room respectively. This gives us the Adjustment volume factor as 1.62. Thus, the adjusted volume becomes,

For 360 L, Fresh Room Volume= 256 L
Freezer Volume= 79 L
Adjusted Volume= 383.98 L

For 340 L, Fresh Room Volume= 236 L
Freezer Volume= 79 L
Adjusted Volume= 363.98 L

Therefore, the Energy limit from BEE for our model is set as follows,

Star Rating Band (FF)	**Formula**	**Energy Value (kWh/year)**
1 Star *	(0.286 x Adjustment Volume) + 249	358.8/353.09
2 Star **	(0.228 x Adjustment Volume) + 199	286.6/281.98
3 Star ***	(0.183 x Adjustment Volume) + 159	**229.3/225.6**
4 Star ****	(0.146 x Adjustment Volume) + 127	183.1/180.14
5 Star *****	(0.117 x Adjustment Volume) + 102	146.9/144.58

Table 5.2 Energy Limits set by BEE according to Refrigerator Volume

Considering that our machine is 3 Star, our limit is 229.3 and 225.6 kWh/year. On this, an internally tested limit is set at 95% of the BEE limit, and thus our declared value is set at **217 and 214 kWh/year**.

Results & Discussion- For our model, the result was obtained above the declared limits in the first notch, i.e. Cold/Cold. So the machine underwent the next two notches to obtain a value well within the limits. It went through 3 notches because of its freezer and fresh room having independent controls and fans. The results obtained for a single machine in DV Testing were as follows,

360 L		
Cold/Cold Notch		
Parameter	**Result**	**Conclusion**
Freezer Temperature (°C)	-15.28	OK
Fresh Room Temperature (°C)	2.03	OK
Energy (kWh/year)	220.94	Not OK
Cold/Warm Notch		
Freezer Temperature (°C)	-15.13	OK
Fresh Room Temperature (°C)	3.35	OK
Energy (kWh/year)	211.21	OK
Warm/Warm Notch		
Freezer Temperature (°C)	-13.35	OK
Fresh Room Temperature (°C)	3.45	OK
Energy (kWh/year)	205.13	OK
3-p Interpolated Energy	213.29	OK

Table 5.3 Energy Test Results for 360 L

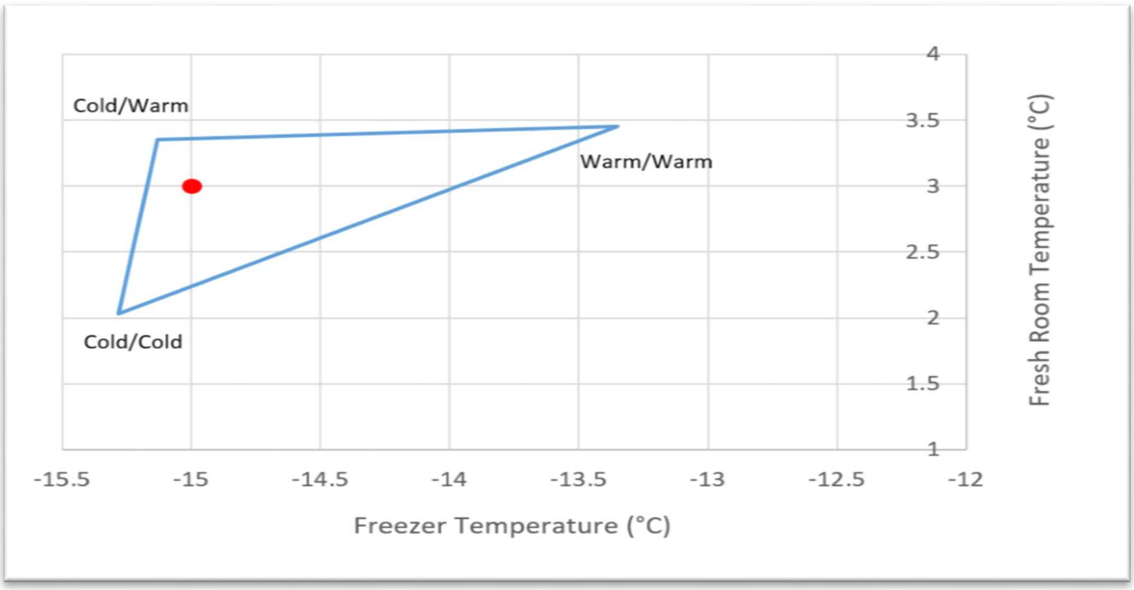


Figure 5.7 3 Point Interpolation Validity check for 360 L

340 L		
Cold/Cold Notch		
Parameter	**Result**	**Conclusion**
Freezer Temperature (°C)	-15.36	OK
Fresh Room Temperature (°C)	2.59	OK
Energy (kWh/year)	215.35	Not OK
Cold/Warm Notch		
Freezer Temperature (°C)	-15.29	OK
Fresh Room Temperature (°C)	3.49	OK
Energy (kWh/year)	211.45	OK
Warm/Warm Notch		
Freezer Temperature (°C)	-13.26	OK
Fresh Room Temperature (°C)	3.63	OK
Energy (kWh/year)	200.95	OK
3-p Interpolated Energy	211.96	OK

Table 5.4 Energy Test Results for 340 L

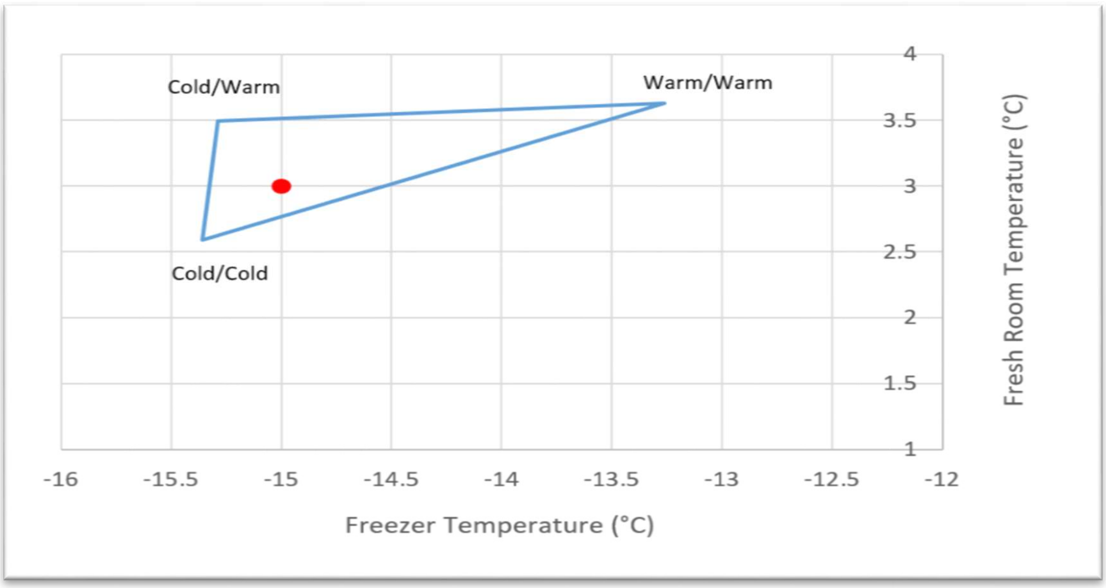


Figure 5.8 3 Point Interpolation Validity check for 340 L

The average energy that came out of all 4 machines was found to be 212.32 kWh/year and 210.84 kWh/year for 360 L and 340 L respectively.

5.3. Customer Satisfaction Check

These are the tests performed to ensure that the machines deliver the performance that it promises to give to the customers, for example, the right temperatures at the said settings, undisturbed temperatures in even the most extreme conditions and etc. The tests are given below,

5.3.1. Cycling Test- A very basic test, this is to ensure that at a given set temperatures, the compartment temperatures are obtained or not. For example, setting the temperatures at -18/3 and then to ensure the compartment temperatures are approximately near to set temperature.

Installation & Ambient Conditions- For this test, the minimum number of samples should be 3. Machines are placed on the chamber floor without using any wooden pallets. Since our case was an A Grade project, a total of 4 machines were used. Ambient conditions was set at 25°C and an RH of 65%.

Sensor Location- Sensors are placed in the same manner as the air temperature sensors used in Pull-Down test. The only parameters required to be measured are the compartment temperatures.

Machine Performance and Procedure- Machine runs in normal cycle mode similar to Energy test. Every notch possibility is made to run, with every notch running at least 8 hours to attain sufficient stable data for every notch. During a notch, any change in setting or door opening was not allowed.

Calculations- A simple average of temperatures was first checked for each compartment to ensure it within permissible range. Being an F compartment controlled machine, more focus was put on Freezer temperatures by checking a machine to machine F average temperature comparison (Zst).

$$\text{Favg} = \text{Average (All machines average freezer temperatures)} \quad (39)$$

$$\text{Standard Deviation} = \text{Stdev (All machines Favg)} \quad (40)$$

$$\text{Upper Limit Zst} = \frac{\text{Favg} - \text{Upper Limit}}{\text{Standard Deviation}} \quad (41)$$

$$\text{Lower Limit Zst} = \frac{\text{Favg} - \text{Lower Limit}}{\text{Standard Deviation}} \quad (42)$$

Results & Discussions- The results obtained are tabulated below,

Normal/Normal											
Parameter	**Spec**	**MC#1**	**MC#2**	**MC#3**	**MC#4**	**Avg.**	**StDev.**	**USL °C**	**LSL °C**	**USL Zst**	**LSL Zst**
Favg °C	-18±2	-17.94	-18.07	-17.85	-17.91	-17.94	0.09	-16	-20	-20.96	22.15
Ravg °C	3±1.5	2.87	3.02	2.92	2.94	2.93	0.06	4.5	1.5	-	-
Normal/Cold											
Favg °C	-18±2	-17.90	-18.04	-17.86	-17.87	-17.91	-	-16	-20	-	-
Ravg °C	1.5±1.5	1.17	1.56	1.37	1.37	1.36	-	3	0	-	-
Normal/Warm											
Favg °C	-18±2	-17.87	-18.00	-17.87	-17.92	-17.91	-	-16	-20	-	-
Ravg °C	6±1.5	5.72	6.03	5.91	5.96	5.90	-	7.5	4.5	-	-
Cold/Cold											
Favg °C	-21±2	-20.86	-21.04	-20.74	-20.97	-20.90	-	-19	-23	-	-
Ravg °C	1.5±1.5	1.16	1.53	1.34	1.37	1.35	-	3	0	-	-
Warm/Warm											
Favg °C	-14±2	-13.93	-14.11	-13.78	-13.96	-13.94	-	-12	-16	-	-
Ravg °C	6±1.5	5.81	6.03	5.91	5.91	5.91	-	7.5	4.5	-	-

Table 5.5 Cycling Test Results

The Zst value is calculated only in the Normal/Normal notch for the freezer and should always remain above 3 to ensure passing of test. Once ensured for this notch, it is automatically ensured for all other notches.
The resulting temperatures were all found within the spec and the Zst was also found above 3 ensuring the machines have minimum deviation from each other.

5.3.2. Ambient Variation Test- This test is an extended version of the Cycling test in which the normal/normal notch is made to run in different ambient conditions. This simulates the machine running in extreme climatic conditions and the test itself ensures undisturbed temperature inside the compartments. The number of machines tested, installation, sensor locations and the machine performance is similar to the cycle test.

Ambient Conditions- The machines are made to run in the following order of ambient conditions- 43, 38, 32, 25, 20, 15, 10, and 5 °C.

Calculations- For every ambient, the freezer average and fresh food average temperatures are calculated for individual machines and the variation in temperatures is checked from a reference ambient condition. The 25°C ambient is considered as the reference ambient condition. The variation is checked by calculating the difference between an ambient results and the same from 25°C. The calculation is restricted only from 43°C to 20°C. Variation starts increasing significantly on going beyond this range.

Results & Discussions- The following results was obtained for a single machine during DV tests,

Parameter	43°C	38°C	32°C	25°C	20°C	15°C
Favg	-20.74	-20.25	-18.7	-18.31	-18.37	-18.46
Ravg	1.08	1.29	3.01	3.21	3.23	3.11
F Variation	2.43	1.94	0.39	Reference	0.06	0.15
Spec	±3	±3	±1.5	Reference	±1.5	±1.5
R Variation	2.13	1.92	0.21	Reference	-0.02	0.1
Spec	±3	±3	±1.5	Reference	±1.5	±1.5

Table 5.6 Ambient Variation Test Results

As evident, the results were all found within specs. The variation increases as we go to higher ambient conditions where the temperatures obtained inside are colder. This is because at higher ambient, the condenser to atmosphere heat transfer is decreased due to low temperature gradient. This makes an overall warmer refrigerant in the whole cycle. So the cooling takes place slower, but the compressor runs for longer periods, thus making the compartment temperatures go colder than normal. At lower ambient conditions, again, the temperatures inside the compartments are found colder because of minimum heat leakage and easy temperature attainment. Also, the refrigerant in the cycle has an overall significantly cold temperature bringing the compartments colder than usual.

5.4. Safety Check

Safety check is always kept at top priority for nationwide sales. Being an electronic product running at higher voltages, safety related to it should be of paramount importance. Tests were conducted for the same which ensured that the electrical circuits were safe. The following tests were conducted for the same, 5.4.1. Product Liability Test- This test does not involve any performance check other than basic switching ON/OFF of the machine. A proper sample machine was prepared. Focus was mainly given to the electrical circuit routing near the PCB area. The machine was submitted to the PL Lab and a checklist sheet was prepared according to which the machine was checked. The following were mainly listed in the sheet,

- Wire Routing
- Wire Strength & quality
- PCB
- PCB case
- PCB cover
- Power Cord material and its quality
- Earthing Wires quality
- Earthing Screws
- PCB cover screws
- Fan Motors
- Wires in fan motors
- Wires in control box
- Owner's manual
- Energy Label
- Circuit Diagram

On checking all of these and a few more additional points, the test was regarded passed when the above points were found safe and reliable by the testing engineer.

5.4.2. Temperature Rise of Components Test- This test is also a part of the product liability test. The test was performed inside chambers. Sensors were placed on all components of the PCB, and the compressor and the machine was made to run in normal cycle mode at 25°C ambient. After this, the rise in temperatures of the components is measured and concluded if temperature rise was found within spec.

5.4.3. Spike Test- This is a test to ensure that any extremely high peaks and surges of voltage can be endured by the machine without any explosion or dangerous electrical leakages or discharges. For this test, a single machine was tested on a simulator and the PCB attached is changed. A quantity of 5 PCB samples were tested and the simulator provides high peaks of voltage. It ends up damaging the PCB. The test was considered pass.

5.4.4. Electrical Characteristic Test- This test was performed to check whether any leakage current is detected on the body of machine. Every location on the machine was checked using a computerised multi-meter and reading was noted. The paint on the body was scratched off and then leakage current was checked ensuring more safety. The test was considered pass.

Chapter 6
Child Variants Development

On completion of the A grade project testing, our focus was shifted on to the enhancement of the model, to deliver the next variants of the models. These models enhancements were based on cost reduction or what we call as the Value Innovation Project. This was achieved by bringing out various models, and in each. a certain variety of features being removed and newer and cheaper features getting included. These models came under grade C2 of development. A C2 grade project is in which the base model is the A grade project and on that performance based and control based changes are made. It is registered in the system with a promised duration of not more than 60 days, at the end of which, its mass production must be started.

There were a total of 8 models that came under the C2 grade project. The models are listed out below with their changes and the impact of those changes on the performance mentioned.

6.1. 360L/340L 3 Star Spec Reduction model

In this model, the only changes made from the base model was the elimination of hygiene LEDs and cover of chiller, making the chiller as a simple pull out tray. No other changes were made and therefore performance wise, this model achieved the same results as the base model.

6.2. 360L/340L 2 Star External Control model

In this model, major changes in performance was seen with respect to the previous spec reduction model which resulted in the star rating change of the model from 3 star to 2 star. Control systems were same as the base model.

6.2.1. Changes- The changes brought in this model with respect to the base model were as follows,

Compressor- Compressor change was made from a higher EER to a lower EER keeping the machine volume constant. This was done by using a smaller sized cylinder in the compressor. The stroke length, bore diameter were also reduced, resulting in the reduction of capacity displacement. For the same, the suction port location was changed.

Suction- The suction length was changed because of the change in suction port location.

6.2.2. Impact- The impact was majorly seen in Energy values obtained. For 360L, the energy obtained was 272 kWh/year and for 340L, the energy obtained was 263 kWh/year. The values came under 2 star limits according to the volume used, i.e. 286 kWh/year for 360 L and 281 kWh/year for 340 L.

6.3. 360L/340L 2 Star Internal Control model

In this model, hardly any performance change was detected with respect to the 2 Star External Control model with the Energy Values also coming same. Only changes were the control system and air flow path.

6.3.1. Changes- The changes are as follows,

Control System- Previously in the base model and the model mentioned in 6.2. had external temperature control display system fixed on the freezer door. In this model, the temperature control was made internal inside the fresh room compartment. Display was also changed from numbering to cold-coldest dot system.

Door Cooling- This model comes without the door cooling feature, and therefore changes were made in the air flow path, i.e. now air flow was completely restricted to freezer and through the lower section of the evaporator leading into the fresh room compartment.

6.3.2. Impact- No performance impact was detected with respect to 2 Star External controlled model as there were no changes in cycle parts. Only door basket temperatures were obtained warm but not more than 1°C due to deletion of door cooling feature.

6.4. 360L/340L 2 Star Internal Control Non-Convertible model

This model saw major changes in many aspects as it changes from Convertible to Non-Convertible. Apart from controls and air flow path, this machine is similar to the internal controlled 2 star model mentioned above.

6.4.1. Changes- The changes are listed below,

Non-Convertible feature- Non-Convertible implies that the freezer cannot be converted into fresh room conditions, which is possible in the Convertible models because of its dual fan system, each compartment having a dedicated fan. In Non-Convertible models, only one fan is used to cool both freezer and fresh food compartment. Since the fresh food compartment takes longer to attain its set temperature, the machine is also known as an R controlled machine. The compressor and fan runs until the fresh food compartment achieves its temperature, and in the process, a part of the air goes into the freezer and therefore cools it. This makes the freezer compartment temperature dependable on the fresh food compartment set temperature.

Control System- This machine is also controlled internally from fresh food compartment but only fresh food temperatures can be controlled from here. Any change will have its effect on the freezer. The freezer has a mechanical method of controlling its temperature to an extent. The grill fan is equipped with a knob. Rotating the knob controls air flow into the freezer. This can be explained from the figure 6.1. below which is a representation of the inner part of the grill fan also called as the shroud,

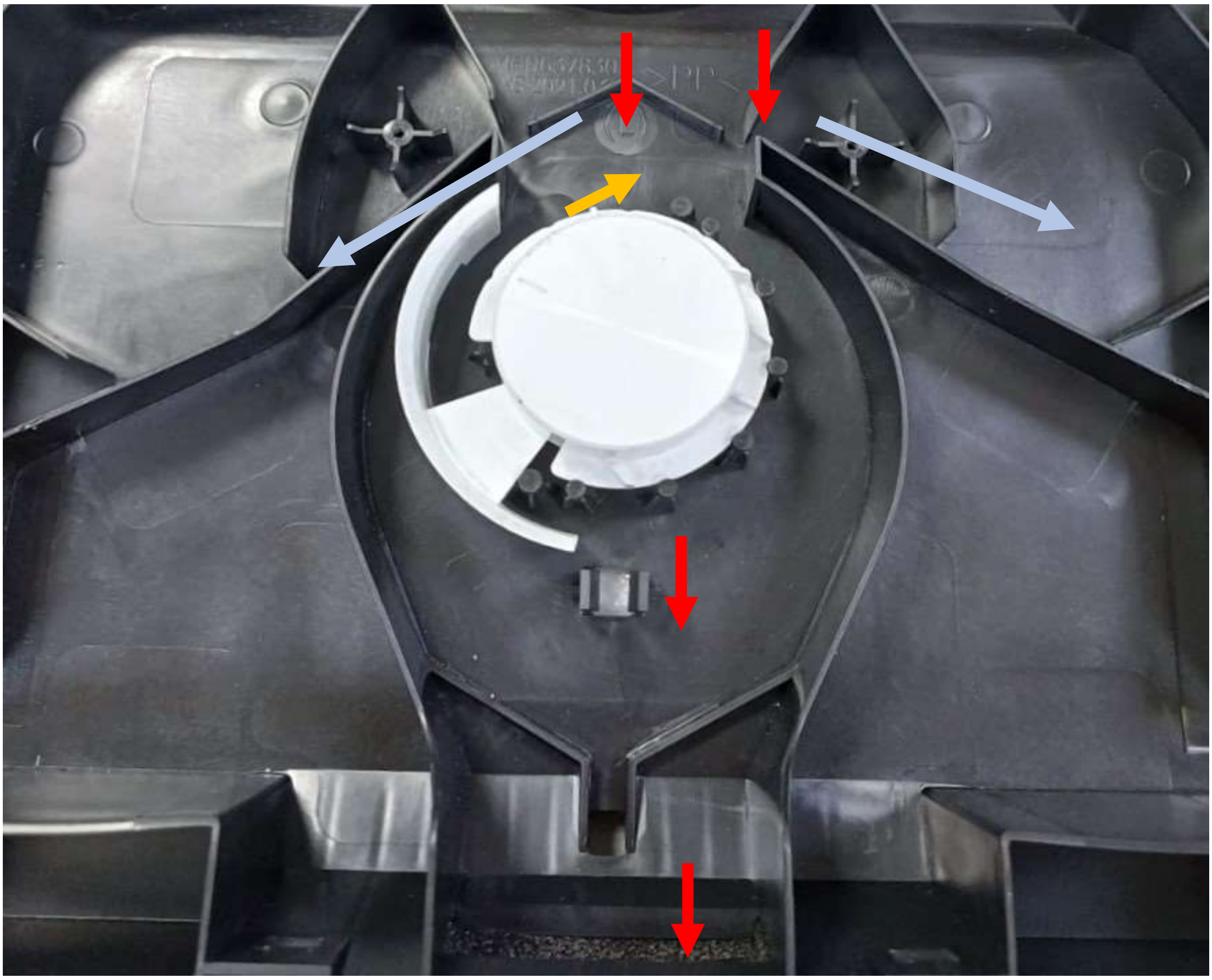


Figure 6.1 Non-Convertible Knob functioning and air flow control

Referring the figure above, air is provided from the fan above (red arrows above). In initial condition, the knob is fully open letting complete air flow through it down to the fresh food compartment (red arrow below). Minimal (not zero) air flows into the freezer compartment. When the knob is rotated clockwise (towards yellow arrow direction), it starts restricting the path with the vane attached to it. This vane diverts the air sideways (blue arrows) into the area where vents are provided for air passage into the freezer, thus maximising air flow into the freezer. Since this is an R controlled machine, maximising freezer air flow will not affect the fresh food temperature. Instead, the ON time of compressor and fan increases as it takes more time for fresh food compartment to attain temperatures.

Impact- Since compressor is same as the previous 2 star models, the energy values of this model is same. The temperature combinations of Freezer and Fresh food in normal cycling mode changes. In cycling test, the spec changes to the following,

Parameter	Normal/Normal	Normal/Warm	Normal/Cold
F avg	-17±2 °C	-14±2 °C	-20±2 °C
R avg	2.5±1.5 °C	5.5±2 °C	0.5±2 °C

Table 6.1 Non-Convertible Cycling Test Specs

These 8 models were successfully tested and all were launched by the end of April 2022, thus marking the completion of C2 grade development of the domestic model. After C2 grade, the next minor project was completed known as D grade projects. In this grade, the only changes are the finish and looks and the model number.

Chapter 7
Conclusion and Future Scope

7.1. Conclusion

The models were built as an equivalent to a particular previous running models, with the objective of getting better performance. This was achieved in the following way,

Parameter	360L Previous 3 Star model	360L Current 3 Star model	335L Previous 3 Star model	340L Current 3 Star model
Gross Volume (L)	360	360	335	340
Storage Volume (L)	330	335	310	315
Energy Consumption (kWh/year)	216	217	213	214
Pull-Down Cooling Speeds Freezer (minutes)	127	110	119	104

Table 7.1 Comparison of developed models with previous models

From the above results, it was evident that even with an increase in the storage volume in the developed models, the energy value has proportionately increased much lesser. This was achieved as a result from the upgraded design of the various parts.

1. Improved Air circulation path- The return path of air in fresh food compartment being changed into inner side of the refrigerator rather than previous front side return, which resulted in better circulation and quicker attainment of temperatures, thereby reducing energy consumption.
2. Use of compressors having higher EER than the previous models.
3. Changes in cycle parts, increased condensing length,
4. Use of Evaporator with higher capacity.

7.2. Future Scope

A total of ten models were developed in the stipulated time, the models being the variants of the first base model, the 360L/340L and it covered rigorous developments due to the introduction of a totally new model. Development of more variants is yet to be completed and so for future, the following are being planned and work has already been started,

Introduction and Certifications for IS-17550- As the new standard IS 17550 is about to start its tenure from the August of 2022, the scope for future is to revise all the testing results according to the new norms set for all the models that are and will be running for domestic production. Major changes will be seen in the Energy values as the calculation changes completely.

For Frost Free refrigerators, what used to be a 72 hours test to calculate energy will now change into a test which will require a minimum of 2 natural defrosts and at least 6 hours of stable data before and after the defrosts. Focus is mainly based on achieving a more stable data by extending the run durations and also by increasing the areas in the data for calculation. Daily energy will be calculated using the given equation,

$$E_{daily} = (P \times 24) + \left(\frac{\Delta E_{df} \times 24}{\Delta t_{df}}\right) \quad (43)$$

Where, E_{daily}= Daily Energy consumed in Wh

P= Steady state power in watt for a selected set temperature

24= hours/day

ΔE_{df}= Energy increment during a defrost and its consequent recovery period

Δt_{df}= an estimate of defrost intervals

This whole calculation is done across both sides of an initial defrost by selecting periods only in stable regions. From these regions, the steady state power is achieved. On calculating the energy consumed from the first period to the second period including defrost, and then subtracting the energies consumed only in the stable period, the incremental energy of defrost is calculated. The defrost interval is calculated using the ON time of the compressor.

Export Model Development- With the main domestic models already released, the next major development is the models for export, which has already started. The countries mainly include some African countries and Middle Eastern countries. For export, a different variant of the Non-Convertible models is being developed. It comes with door cooling and knob control. Different countries follow different versions of the IEC 62552. Here, testing requires the use of M-packages and test packages-packages which simulate the behaviour of meat, as it is commonly used in foreign countries. There are additional tests such as Storage temperature test where the temperature and stability for M-packages is checked over defrost period, Freezing capacity test which determines the speed as well as amount of storage that can be frozen from a higher temperature to lower.

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