Thesis Report

DEVELOPMENT & PERFORMANCE TESTING OF DOMESTIC AIR-CONDITIONER

Thesis Submitted in Partial Fulfilment of Requirements for The Degree of

MASTERS OF ENGINEERING

in

THERMAL ENGINEERING

by

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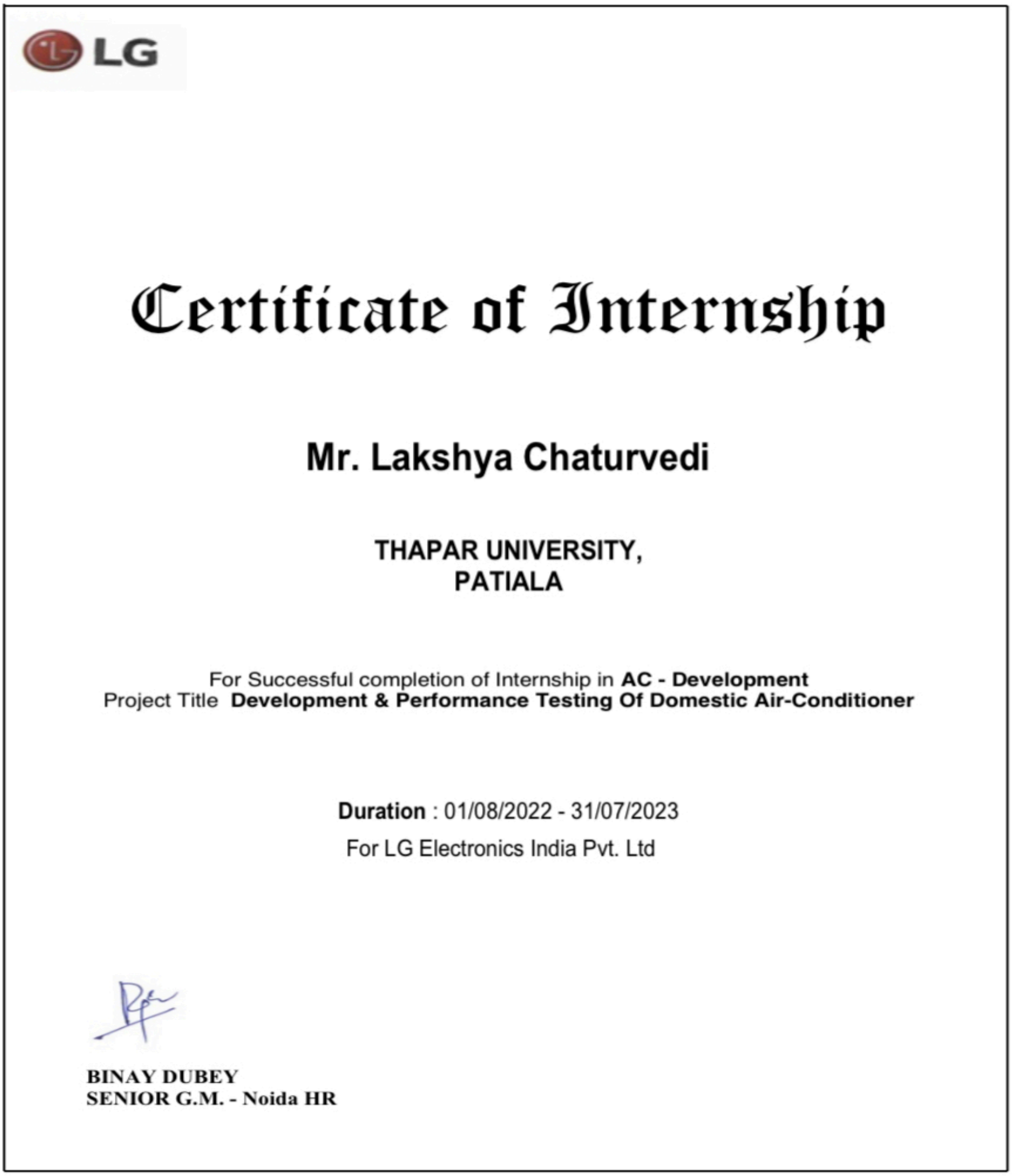

LG

Certificate of Internship

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CERTIFICATE

This is to certify that Lakshya chaturvedi's master's dissertation, "Development & Performance Testing of Domestic Air-Conditioner," is a genuine record of the work he completed during his enrolment from August 2022 to July 2023. In order to partially fulfil 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 2022–2023, this project work was completed under our additional assistance.

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NOMENCLATURE

Symbol	Description [unit]
A	Area [m^2]
C_d	Flow Coefficient Of The Nozzle
K	Latent Heat Of Evaporation For Water At 15°C
P	Pressure [N/m^2 Or Bar]
V	Moist Air Specific Volume [m^3 / Kg]
Q_{tci}	Total Cooling Capacity [W]
Q_{sci}	Sensible Cooling Capacity [W]
Q_{lci}	Latent Cooling Capacity [W]
W	Moist Air Specific Humidity [kg/kg]
Ø	Nozzle Throat Diameter [mm]
h	Specific Enthalpy [J/kg]
t	Air Temperature [°C]

ABBREVIATION

BEE	Bureau of Energy Efficiency
BOM	Bill Of Material
CAD	Computer - aided Design
CFD	Computational Fluid Dynamics
EEV	Electronic Expansion Valve
EER	Energy Efficiency Ratio
GWP	Global Warming Potential
HP	Heat Pump
IDU	Indoor Unit
ISEER	Indian Seasonal Energy Efficiency Ratio
NABL	National Accreditation Board for Testing and Calibration Laboratories
ODP	Ozone Depletion Potential
RAC	Room and Air-Conditioner
RPM	Revolution Per Minute

Abstract

This master's thesis aimed to investigate and improve the performance of existing cooling systems and develop innovative solutions to address emerging challenges in the Residential Air Conditioning (RAC) industry. The research began with a comprehensive literature review, which provided a foundation for understanding the latest technologies and identifying areas for improvement. Experimental investigations were conducted to analyse the performance characteristics of various systems, collecting data on energy efficiency, cooling capacity, and overall system performance. Advanced control algorithms, optimised system designs, and integration emerging technologies were proposed as innovative solutions to enhance energy efficiency, reduce environmental impact, and improve user comfort. Close collaboration with LG Electronics' R&D team ensured valuable insights and feedback throughout the research process.

Testing was performed in the company's labs following strict standards set by governmental bodies, ensuring compliance with regulatory requirements. Multiple stages of testing were conducted, and the results consistently remained in internal limits set by LG Electronics, with margins maintained within 5%. The performance and capacity results were compared to benchmark companies, ensuring healthy competition and confirming the competitiveness of the developed models. Machine-to-machine variation was also assessed and found to be within the acceptable three-sigma limit.

The significant findings of this research highlight the successful development of new air conditioner models that replace previous ones. The modifications, including introducing additional functions and a new tubing design, resulted in improved cooling capacity with relatively lower energy consumption. The detailed procedure of the performance parts selection, as per LG Electronics standards, was recorded and implemented throughout the research process. The outcomes of this research contribute to the advancement of refrigeration and air conditioning technologies, benefitting LG Electronics and offering valuable insights to the broader industry to develop more efficient and environmentally friendly cooling systems.

Keywords: Domestic Air-Conditioner; ISEER ; Performance; Testing; Standards

CHAPTER 1: INTRODUCTION

1.1 PROJECT ROAD MAP

The Project Road Map is created before the start of every project to provide us with a bird's eye perspective of the whole project process. Our Road Map, as established by the company, is shown below.

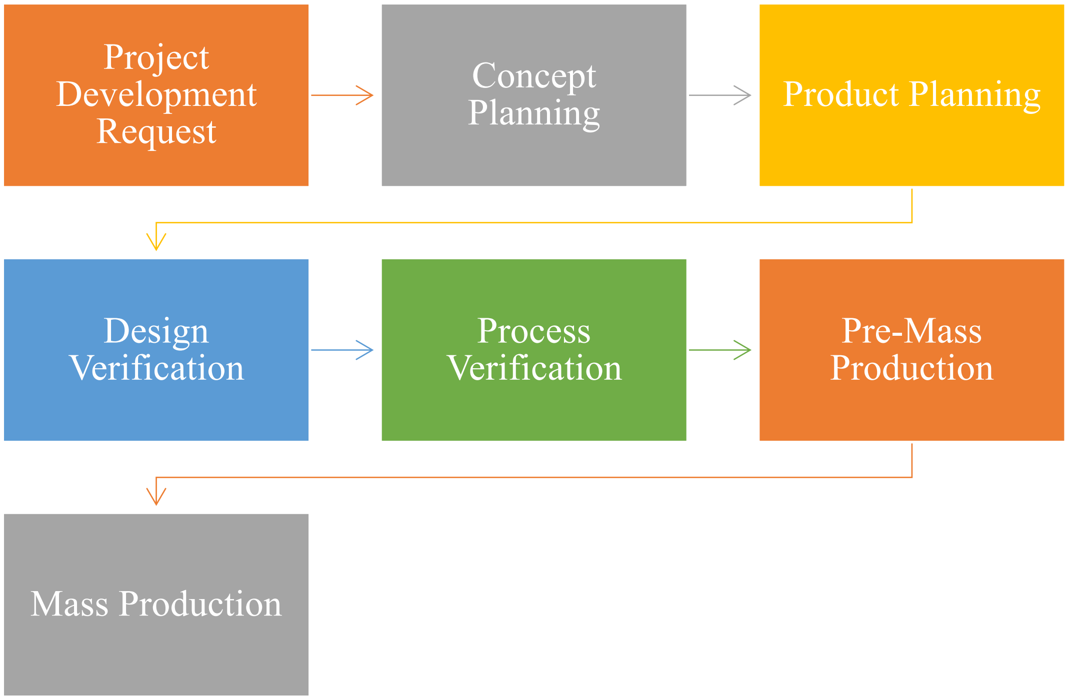

Figure 1. Project Road Map

Product Development Request- A request is created on the firm server system that includes the idea developed from the combined findings of market research and R&D ideas. The new project is introduced, and timeframes are defined in the system for it.

Concept Planning- A product concept is developed and designed in CAD software based on market survey ideas and consumer requirements.

Product Planning- The CAD model is next investigated by creating a prototype and doing practical testing or by running CFD-based simulations, which leads to a product feasibility determination. Various activities are covered within this, including the ones listed below.

- BOM is made, with every part and child part material finalized.
- New Part List and Changed Part Lists are made and finalized
- Design review is done based on the part failure method, and tests are prescribed accordingly.
- Modifications and upgrading of tools and modifications in the production line are made.
- Critical dimensions are inspected to ensure the best fitment of parts.
- Performance tests are performed to obtain results with a 10% safety margin.

- Design Standard is released in which all Product Test, Performance, Safety parameters, Noise, Drop, and Transportation is mentioned with their specs also specified.

Design Verification- After confirming design reviews, line adjustments, and tooling modifications, the Quality Team approves R&D to begin testing. Cost input is done in the system at the same time. The production guidelines are supplied to the production and quality control teams. All of this is followed by sample manufacturing on the production line. Issues discovered at this stage are addressed in the DV2 event, where countermeasures are implemented. After each successful test, the event ended project continues to the next event.

Process Verification- In this event, the production and manufacturing teams inspect for line, line quality, and product scanning issues.

Pre-Mass Production- The project is eventually turned over to the production team, who check the product's quality again to see whether it's ready for mass production.

Mass Production- This event is carried out according to the sales requirement, and from this point, the Field Inspection team comes into play to ensure customer product performance.

The following is a list of the components that go into making a standard RAC, as utilised in the production supply chain.

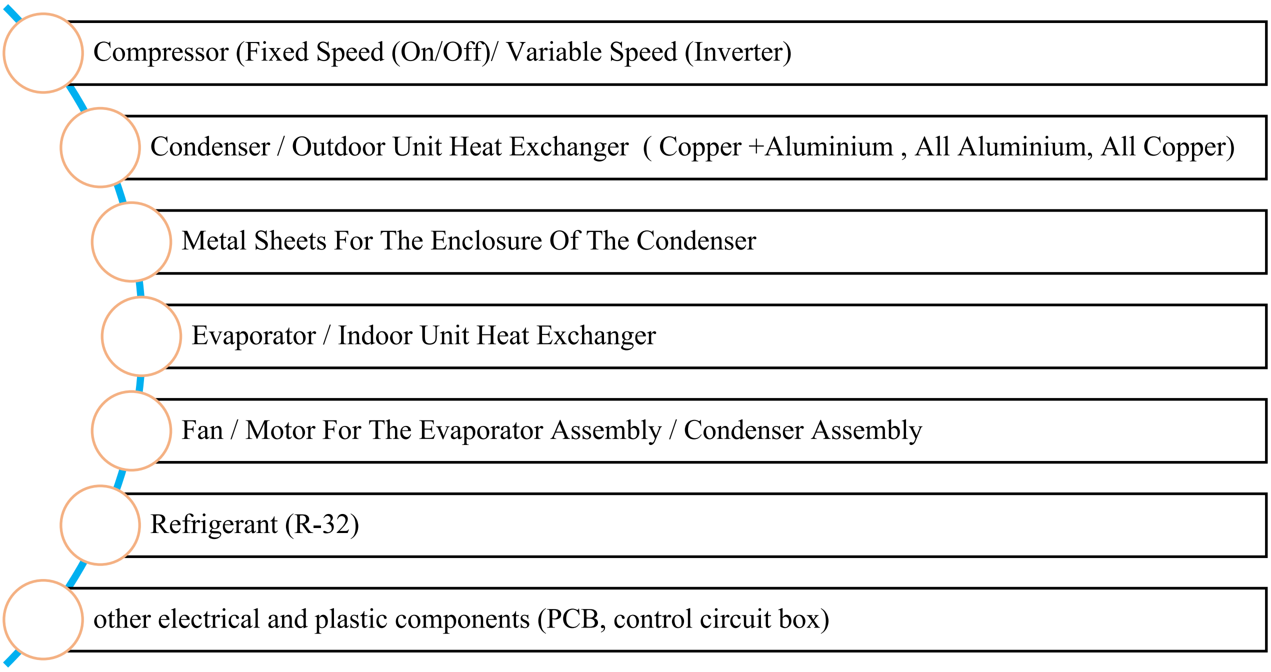

Figure 2. List of AC Parts

The below figure presents the AC Parts and Distribution chain of the above bill of materials in India and summarizes its localization vs. import.

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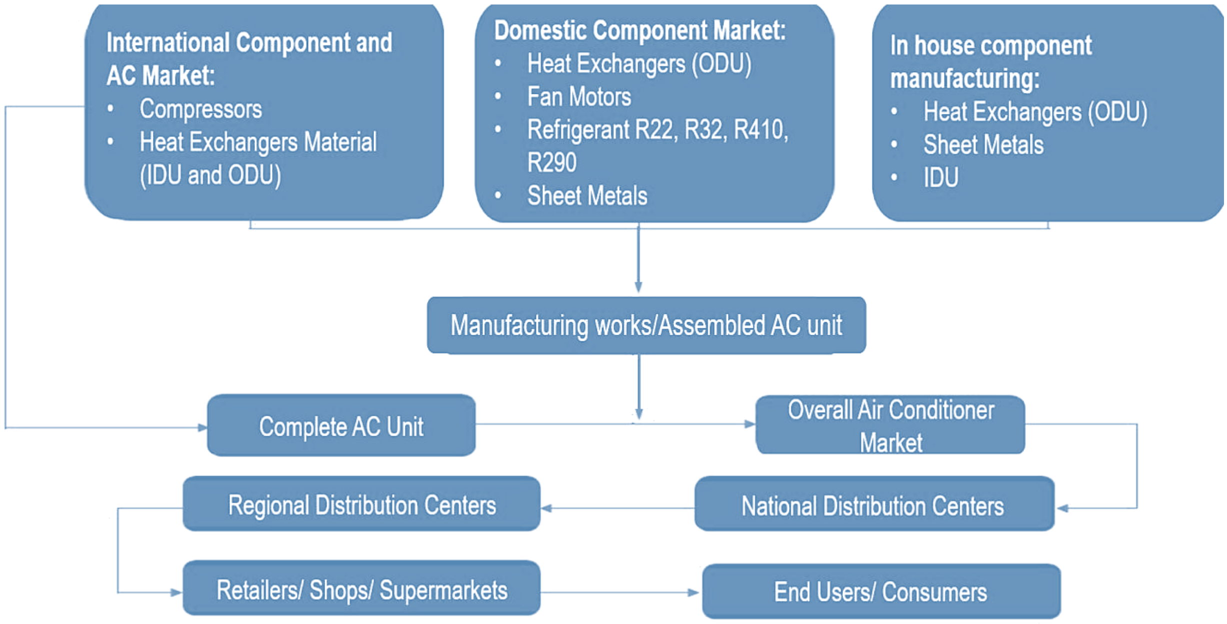


Figure 3. RAC production and sales chain in India

1.2 KEY FEATURES

The new features included in these models are as follows-

• **AI Dual Inverter:** The AI Dual Inverter feature in LG split systems utilizes advanced algorithms to predict the optimal cooling capacity and adapt to room circumstances. By intelligently selecting the necessary fan speed and temperature settings, it ensures precise and efficient cooling, providing users with enhanced comfort while minimizing energy consumption.

• **Viraat Mode:** The Viraat Mode guarantees consistent temperature and quicker cooling. It achieves this by boosting the air conditioner's cooling capacity from 110% to 117%, depending on the model. This feature is handy during hot summer days when rapid cooling is required to create a comfortable indoor environment.

• **Plasma master Ionizer++ Technology**: LG's Plasma master Ionizer++ technology is integrated into split air conditioners to purify the indoor air environment. It effectively destroys tiny particles, germs, and bacteria, ensuring users a cleaner and safer living space. This advanced air purification system improves indoor air quality and promotes a healthier environment.

• **AI+**: The AI+ feature is an intelligent system that continuously detects and monitors the user's usage patterns and the load on the environment. This information is communicated to a server, allowing the air conditioner to adapt and optimize its operation based on deep learning. This adaptability ensures ultimate comfort and personalized settings for each user.

• **ThinQ Connectivity:** The ThinQ Connectivity feature makes LG air conditioners smartphone compatible. It enables users to monitor and operate the system anytime and anywhere remotely. Smartphone users can easily control their air conditioners, adjust settings, and manage energy usage, providing convenience and flexibility.

- **Smart Inverter Compressor:** LG's Smart Inverter Compressor is designed to adjust its frequency according to the machine's load and the required temperatures. By optimizing the compressor's operation, this technology enhances energy efficiency and reduces energy wastage, resulting in cost savings for users while maintaining consistent cooling performance.

1.3 AN OVERVIEW OF AIR CONDITIONING

As society and the economy progress, people's living standards improve, leading to a greater focus on air conditioning to enhance comfort. Air conditioning is crucial in providing comfort to individuals and facilitating various industrial processes by controlling temperature, humidity, airflow, and cleanliness. It encompasses all the technical factors crucial for human well-being and the effective functioning of industrial and scientific operations. Air conditioning involves adjusting the indoor air's temperature, humidity, airflow, and cleanliness to ensure occupants' health and happiness or optimize goods production. There are two main types of AC: summer and winter. Summer AC cools the space and removes excess moisture using refrigeration and dehumidifiers. In contrast, winter AC warms the space and adds moisture, primarily working as heat pumps and humidifiers. Additionally, air conditioning can be categorized into comfort air conditioning, which focuses on providing comfort for homes, businesses, vehicles, and more, and industrial air conditioning, which targets specific control of environments for processes such as printing, textiles, and computer rooms.

1.3.1 THE PURPOSE OF AIR CONDITIONING

Air cooling is more than just a nice thing to have, especially in places where it is necessary. High humidity and uncomfortable weather can make people less relaxed and less productive. Air cooling not only affects people's health and happiness but also considerably affects the economy. When people are comfortable at work, they tend to be more productive. Also, air cooling is used in many businesses to meet unique process needs. Electronics last longer and work better when the temperature is lower, so computer systems and other microprocessor-based tools need air conditioning to work well. As our world progresses, the need for air conditioning will continue to grow, becoming an increasingly integral part of modern living and industrial practices.

1.3.2 HOW AIR CONDITIONING SYSTEMS WORK

There are several ways to execute air conditioning, including the absorption refrigeration system and the vapour compression refrigeration technique. The VCRS procedure is the most often used technique. The cooling coil or the evaporator, compressor, condenser, and expansion valve are the four essential parts of a VCRS cycle.

Warm air is pumped through a cooling coil in this procedure, where a low-temperature two-phase refrigerant cools it. The coil dehumidifies the air if the evaporator's surface temperature is less than the air's DP temperature. The refrigerant turns from a liquid to a vapor by the heat supplied By room air. The refrigerant vapour from the Eva coil is removed by the compressor and released at a high temperature and high pressure into the condenser. A coolant, often water or air, removes the thermal energy of the refrigerant in the condenser, allowing the refrigerant to revert to a liquid condition at that high pressure. A throttling mechanism transforms the high-pressure liquid refrigerant into a two-phase, vapor plus liquid, low pressure and low-temperature refrigerant. After that, the refrigerant enters the Eva, where it cools and dehumidifies the heated air. When heat and mass have been transported, the air is supplied to the conditioned room at cooler temperatures and with less moisture to balance the load on the air conditioner.

It should be noted that the system uses a closed cycle to function. This refrigeration system may also function as a heat pump, with the high-temperature heat rejected at the condenser serving as the usable output. An alternative is to employ a refrigeration system for summer cooling and winter heating.

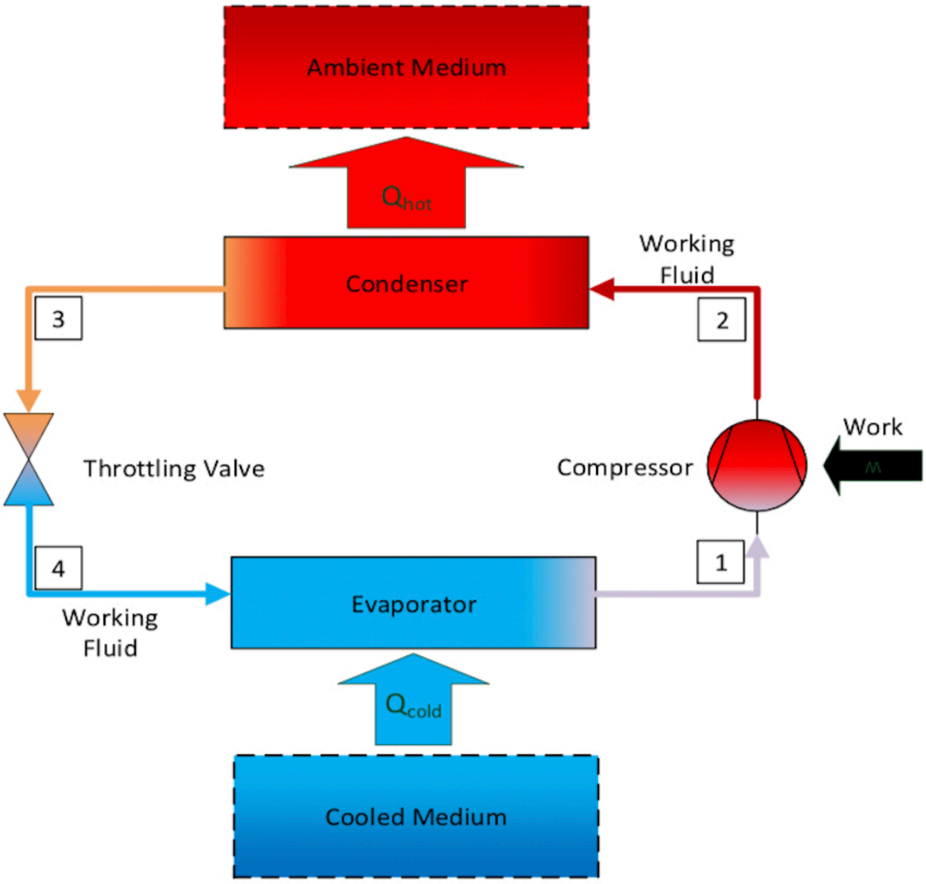


Figure 4. Refrigeration Cycle

According to Figure 4, the ideal VCRS cycle consists of four processes:

1-2 Isentropic compression by the compressor

2-3 Constant-pressure removal of heat by a condenser

3-4 Throttling by expansion device

4-1 Constant-pressure heat absorption by the evaporator

1.4 ROOM AIR CONDITIONING (RAC): TYPES AND DEFINITIONS

Room air conditioner (RAC) group includes Unitary (Window) type and Split type ac units with cooling capacity of up to 18 kW. BEE has set guidelines for how air conditioners should be put into these groups. The Indian standard for RAC is IS 1391. IS 1391 parts 1 for Unitary air conditioners and 1391 parts 2 apply to split air conditioners,

The definitions of Unitary (window)and split AC are as follows:

Unitary (Window) AC: A self-contained system meant to be mounted in a window, through a wall. It has a compressor, heat exchanges, and a system for moving air; all together in one box.

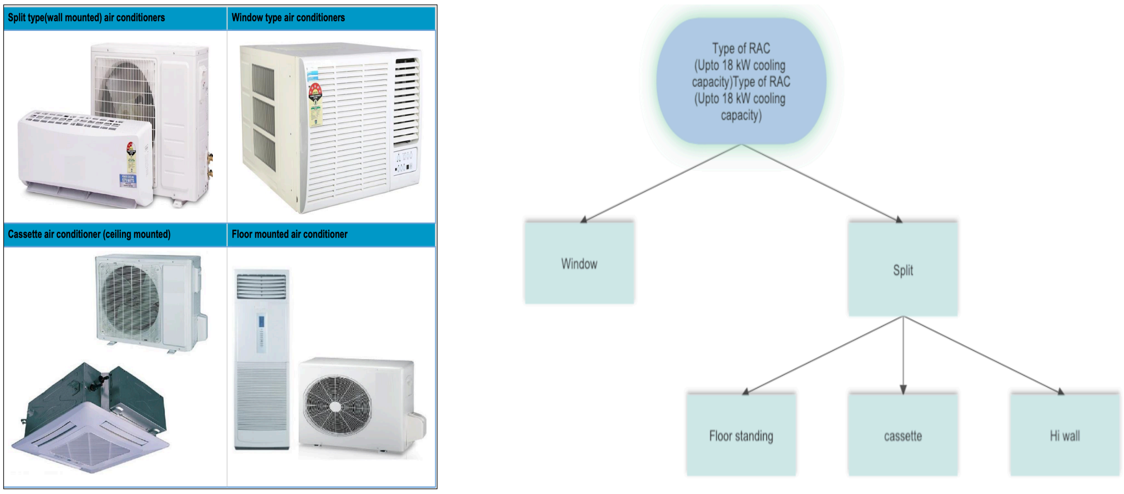


Figure 5. Room Air Conditioner (RAC) Types

Split AC: It has two parts: one outside and one inside. The IDU is attached to the wall or roof inside the room, while the ODU is attached to the outside of the wall. The split AC unit comprises two cabinets that hold a compressor, heat exchanges, fan motors, and an air handling system.

Unitary ACs on the market have a cooling power of less than 7 kW or about 2 TR. In contrast, the Split AC category has three different products up to 18 kW (about 5.1 TR).

Hi-wall Units- less than 10.5 kW (around 3 TR)

Cassette AC: Most cassette units on the market can cool between 10.5 kW (about 3 TR) and 18 kW (about 5.1 TR). Few are offered with a cooling ability of less than 10.5 kW. The air conditioners' indoor units are placed on the roof.

Floor Standing: Most floor-standing units on the market have a cooling ability of between 10.5 kW and 18 kW. Few are offered with a cooling ability of less than 10.5 kW. The indoor units of these ACs are kept on the floor, as the name suggests.

Room airconditioner are categorised into two types depending on their usage: cooling alone and heating /cooling.

Extreme weather is expected in India, especially in the north. Winters without heaters may be challenging, while summers without air conditioners are unfathomable. As a result, manufacturers create items that may be used for cooling and heating. In India, All-weather AC items are uncommon and have a little market share. However, reversible split air conditioners are more prevalent than their reversible window counterparts. In India, there are no regulations for heating. Thus reversible items are evaluated according to how well they cool. Room air conditioners are categorised into two types depending on their usage: cooling alone and heating/cooling.

1.5 MARKET OVERVIEW AND KEY PLAYERS

More than 22 companies from all over the world compete in India's RAC business. They meet the various wants of India's many customers. The picture below shows some important players: India's air conditioners market has grown.

Figure 6. Top Companies Of RAC In Indian Market

At a CAGR of 19% between FY 14 and FY 19. All types of RAC markets in India are expected to sell close to 13.5 million units (2025-26)

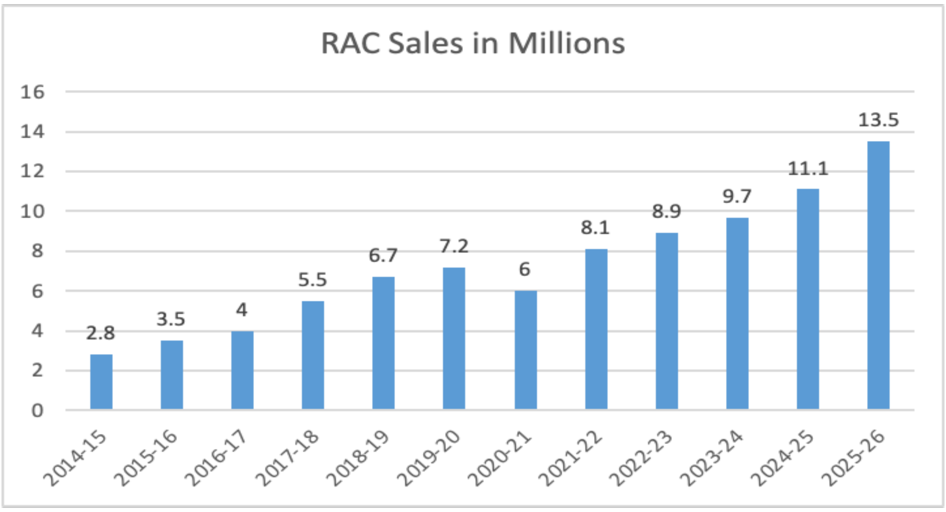


Figure 7. RAC Sales Forecast In India.

1.6 TECHNOLOGY OF RESIDENTIAL AIR CONDITIONER

Unitary air conditioner market share has dropped 10% in five years. Since split air conditioners are now cheaper than window air conditioners, their market share will likely stabilise at roughly 90% over the next several years. By FY24, 80% of split AC will be inverter-based. Technology classifies them as fixed-speed or inverter types. Inverter and fixed-speed air conditioners are similar except for compressor technology. Inverter air conditioners vary power supply frequency (Hz) to change compressor speed dependent on temperature. Fixed-speed air conditioner compressors start and stop at the designated point.. Figures show the market trend of RACs based on their kind and technology.

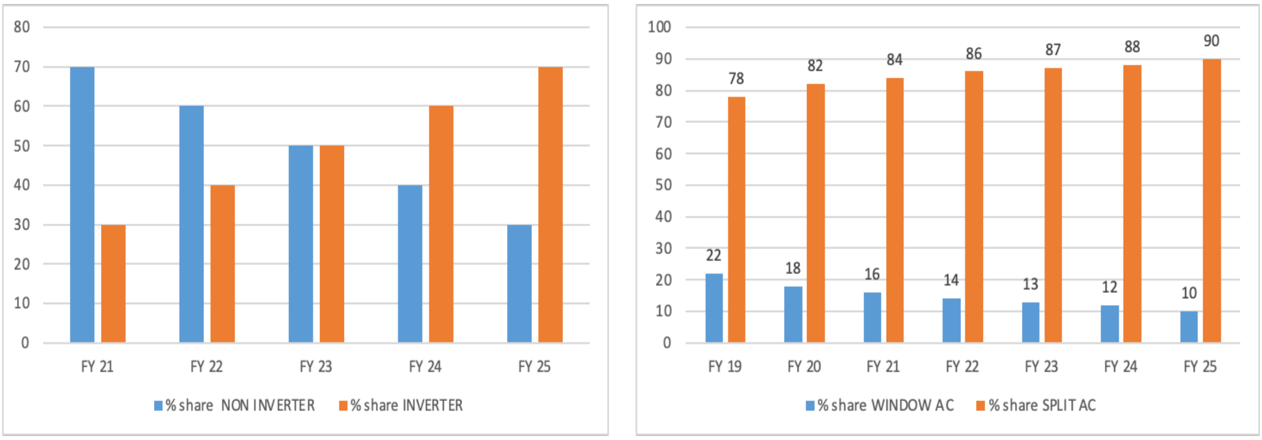


Figure 8. AC Type and Technology Market Trend

1.7 STANDARD REFRIGERANT FOR ROOM AIR CONDITIONERS

R410A, R22, R-32, and R-290 are the most common refrigerants used in RAC systems today. The following table lists the global warming potential (GWP) and ozone depletion potential (ODP) of some of the refrigerants included in RACs.

Table 1 RAC refrigerants GWP and ODP values

Refrigerant	Chemical Formula	GWP	ODP
R-22	$CHClF_2$	1760	0.055
R-410A	CH_2F_2/CH_2F_3	1924	0
R-32	CH_2F_2	677	0
R-290	C_3H_8	3	0

In 2017-2018, R-22 was India's most used refrigerant. However, due to its detrimental impact on the ozone layer and its high (GWP), India has taken proactive steps to phase out hydrochlorofluorocarbons (HCFCs), including R-22. This phase-out plan aligns with the objectives of the Montreal Protocol, aimed at protecting the ozone layer and mitigating climate change. As part of this steady phase-out process, India is transitioning towards more environmentally friendly refrigerants with lower GWP and zero (ODP), such as hydrofluorocarbons (HFCs) like R-32 and hydrocarbons (HCs) like R-290.

Based on the type of refrigerant used, R-32 and R-410 made up nearly 75% of the market for RAC sales in 2020-21. R-22 has a market share of about 25%, and R-290 has a market share of about 2%.

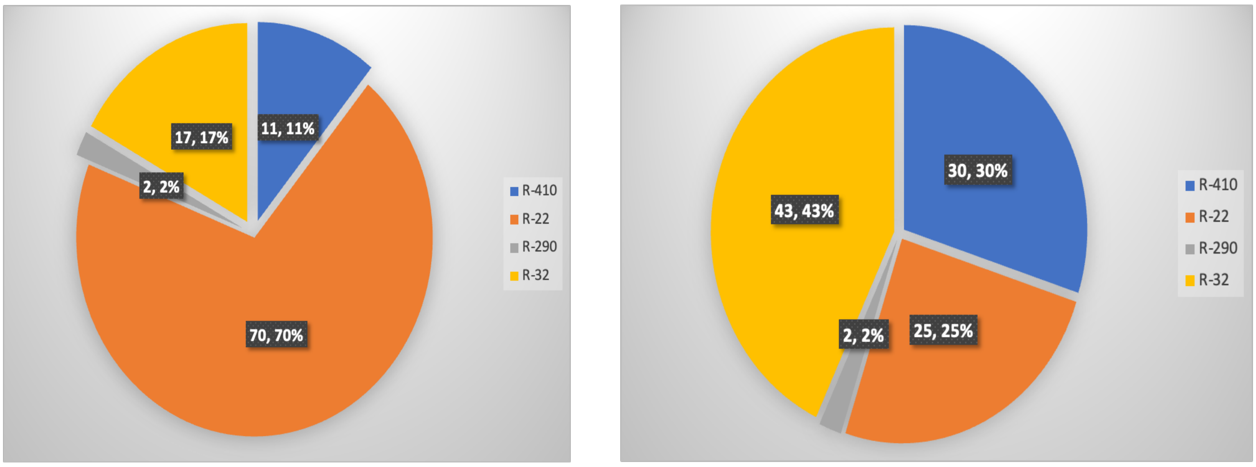


Figure 9. RAC Sales By Refrigerants (2017-18) - (2020-21)

1.8 ROOM AIR CONDITIONER GRADING SYSTEM

In 2009, the "Bureau of Energy Efficiency" (BEE) made the Independent Star labelling plan for fixed-speed Room Air Conditioners (RACs) mandatory. Initially, star ratings were determined using EER values., which measured the efficiency of the RAC at a fixed outside temperature of 35°C. However, EER had limitations as it could not capture the RAC's performance under different temperature conditions.

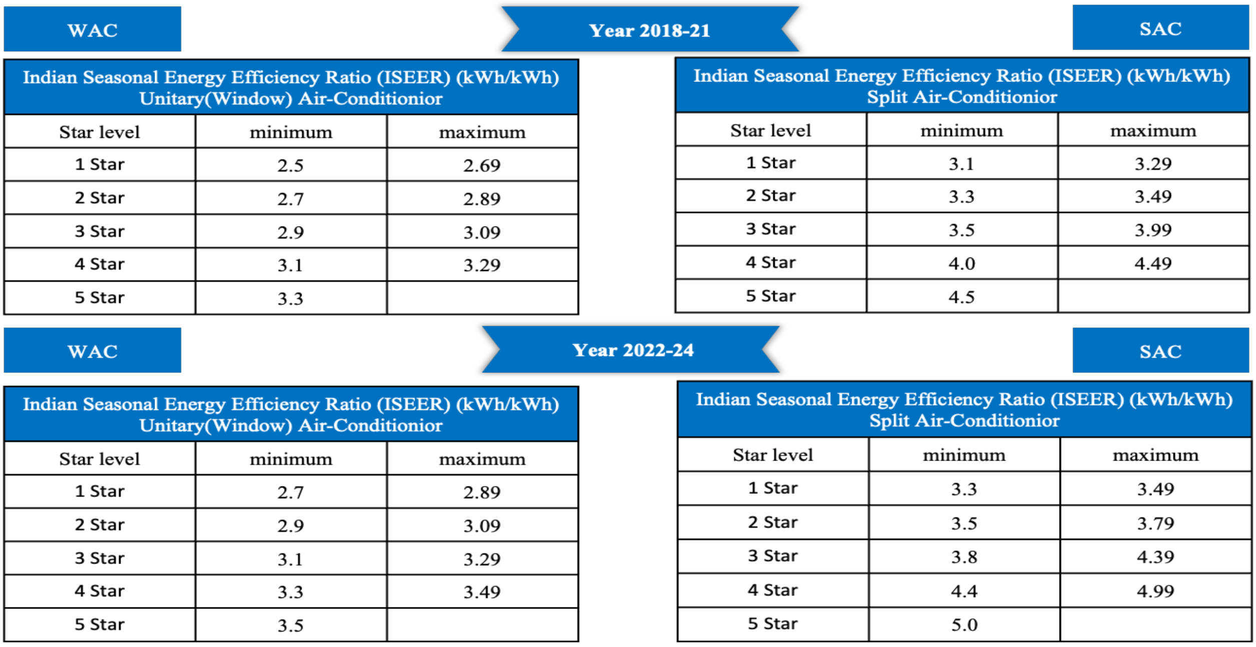
EER = Refrigeration capacity/ Input power.

BEE adopted a new grading system, the Indian Seasonal Energy Efficiency Ratio (ISEER), in 2015, which considered temperature variations and provided a more comprehensive measure of energy efficiency. The ISEER rating became mandatory from 2018 onwards, replacing the EER-based star rating system. ISEER considers the RAC's performance at various outside temperatures, providing a more accurate representation of its overall energy efficiency.

ISEER measures how efficiently the RAC operates across a range of temperatures and assigns a corresponding efficiency figure. This approach allows consumers to make informed decisions based on the RAC's performance in different weather conditions, ensuring more effective cooling and energy savings.

The BEE star labelling program uses ISEER to assign star ratings to Unitary (windows) and split ACs. These star ratings help consumers identify and choose energy-efficient air-conditioning units, promoting sustainable practices and reducing energy consumption in the Indian market.

Table 2 BEE ISEER Star Rating.



WAC

Year 2018-21

SAC

Indian Seasonal Energy Efficiency Ratio (ISEER) (kWh/kWh) Unitary(Window) Air-Conditionior		
Star level	minimum	maximum
1 Star	2.5	2.69
2 Star	2.7	2.89
3 Star	2.9	3.09
4 Star	3.1	3.29
5 Star	3.3	

Indian Seasonal Energy Efficiency Ratio (ISEER) (kWh/kWh) Split Air-Conditionior		
Star level	minimum	maximum
1 Star	3.1	3.29
2 Star	3.3	3.49
3 Star	3.5	3.99
4 Star	4.0	4.49
5 Star	4.5	

WAC

Year 2022-24

SAC

Indian Seasonal Energy Efficiency Ratio (ISEER) (kWh/kWh) Unitary(Window) Air-Conditionior		
Star level	minimum	maximum
1 Star	2.7	2.89
2 Star	2.9	3.09
3 Star	3.1	3.29
4 Star	3.3	3.49
5 Star	3.5	

Indian Seasonal Energy Efficiency Ratio (ISEER) (kWh/kWh) Split Air-Conditionior		
Star level	minimum	maximum
1 Star	3.3	3.49
2 Star	3.5	3.79
3 Star	3.8	4.39
4 Star	4.4	4.99
5 Star	5.0	

$$\text{ISEER} = \text{CSTL} / \text{CSEC}$$

Where: **Cooling Seasonal Energy Consumption (CSEC)** – The annual amount of power (electricity) consumed by the apparatus when functioning in active mode for cooling.

Cooling Seasonal Total Load (CSTL) – The annual amount of heat that is taken out of the indoor air by the apparatus when functioning in active mode for cooling.

In India, there are air conditioners with efficiency levels that are 20% to 30% higher than the most strict standards. The table shows that these air conditioners are primarily available in the 1-ton category.

Table 3 Best-in-class RAC in India

S. N	Brand	Model Name	Tonnage	Refrigerant	Star Rating	ISEER
1	DAIKIN	FTKF35UV16U+RKF35UV16U	1	R-32	5	6.20
2	HITACHI	RSOS512HCEAP	1	R-410A	5	6.10
3	WHIRLPOOL	SAI12B53DXDO	1	R-32	5	6.01
4	MITSUBISHI	SRK13YVS-W6	1	R-32	5	5.94
5	DAIKIN	FTKF50UV16T+RKF50UV16T	1.4	R-32	5	5.80
6	GODREI	GIC 12TGC7-WVA	1	R-290	5	5.80
7	MITSUBISHI	SRK18YXS2-W6	1.7	R-32	5	5.70
8	TOSHIBA	RAS-18PKCV2G-IN+RAS-18PACV2G-IN	1.5	R-32	5	5.60
9	GENERAL	ASGG18CETA-B	1.5	R-32	5	5.56
10	WHIRLPOOL	SAI12B53DXD1	1	R-32	5	5.51
11	CARRIER	CAI13SX5R30F0	1.1	R-32	5	5.42
12	MITSUBISHI	SRK10YL-S6	0.8	R-410A	5	5.41
13	MITSUBISHI	SRK24YVS-W6	2.2	R-410A	5	5.41
14	MITSUBISHI	SRK10YL-S6	0.8	R-410A	5	5.41
15	BLUE STAR	IA718YCU	1.5	R-32	5	5.41
16	CARRIER	CAI18DN6R39F0+CI186R3BC90	1.5	R-32	5	5.40
17	DAIKIN	FTKZ50UV16U4+RKZ50UV16U4	1.5	R-32	5	5.40

CHAPTER 2: LITERATURE REVIEW

There are many applications for air conditioning, and its range is vast. On its creation, thousands of engineers and scientists have labored. Much study has been done on many aspects of RAC systems. This chapter discusses the literature on developing different models, technologies, and techniques for improving performance, design, efficiency, energy-saving techniques, dependability, durability, waste heat recovery techniques, environmental protection aspects, refrigerant selection, and choice of various air conditioning systems. The literature review also includes the assessment of the system methodologies employed in the proposed study.

2.1 INTERNATIONAL STATUS

Compared to an inverter and non-inverter AC, the inverter may reduce energy usage by up to 44% compared to non-inverters, which use 3471 and 6230 kWh annually. Furthermore, a study shows that an inverter can reduce CO2 release by 49% [1]. The research explains the benefit of utilizing inverter air conditioners over non-inverter ones, mainly given the climate in Arab, which will result in less energy use. Inverter technology can result in considerable cost reductions because of the anticipated increase in AC demand and rise in ambient temperature brought on by global warming. In addition, the inverter type is more suited to lowering CO2 release due to the requirement to reduce greenhouse gases. A crucial component of performance evaluation standards is distributing air conditioners with more energy efficiency. SEER more properly measures performance than EER. Thus, switching the KSA standard from EER to SEER may result in greater energy efficiency. Additionally, it will increase customer awareness of energy savings and help them comprehend how inverter air conditioners save electricity.

The findings of this study reveal that R32 is an excellent two or more-stage refrigerant [2]. Two or more-stage employing refrigerant R32 provides a high cop while decreasing compressor work. Multi-stage refrigeration cycles employing R32 can enhance refrigeration cycle performance by 8.8% over simple systems. Two or more-stage ideas for VCRS offer efficiency.

The report observed performance from the simulation of a tetragon BLDC motor driven by the tetragonal drive and a sine wave BLDC motor energised by the field-orientated control in their study [3]. The performance of each motor and driver combination is compared. Due to efficiently suppressing the PWM carrier impact in low voltage and turbo regions, the BLDC motor with tetragonal drive has more outstanding performance under low voltage (24 V) for the functioning of the DC link than the BLDC motor with sine wave drive (280 V). Tetragonal drives utilise chopping signals for a single button, maximising inverter performance for BLDC motors. As a result, the BLDC was created. Because tetragonal drives employ chopping signals for just one switch, the BLDC motor with a tetragonal drive provides the maximum inverter efficiency. As a result, the designed BLDC motor with a tetragonal drive has the most outstanding overall performance among motor-drive combinations. These findings support using trapezoidal BLDC motors with trapezoidal drives in AC fan motor systems to reduce power use and increase drive performance.

According to Koichi Fujishiro (Mitsui & Co. Global Strategic Studies Institute Monthly Report February 2021), demand for improved air quality is on the rise globally, and this trend may be attributable to people's desire for cost-effective, risk-free, clean air solutions. Japanese ac companies, including Daikin, Fujitsu General, Mitsubishi Electric, and Panasonic, may benefit from these regulations. These companies are ahead of the curve in production capacities, such as cumulative energy-saving, control, and cooling technologies. Daikin is a specialist maker with expertise in cooling technologies and heat exchangers, which play critical roles in AC systems. While Panasonic, an organisation in the home appliance business, can make AC units, Mitsubishi leads in their control technology. Businesses in the air cleaner industry have developed new technologies and products in response to rising demand from Japanese consumers.

The Portable Air Conditioning System mentioned in this study may be employed in dual-mode operation, heating, and cooling [4]. This system achieves a minimum temperature of 16 degrees Celsius, a maximum temperature of roughly 40 degrees Celsius, and a maximum voltage in about 30 minutes. This technology might replace traditional air-conditioning systems that use coolant that is safe for people in the long run. There is much room for advancement in thermoelectric materials, manufacturing, heat sink design, etc. In the future, thermoelectric module-based cooling will be capable of cooling 10x10 rooms with only a few modules in a relatively short period. The module will provide enough air cooling for interior applications. The effect has a 10 - 15% efficiency compared to the refrigerants' 40 - 60% efficiency. Using the Effect, a temperature differential of 70 °C in heat absorption may be produced. More sink thermal mass is typically beneficial to the effectiveness of the effect in air cooling. A boost converter may control air conditioning operation by controlling the current delivered to handle temperature variances. Air conditioning work or efficiency can be enhanced using the See back effect to generate power from temperature differences. The above explanations show that thermoelectric module cooling is more beneficial than traditional air conditioning.

A study on "Consumers Behavior Towards Purchase of Air Conditioners" indicated that demographic factors such as gender, marital status, and income influence customers' buying decisions when purchasing ACs [5]. The study also discovered a link between demographic characteristics and the aspects people favour when shopping for air conditioners. According to thirty-one per cent of respondents, the main factors influencing AC users' buying choices are how quiet the AC is. Less electricity utilisation influenced 28% of survey respondents. 28% of respondents indicated that an easy-to-use design impacted their purchase. Thirty-three per cent of respondents stated brand name made their purchase. 31% of respondents stated that price influences their purchase decision. 20% of respondents claimed decreased CO2 emission influenced their purchase. Wi-Fi mode is the primary reason to purchase for 17% of respondents. Its power efficiency affected the purchase. 28% of respondents indicated that an easy-to-use design impacted their purchase. Thirty-three per cent of respondents stated brand name made their purchase. 31% of respondents stated that price influences their purchase decision. 25% of respondents claimed decreased CO2 emission influenced their purchase. Seventeen per cent of respondents thought Wi-Fi mode is the most crucial while buying.

An experimental investigation examined how a natural clogging substance on the evaporator's cooling tube affects RAC unit efficiency and the Room air's cleanliness [6]. After the studies, the bacterial contents of the clogging substance on the tube's surface were examined. The front of the tube's surface was found to have thick clumps of various Aspergillum fungi. This finding is critical for closing the information gap between physical deposition, colonization, and the projected health concerns of people living in areas with dirty evaporators. The effect of these blocking substances on the unit's effectiveness showed that the unit's COP for a fresh evaporator tube at the standard air speed of 1.53 m/s was 2.82. It went down to 1.89 once 100 g of clogging substances were added, 1.79 when 200 g were put in, and 1.23 despite 300 g being inserted. Due to contamination, the efficiency of room AC units decreases significantly.

They Presented that The influence of the standard deviation of the external evaporator output temperature on the system COP of the heating condition was investigated and analyzed in this article. We were able to confirm the relationship between system COP and the standard deviation of the outside evaporator outlet temperature. The following are the main consequences of this article. A 1°C reduction in the standard deviation of external evaporator output temperatures can result in a gain of roughly 10% in heating COP. For the same system, more capacity results in a higher standard deviation of outside evaporator outlet temperature and lower system COP. Designing Considering the standard deviation of evaporator output temperatures is critical for achieving optimal heat exchanger performance.

They explored hybrid-individual overheat management by simulating a 10.55kW R410A-cooled residential heat pump [7]. This model was verified by comparing the simulated results to two sets of actual test data: refrigeration capability and COP at varied ambient conditions and cooling capability and COP at various evaporator air circulation rates. Data matches anticipated refrigeration capability and COP. The confirmed simulation model tested individual overheat control's advantages. A hybrid-individual overheat control approach has been assessed using microvalves in every channel and a significant expansion device to handle evaporator overheat. The main throttling valve reduces pressure, while other valves regulate circuit flow. Install flow-regulate valves before or after the evaporator. Each was analysed with no flow control.

Experiments were carried out to indicate the impacts of EEV-opening and coolant fill amount on the efficiency of the water source trans critical CO2 HP water heater by adjusting the coolant fill with various EEV-openings [8]. As the coolant fill grew, so did the P in the gas cooler and the evaporator. As the coolant fill grew, so did the gas cooler and evaporator pressures. As the temperature rose, so did the gas cooler and Eva pressures. Heating ability and heating COP improved swiftly, hit a maximum, and fell as the coolant amount at a fixed EEV opening increased.

The pressures surged as the EEV opening increased, and so did the coolant at a constant EEV opening. The following are the other conclusions: The EEV opening, and coolant fill quantity substantially impacted the system working. When all other system operating parameters remained constant, an ideal COP was discovered that matched a given coolant fill and EEV opening. Test results show that the COP hit 1.8 kg of charge when the EEV was 40% of its entire capacity. When the EEV opening was variable, COP had a different maximum value for a particular coolant charge. The ideal COP went down as the EEV gap grew. Also, at the same charge level, different EEV apertures led to different COP.

So, the amount of coolant charged and the level of the EEV are crucial factors that affect the system's COP. For the CO2 HP system to work at its best, it needs the right amount of coolant fill and, more specifically, careful control of EEV opening.

Compare two inverter split ac, one with a typical air-cooled condenser and the other with an evaporative-cooled condenser [9]. The effect of evaporative cooling on system performance characteristics is investigated. The system's electrical consumption drops, and changes in cooling ability, condensation heat rate, and COP are being analysed. Four external conditions (cases) are tested at varying temperatures and relative humidity. The differences between the examples and comparing the CT and EC models are examined. Following the comparative process, optimisation is undertaken to identify the best outside circumstances that minimise power usage and maximise the performance of the EC system. Both studies' results may be described as follows: Using an evaporative-cooled condenser considerably improves the efficiency of the inverter split ac.

2.2 NATIONAL STATUS

A stable test platform has been made to examine how an air cooling system works in both a steady and moving state of a vehicle [10]. As closely as possible, the testing facility employs the exact parts found in the whole system while simulating the hardware configuration of the actual car. Since there is no engine in the facility, a variable frequency motor changes the compressor's speed. This motor connects to the compressor by a magnetic coupling. Additionally, the test facility has been using a locally created controller. The coolant charge level, compressor and evaporator fan speed are the only independent factors affecting the system's performance in a steady state. Therefore, their effects have been studied in a moving vehicle. The following trends have been seen.

The coolant charge lowers suction and discharge temps but raises pressure. Compressor speed increases discharge pressure and temperature with increased blower speed and a corresponding drop in discharge pressure and temperature, suction pressure and temperature rise. As the compressor speeds up, cooling load and work input increase, yet system COP decreases. Cooling ability, COP, and work input rise with coolant charge up to a specific range, then fall.

In their work, D. S. Prasad et al. (2014) A stationary test bench was used to assess the efficiency of a vehicle air cooling system due to poor air distribution on the condenser surface. On the condenser surface, screens of 30, 40, and 50% blockage of geometries such as peripheral, side, center, and uniform provide airflow-poor distribution. Experiments were carried out by adjusting the compressor's speed in the presence of each obstruction and the absence of a blockage. The following patterns have been identified.

As the percentage of blockage rises, so does the suction and discharge pressure. The percentage of blockage rise condenser outlet refrigerant and air temperature. However, there is no substantial influence on condenser intake refrigerant temperature owing to obstructions. Both refrigerant and air pressure reductions rise as an effect of the obstruction. The system's coolant flow rate rises as the compressor speed and percentage of blockage increase.

Furthermore, when the proportion of blockage increases, the pressure ratio drops. This increases compressor volumetric efficiency and refrigerant output density. These factors enhance the coolant flow rate across the circuit. The airflow rate on the condenser surface decreases as the percentage of obstruction increases. Thus, the decrease in flow rate is substantially impacted by the amount of blockage and the kind of obstruction. The decrease in airflow is minimal in peripheral obstruction and maximal inside blockage. An infrared camera inspects the refrigerant temperature distribution on the condenser surface for any obstructions. Cooling ability and work input increase as compressor speed increases.

Explain their findings in their paper, The fin is crucial for increasing the heat transfer rate for many systems [11]. Fins are put on the system's surface to enhance the heat transmission rate. Thermal analysis of fins may be used to determine heat dissipation and heat transfer rates in various fin types. Thermal analysis of fins helps determine heat dissipation and heat transfer rates in various fins. Increasing the pin layout's surface area increases this process's heat dissipation rate, but developing such massive, complicated systems is highly challenging. As a result, fins are installed on the system's surface to improve heat transmission. A round, square, or rectangular fin that extends from a pin arrangement to the surface. A circular, square, or rectangular fin extending from a pin structure enhances the heat transfer rate from the environment by boosting convection. This principle of conduction, convection, and radiation of a fin structure determines the quantity of heat and its transfers. Heat transfer is increased by increasing the temperature differential between the fin configuration and the environment, slightly increasing the convection heat transfer coefficient, or increasing the surface area of the object's pin configuration. Changing the first two alternatives is only sometimes cost-effective or practical. However, increasing the surface area of circular, square, and rectangular fin configurations can occasionally be an affordable solution to heat transmission concerns. According to the paper, using fins (extended surfaces) provides effective heat transmission. Heat transmission through rectangular fins is more significant than through other fin shapes. Compared to other fin layouts, the temperature near the end of the rectangular fin is the lowest. The efficacy of a rectangular fin is better than that of other shapes. Choosing the optimum size fin of rectangular configuration will reduce the heat transfer cost and increase the heat transfer rate.

Based on state space, they developed a full dynamic MIMO model for a direct expansion air cooling system [12]. This model considered how cooling and air circuits change over time and how water drops out of the air to make a more accurate simulation of how a natural system works. The authors suggested a lumped parameter model consisting of first-order ordinary differential equations computed for all system internal variables. These factors influence the system's thermal comfort and energy consumption, either directly or indirectly. The correctness of this model is determined by the accuracy with which the cooling load, heat transfer coefficient, bypass factor, and other parameters are estimated. This is a shortcoming of this model, which occurs for mathematical approximation of any physical plant in general. Simulation and experimental experiments were used to validate the suggested model. The AC system of a train coach was used as a case study for modelling and testing. A performance assessment function in the form of internal variables was also devised and computed for ON-OFF control. On an Indian Railway passenger coach, an air-cooling system with ON/OFF control was validated experimentally. The model and experiment produced rapid and stable responses for indoor air-specific humidity and dry-bulb temperature. When compared, the writers found the model easy to use based on what they knew about the system and how it worked. This is because it only requires the solution of a set of first-order ordinary nonlinear differential equations. Using nonlinear control theory, this model could also be used to make a feedback controller.

Showed transient characteristics of split air conditioners using R-22 and R-410A refrigerants. The system simulation model includes the compressor, capillary, condenser, and evaporator sub-models [13]. Using the implicit finite difference technique, the condenser and evaporator were simulated over space and time using continuity, momentum, and energy equations. Although the study compares transient pressure response with smooth tubes, both heat exchangers were believed to be built of micro fin tubes. The author's used-acceptable correlations to calculate the two-phase heat transfer coefficients, liquid vapors slip, and friction factors. A simulation program in the MATLAB (Math Works 2004) environment has been built and coupled with REFPROP for refrigerant characteristics. According to the created model, the transient characteristics of the split air conditioner employing R-22 and R-410A were pressure, temperature, and mass flow response. A psycho-meter test on a split air conditioner was used to evaluate the temperature response, and published experimental data was used to confirm the pressure response. The transient pressure response of a split air-conditioning system utilizing micro fin tubes was initially compared to that of a smooth tube system. Micro fin tubes' discharge and suction pressure responses were around 15 times quicker. The transient properties of R-22 and R-410A refrigerants for the split air conditioner employing micro fin tubes were compared thoroughly. Although the suction pressure response for both refrigerants is comparable, the discharge pressure for R-410A reaches the steady-state value 35 seconds later than R-22. R-410A condensing temperature was determined to be 2.7°C (36.86°F) lower than R-22 (for the same size condenser). The pressure drops in the condenser and evaporator for R-410A were smaller than those for R-22. The total transient loss at start-up for the R-410A system was determined to be 18.5% and 18.7% for the R-22 system, respectively. The transitory loss caused by refrigerant migration is reduced in the R-410A system.

The authors proposed that optimizing the sizes and designs of heat exchangers might decrease transient losses.

2.3 RESEARCH GAPS

1. Limited research on comparing inverter and non-inverter ac in the context of power usage and CO2 emissions reduction: The text briefly mentions the study by Ahmed Almogbel et al. (2020) . Comparing inverter and non-inverter ac, it needs to analyse existing research in this area comprehensively. Further investigation and analysis of the energy-saving potential and environmental benefits of inverter technology compared to non-inverter technology would be valuable.

2. Lack of research on the impact of blockages on automotive air conditioning system performance: The study by D. Prasad et al. (2014). It focuses on the steady and moving states of a vehicle air cooling system, but it does not extensively explore the effects of blockages on system performance. Investigating the impact of different blockage types and percentages on the efficiency and effectiveness of automotive air conditioning systems would provide valuable insights for improving their performance.

3. Insufficient research on the use of (R32) as a multi-stage refrigerant: The text mentions the study by H. V. Sihombing et al. (2020). On the effectiveness of a multi-stage refrigerant, it does not delve into the existing research gaps in this area. Further exploration of the potential advantages and challenges associated with using R32 as a multi-stage refrigerant, including its impact on system performance and energy efficiency, would be beneficial.

4. Limited research on the efficiency of different motor-drive combinations in AC fan motor systems: The study by M. A. Hassan et al. (2015) briefly compares the efficiency of trapezoidal and sine wave drive systems for BLDC motors AC fan motor systems. However, there is a need for more comprehensive research comparing various motor-drive combinations, exploring their efficiency, energy consumption, and overall performance in air conditioning applications.

5. Inadequate research on optimising heat transfer in air conditioning systems using different fin configurations: The text mentions L. Prabhu et al.'s (2018) . Paper on the thermal analysis of fins in heat transfer systems. However, there needs to be more research in investigating and optimising heat transfer in air conditioning systems by considering different fin shapes, sizes, and configurations. Further research could provide insights into enhancing air conditioning systems' heat dissipation and efficiency.

6. Limited research on consumer behavior and preferences influencing the purchase of air conditioners: The study by M.N. Artha et al. (2019) . Briefly addresses the influence of demographic factors on consumers' buying decisions for air conditioners. However, more comprehensive research is needed to understand the complex factors influencing consumer

preferences, such as noise level, power consumption, user-friendly interfaces, brand names, price, CO2 emissions, and additional features like Wi-Fi connectivity. Understanding these factors would help manufacturers and policymakers tailor their products and strategies to meet consumer demands effectively.

7. Insufficient study on how natural clogging substance affects room air conditioner performance and air quality: The study by A. H. Ali et al. (2008) . Examines the influence of clogging substances on the performance of room air conditioner units but does not explore the potential health concerns related to indoor air quality resulting from such fouling materials. Further research is needed to assess fouling material's health implications and long-term effects on indoor air quality and to develop strategies for maintaining cleaner and healthier evaporator coils.

2.4 MOTIVATION AND OBJECTIVES FOR THESIS WORK:

The identified research gaps in air conditioning systems present significant opportunities for further exploration and advancements. Addressing these gaps through a comprehensive thesis work can contribute to a better understanding of air conditioning technologies and their potential for improving energy efficiency and reducing environmental impact. The primary motivations for this thesis work are:

1. Comparison of Inverter and Non-Inverter AC: The limited research on the comparison of inverter and non-inverter AC in terms of power usage and CO_2 emissions reduction highlights the need for a comprehensive analysis in this area. This thesis work aims to bridge this research gap and conduct an in-depth investigation into the energy-saving potential and environmental benefits of inverter technology compared to non-inverter technology. The objective is to provide consumers, manufacturers, and policymakers valuable insights to make informed decisions about ac systems that promote save energy and environmental sustainability.

2. Impact of Blockages on Automotive AC Systems: The lack of research on the impact of blockages on automotive air conditioning system performance presents an opportunity for further exploration. The motivation for this thesis work is to study the effects of different blockage types and percentages on the efficiency and effectiveness of automotive AC systems. By understanding the implications of blockages, the objective is to improve the performance and reliability of automotive air conditioning systems, ultimately enhancing user comfort and reducing energy consumption.

3. Use of R32 as a Multi-Stage Refrigerant: Insufficient research on the use of R32 as a multi-stage refrigerant for a deeper investigation into its potential advantages and challenges. The motivation for this thesis work is to explore the effectiveness of R32 as a multi-stage

refrigerant and assess its impact on system performance and energy efficiency. By addressing the existing research gaps, the objective is to contribute to the development of more efficient and environmentally friendly refrigeration systems.

4. The Efficiency of Different Motor-Drive Combinations in Air Conditioner Fan Motor Systems: The limited research on the efficiency of different motor-drive combinations in air conditioner systems necessitates further examination. This thesis aims to compare various motor-drive combinations and analyze their efficiency and energy consumption in air conditioning applications. The objective is to identify the optimal motor-drive configurations that promote energy efficiency and performance in air conditioner systems.

5. Optimizing Heat Transfer in Air Conditioning Systems using Different Fin Configurations: The inadequate research on optimizing heat transfer in air conditioning systems with different fin configurations presents an opportunity for improvement. The motivation for this thesis work is to investigate and optimize heat transfer in air conditioning systems by considering various fin shapes, sizes, and configurations. The objective is to enhance air conditioning systems' heat dissipation and overall efficiency, leading to improved cooling performance and reduced energy consumption.

6. Consumer Behavior and Preferences in Air Conditioner Purchase: The limited research on consumer behavior and preferences influencing the purchase of air conditioners highlights the need for a comprehensive understanding of consumer preferences. The motivation for this thesis work is to delve into the complex factors influencing consumers' buying decisions, such as noise level, power consumption, user-friendly interfaces, brand names, price, CO2 emissions, and additional features like Wi-Fi connectivity. The objective is to provide insights to help manufacturers and policymakers tailor their products and marketing strategies to meet consumer demands effectively.

7. Impact of Natural clogging substance on Air Conditioner Performance and Indoor Air Quality: Insufficient research on the impact of natural clogging substance on the performance of RAC units and indoor air quality emphasizes the importance of further investigation. The motivation for this thesis work is to assess the health implications of fouling material and its effects on indoor air quality. The objective is to develop strategies for maintaining cleaner and healthier evaporator coils, ensuring better air quality and efficient air conditioner operation.

The thesis work aims to conduct comprehensive research in these areas, identify innovative solutions, and propose practical recommendations for enhancing air conditioning system performance, energy efficiency, and environmental sustainability. The findings and insights from the thesis work can be valuable for the industry, policymakers, and researchers, ultimately contributing to a more sustainable and efficient air conditioning technology landscape.

CHAPTER 3: EXPERIMENTAL METHODOLOGY

Any equipment's test standards give information on the corresponding nation's general efficiency levels (and other market indicators). As described in Chapter 1, India uses BEE's star branding program to control RAC efficiency standards. Similarly, several nations have labelling schemes to govern the RAC market in their own countries. The chart below summarises RAC standards in Asian nations with a dominating RAC market. These countries were chosen because they are the primary global supply sources for technologies and goods worldwide.

Table 4 Indian And International Test Standard For RAC

Country	Standard	Efficiency Matrix	Temperature Range	Operation hrs.	Label	Test method
India	IS 1391 part 1 and part 2	ISEER	24-43°C	1600	1 to 5 stars (5-star is best)	Enthalpy Calorimetric
China	GB 12021.3 for fixed-speed ACs GB 21455 for •variable speed ACs	SEER-cooling Only Product APF-Heat Pump	24-38°C	1,136	(1 to 3) Three grades-Grade 1 best	Air Enthalpy Calorimetric*
Japan	JISC 9612	Annual performance factor(APF)	24-38°C	1,569	1 star to 5 stars (5-star is best)	Air Enthalpy Calorimetric*
Europe	EN 14511:2013	(SEER) for cooling only(SCOP) for heating / cooling products	17-40°C	2602	A+++, A++, A+, A, B, C, D, E, F, G (A+++ is the most efficient).	Air Enthalpy Calorimetric
South Korea	KSC 9306	(CSPF) is used for cooling only products. (CSPF) and (HSPF) is used for reversible type products	24-38°C	941	5 to 1 grade (grade 1 is best)	Air Enthalpy Calorimetric*

The following standards, resources, and research papers were utilized and followed in completing this work and are therefore indicated. Because this was a development-based project conducted in an industry, Indian and international standards were generally followed. LG Electronics' internal materials were analysed for calculations and the selection of performance components and concepts explicitly produced for the model designed.

3.1 INTERNAL STANDARD

Cycle Design and Simulation An internally provided training material for cycle engineers explaining how calculations select the cycle components and how tests are conducted, which validate the measures. It covers the calculation process of thermal load, the cycle parts calculation process, and their performance verification test.

Product Standards are developed for each model independently, as with our models. It includes every element of the model, including measurements, new features, and modifications to existing parts. Except for testing information, it provides every aspect of the machines included.

Design Standard Design standard is similarly made for each model individually. It contains details of the tests the model needs to undergo during its development. Test details include 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.

3.2 AIR CONDITIONER TESTING STANDARDS IN INDIA

The 2001 Energy Conservation Act serves as the foundation for the Indian Standards and Labelling (S&L) project . "The Bureau of Indian Standards" (BIS) is India's National Standard Body responsible for equipment standardisation, labelling, and quality certification. IS 1391 was developed by BIS for RACs and is divided into two parts:

- Part 1 of IS 1391: 1992 Specifications for RAC: Part 1 Unitary (Window) AC
- Part 2 of IS 1391: 1992 RAC Specifications: Part 2 Split AC

IS 1391 (Parts 1 and 2) describes the design and performance standards for RACs. It also describes the test conditions and processes for determining the various performance characteristics of RACs that function without frost while cooling and dehumidifying at standard rating values.

These are summarised in the table below. The cooling capacity and power consumption tests, among others, are crucial in assessing RAC performance. They are discussed in the next section.

Table 5 IS 1391 Tests

TESTS	Product testing on produced goods (Mass Production AC Machine)	Qualifying testing (Production routine testing may be done at the purchaser's request)
Cooling Ability test Power input test Maximum operating (high Voltage and Current) test Freeze up testing. Enclosure sweat testing. Energy consumption test Safety Condensate test Noise Test Heating capacity test	•General running Performance •Pressure drop or leakage test •Insulation resistance checkup •High voltage Condition Test •Leakage current (I) test •Earthing resistance test	•DBT of return air •DBTof supply air • I (current) consumption •Total Electric power used •Leakage test

3.3 PERFORMANCE TEST

Some of the essential tests for RAC performance include cooling capacity, power consumption, and ISEER Calculation. The term "cooling capacity" refers to the total quantity of sensible heat and latent heat that is eliminated from the conditioned space in a particular period. The test settings for cooling capacity and power consumption are shown in Table 6.

Table 6 Cooling Ability and Energy consumption test condition

Test	Temperature	Room air temperature	Outside air temperature
Cooling Ability and Energy consumption test condition	DBT	27°C	35°C
	WCT	19°C	24°C

The maximum energy consumption amounts that an air conditioner may not exceed are also specified in IS 1391 Part 2; these values are given in Table 7:

Table 7 Maximum power consumption

Rated Cooling Capacity (Ton)	Maximum Energy Consumption (kW)
0.5	1.0
0.8	1.2
1.0	1.6
1.3	1.8
1.5	2.2
2.0	2.9
2.5	3.4
3.0	4.2

RAC performance is generally expressed in the following:

Energy Efficient Ratio (EER) - calculates how effectively a RAC will work at a given outdoor temperature. EER was used to determine RAC efficiency until 2015 (it became required in 2017), and the performance was tested at 35°C. The primary disadvantage of EER is that it does not account for RAC performance across temperature profiles. This equation may be used to compute the EER:

EER = cooling capacity / Input Power

In India, the "Indian Seasonal Energy Efficiency Ratio" (ISEER) is used for determining Performance efficiency in AC machines, as recommended by the BEE star labelling (S&L) project.

ISSER was started as an optional project from 2015 to 2017 and became compulsory in 2018. An evaluating methodology considers temperature variations and provides an efficiency value appropriately.

ISEER = (CSTL) / (CSEC)

Where: **CSES (Cooling Seasonal Energy Consumption)** – The total amount of Electric Power consumed by the device each year when it is put into its operational state and used for cooling purposes.

Cooling Seasonal Total Load (CSTL) – The total value of heat taken out of the room air each year when the device operates in cooling mode.

The evaluation procedure for ISEER is based on the bin hours of the national climatic zone, the bin temperature range of 24 to 43 degrees Celsius, and the annual operating hours of 1,600. Table 8 displays receptacle hours and temperature for each of them.

Table 8 Bin Hours Against Each Bin Temperature

Temperature (°C)	Average Annual Duration (hr)	% Share	Bin Duration (hr)
24	527	9.1	146
25	590	10.2	163
26	639	11.1	177
27	660	11.4	183
28	603	10.4	167
29	543	9.4	150
30	451	7.8	125
31	377	6.5	104
32	309	5.4	86
33	240	4.2	67
34	196	3.4	54
35	165	2.9	46
36	130	2.3	36
37	101	1.7	28
38	79	1.4	22
39	59	1	16
40	44	0.8	12
41	31	0.5	9
42	20	0.3	6
43	10	0.2	3
Total	5774	100	1600

The more stars an air conditioner has, the more efficient it is, which is measured by its ISEER number. The CSPF is measured at different temperature and bin hours, as shown in Table 8. This is used to figure out the ISEER number. The CSPF or ISEER measures the total amount of heat the system can take from the indoor space when it is cooling in its operational state to the total amount of electric power that the system consumes in the same period.

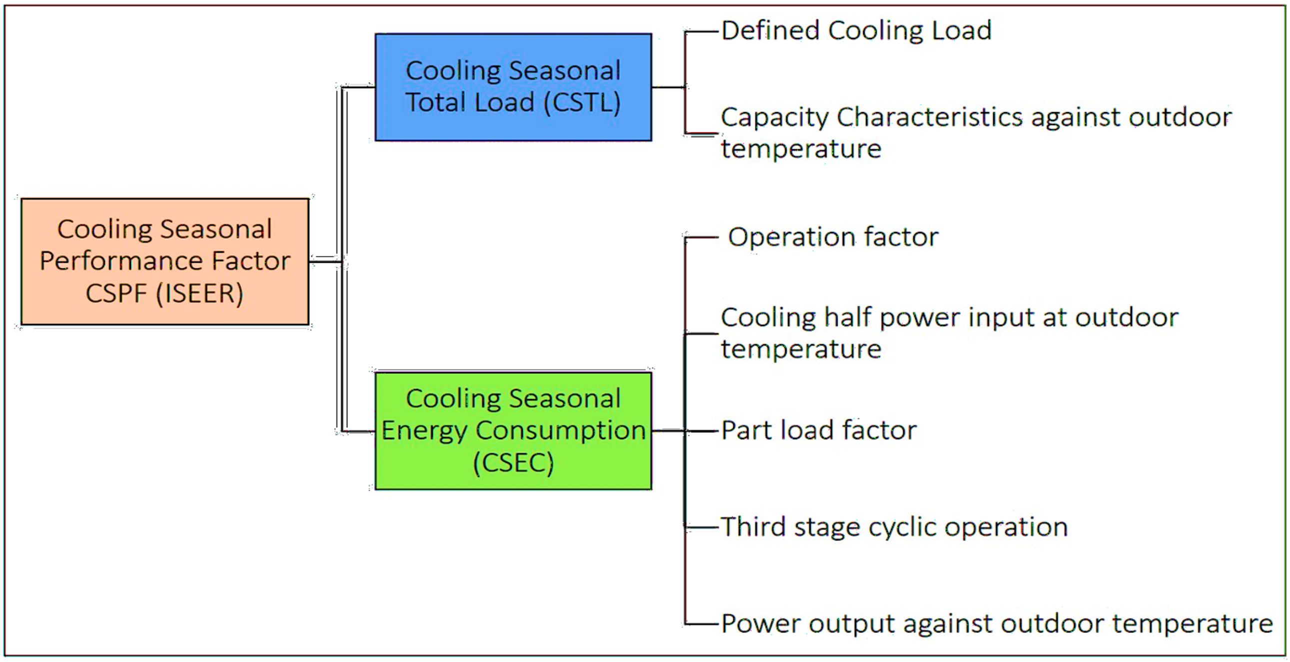


Figure 10. Calculating ISEER As Per ISO 16358-1

$$ISEER \text{ or } C_{SPF} = C_{STL}/C_{SES} \tag{3.1}$$

Where C_{STL} = cooling seasonal total load (CSTL) and

C_{SEC} = cooling seasonal energy consumption (CSEC)

Two sets of test data are required for CSPF computation and are-

Full and half cooling capacity operation at 35°C

Full and half Cooling capacity operation at 29°C

When used in ambient conditions, the equipment's capacity $C_{ful}(T_j)$ varies linearly with the temperature T_j. The testing facility or laboratory measures the capacity and power at 35°C and 29°C.

$$C_{ful}(T_j) = C_{ful}(35) + \frac{C_{ful}(29) - C_{ful}(35)}{35 - 29} \times (35 - T_j) \tag{3.2}$$

During operation, the equipment's power input $P_{ful}(T_j)$ changes linearly with the outdoor temperature T_j .

$$P_{ful}(t_j) = P_{ful}(35) + \frac{P_{ful}(29) - P_{ful}(35)}{35 - 29} \times (35 - T_j) \tag{3.3}$$

Following the completion of testing to establish capacity and power consumption at temperatures of 29°C and 35°C, respectively, we can now compute C_{STL} and C_{SES} at different times using the formulae that have been presented. To determine C_{STL}, first, add up the cooling load for each different outside temperature T_j, then multiply that total by the number of bin hours corresponding to that temperature.

$$C_{STL} = \sum_{j=1}^{m} C_L\left(T_j\right) \times n_j + \sum_{j=m+1}^{n} C_{ful}\left(T_j\right) \times n_j \tag{3.4}$$

Where ,$C_L(T_j)$ Is the computed cooling capacity at outdoor temperature T_j from the bin temperature distribution table:

$$C_L(T_j) = C_{ful}(T_{100}) \times \frac{T_j - T_0}{T_{100} - T_0}$$

Where:

$C_{ful}(T_{100})$ is the cooling load at T_{100} at full capacity operating conditioners and T_{100} is 35°C and $T_0 = 23$°C

Similarly, C_{SEC} is calculated as the sum of cooling power used at each outside temperature T_j.

$$C_{SEC} = \sum_{j=1}^{n} X\left(T_j\right) \times P_{ful}\left(T_j\right) \times \frac{n_j}{F_{pl}(T_j)} \tag{3.5}$$

Where: $X(T_j) = C_L\left(T_j\right)/C_{ful}\left(T_j\right)$; $F_{pl}(T_j)$ - Part load factor

Because the physical data at two temperature points are interpolated/extrapolated to calculate ISEER, time and resources are saved. The table summarises the testing required for calculating ISEER.

Table 9 ISEER Measurement Testing Conditions

Test	Characteristics	Fixed	Two-stage	Multi-stage	Variable stage	Default Value
Standard Cooling load (Indoor) Dry bulb – 27 °C Wet bulb – 19 °C (Outdoor) Dry bulb – 35 °C Wet bulb – 24 °C	Total Load Capacity (35 °C)	Mandatory	Mandatory	Mandatory	Mandatory	
	Total Load Power input (35 °C)					
	Half Load Capacity (35 °C)	N/A	N/A	Optional	Mandatory	$C_{half}(29)$ / 1.077
	Half Power input (35 °C)					$P_{half}(29)$ / 0.914

In the IS 1391 standard, there are two methods used to test cooling ability and power usage at different temperatures, which are :

Method for testing the heat balance of a room (Calorimeter Test) – A calorimeter can be either measured or adjusted to the atmospheric temperature. In the balanced ambient type, two walls separate the inside room area from the outside. The air between the walls is kept at the same dry bulb temperature as the inside room to reduce losses. The interior room chamber is divided by a single wall, and the outside area is calibrated.

The calorimeter test is based on the first law of thermodynamics, called the concept of Energy conservation.

Input Energy = Output Energy.

In An energy balance is maintained within the room throughout the calorimeter test. When the DB and WB have stayed steady for a required duration, the total of energy supplied to the room equals the cooling capability of the AC. This approach is very accurate and has a low mistake rate.

Enthalpy difference approach (Psychometric Test) - The air enthalpy technique measures the air enthalpy at the indoor air conditioner's input and output. The air conditioner's mass flow rate is also measured. The capacity of an air conditioner is derived by multiplying the enthalpy difference by the mass flow. This technique requires a less expensive laboratory and shorter testing times**.** **Tolerance limitations on performance tests:** The following tolerance limits are authorised in performance testing:

- The standard cooling must be at least 95% of the rated value while operating at total capacity.
- The measured standard cooling shall be 5% of full load capacity at 50% of total capacity.
- Standard cooling power consumption at full capacity shall not exceed 5% of the rated value.
- At 50% total capacity, the observed power consumption for conventional cooling must not exceed 10% of the rated power consumption.
- The measured energy usage must not exceed 5% of the rated amount.
- The ISEER for each unit tested must be more than 95% of the rated value.

3.4 EXPERIMENTAL SETUP AND CALCULATION

The testing facility described here is explicitly designed to measure room air conditioners' cooling and heating capacity with high precision and is NABL certified. It consists of two compartments, one on the IDU side and the other on the ODU side, and each of these compartments is equipped with re-conditioners.

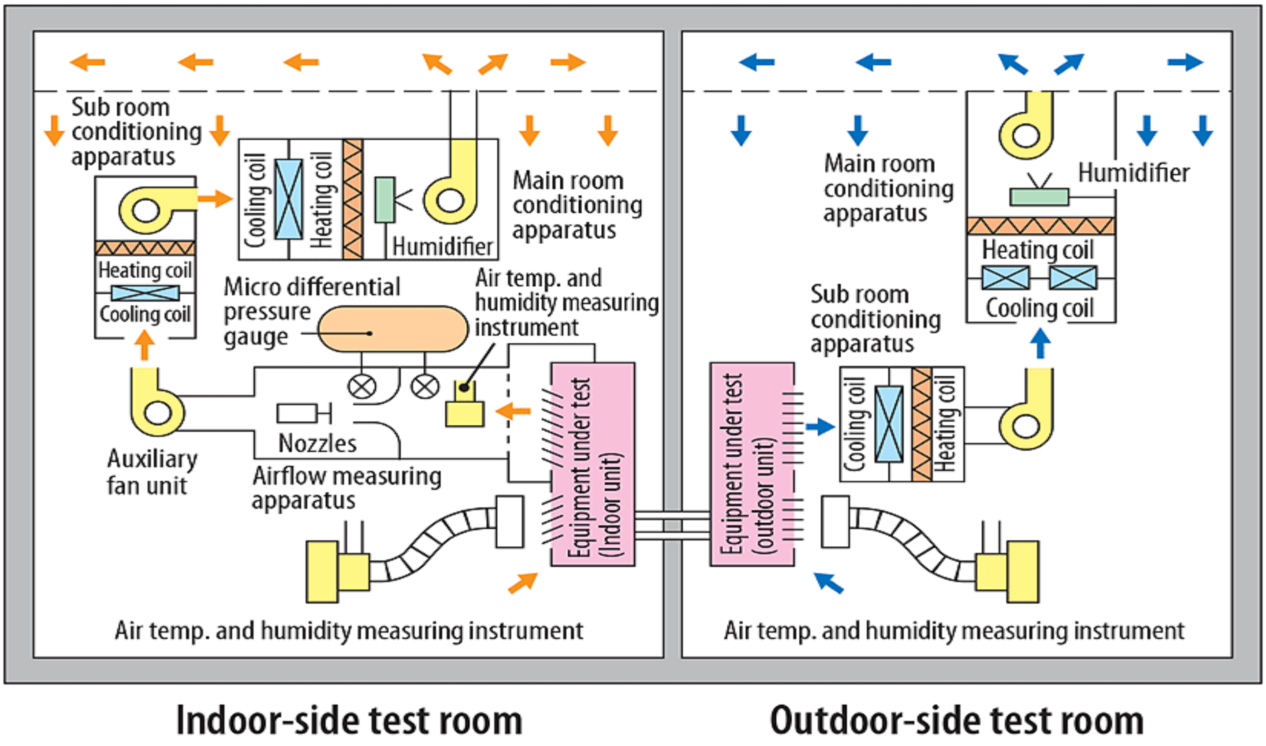


Figure 11. Schematic Layout of Air Conditioning Testing Lab [21]

These re-conditioners play a crucial role in nullifying the cooling or heating capacity of the air conditioner under test.

To ensure consistent and stable testing conditions, the facility adheres to conditions for controlling humidity levels in indoor and outdoor compartments. Furthermore, the humidity within the controlled-temperature air space of each compartment is adjusted to match the specific humidity requirements.

The facility is already equipped with the necessary information about the conduction heat flux. Combining this information with the re- conditioner's stable operation makes it possible to accurately determine the cooling and heating capacity of the room air conditioner being evaluated. The testing facility offers a measurable range for cooling capacity between 0.9 kW and 11.6 kW, while the heating capacity can be measured within a range of 0.9 kW to 12.8 kW.

This testing facility provides a meticulously controlled environment to assess and evaluate the room air conditioner’s cooling and heating performance, ensuring precise measurements within the specified capacity ranges. The main equipment of the lab facility is explained below.

3.5 AIR HANDLING EQUIPMENT

Air handling equipment comprises components that work together to ensure optimal temperature and humidity control in indoor spaces. Electrical heaters increase the air temperature, steam humidification adds moisture, fan motors circulate the air, cooling coils provide cooling, and dehumidification equipment reduces humidity levels. Understanding the functions of these components is vital for designing and maintaining effective HVAC systems that provide comfort and healthy indoor environments.

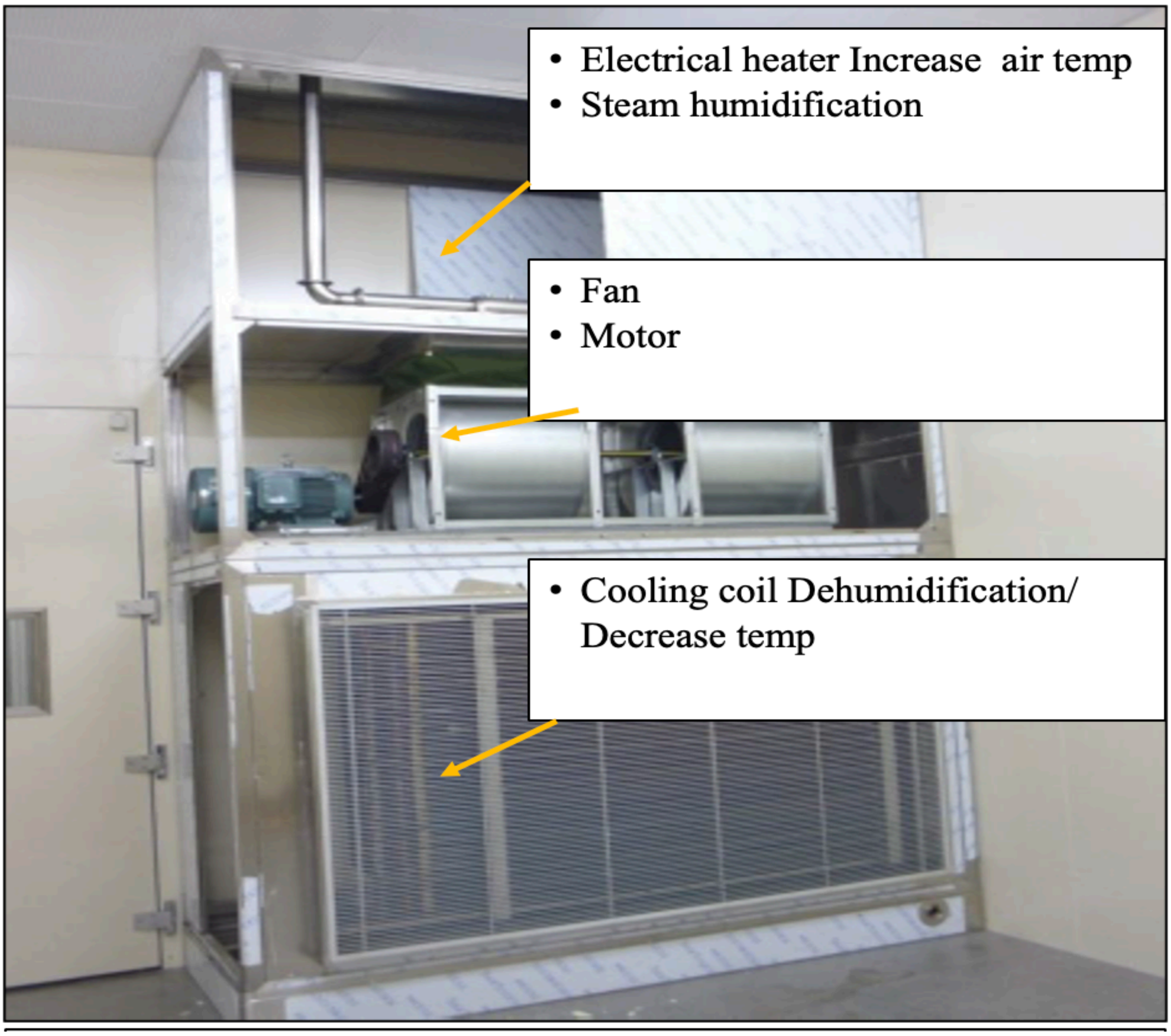


Figure 12. Air Handling Equipment

3.6 AIR FLOW RATE MEASURING EQUIPMENT.

Maintaining the appropriate airflow velocity and pressure drop across the nozzle throat is crucial in air-handling measuring systems. The recommended airflow velocity should be within the range of 15 to 35 m/s. The pressure drop across the nozzle throat should ideally be around 490 Pa. However, the acceptable range is typically between 174 and 784 Pa. Achieving these parameters requires careful selection of the nozzle throat diameter and corresponding air flow rate. The system can efficiently regulate air velocity and pressure by adhering to these guidelines, ensuring effective air handling while meeting standard requirements.

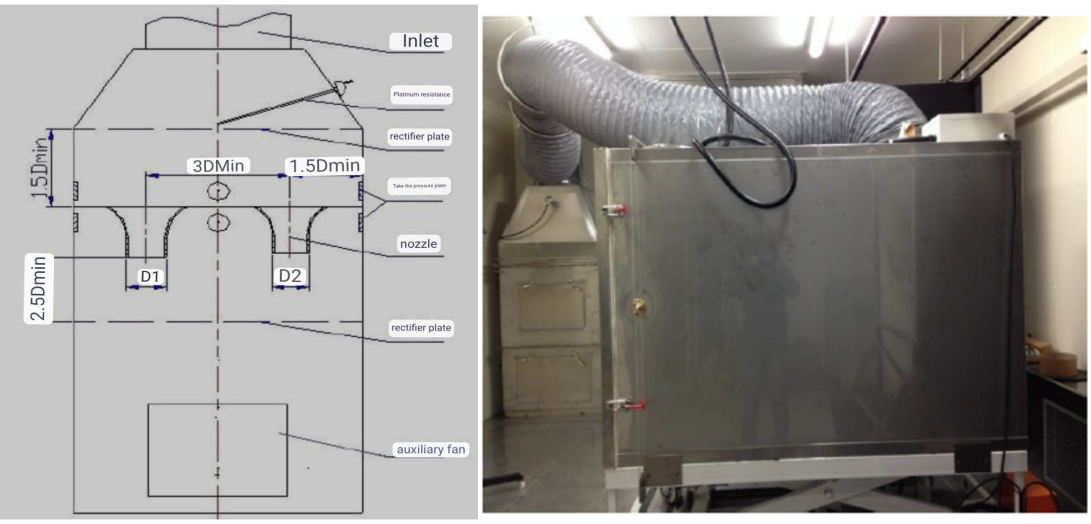


Figure 13. Schematic layout and view Air flow rate measuring equipment.

Table 10 Nozzle diameter and flow

Nozzle Throat Diameter (mm)	Flow Rate Range (m^3/hr)
Ø50	106~247
Ø70	208~485
Ø80	271~663
Ø100	424~990
Ø110	513~1197
Ø150	954~2227
Ø190	1515~3535

Air volume flow rate calculation

$$Q_{mi} = 1.414 \times C_d \times A(1000\Delta P \times V). \tag{3.6}$$

Where,

Q_{mi}– air flow rate, m3/s
C_d– flow coefficient of nozzle,
A– nozzle cross-section area, m^2
ΔP– pressure drop between nozzle inlet and outlet, Pa
V– moist air specific volume,m^3/kg

3.7 AIR TEMPERATURE/HUMIDITY SAMPLING DEVICE

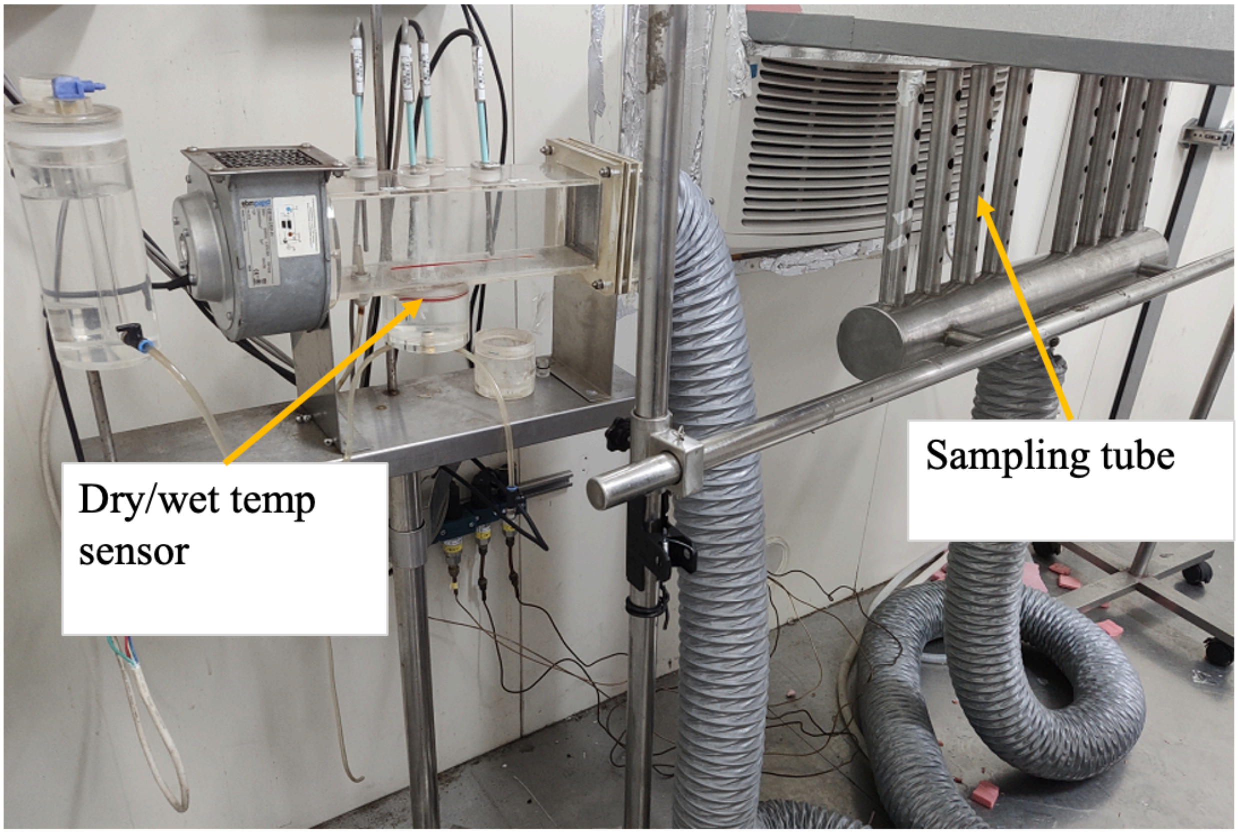


Figure 14. Air Temperature/Humidity Sampling Device

In air conditioning tests, accurate air temperature and humidity measurements are reached by positioning the sampling tube upstream of the air conditioner's inlet airflow. It ensures that the measurements are taken before the cooling or heating process influences the air. Several factors affect measurement accuracy. The thermometer used should be calibrated and precise to provide reliable temperature readings. Maintaining a consistent airflow velocity of 5 m/s through the gauze is crucial. The distance between the sampling tube and the air conditioner should be 150 mm on the IDU side and 600 mm on the ODU side to capture the actual conditions. Uniform airflow distribution across the sampling area is vital to minimise localised variations. Changing the gauze and using purified water before each test is essential to maintain accuracy and prevent contamination. Purified water with an electric conductivity range of 0 to $2\text{x}10^{-4}$ s/m is recommended to avoid interference with humidity measurements. Overall, careful attention to these factors ensures accurate air temperature and humidity measurements in air conditioning tests.

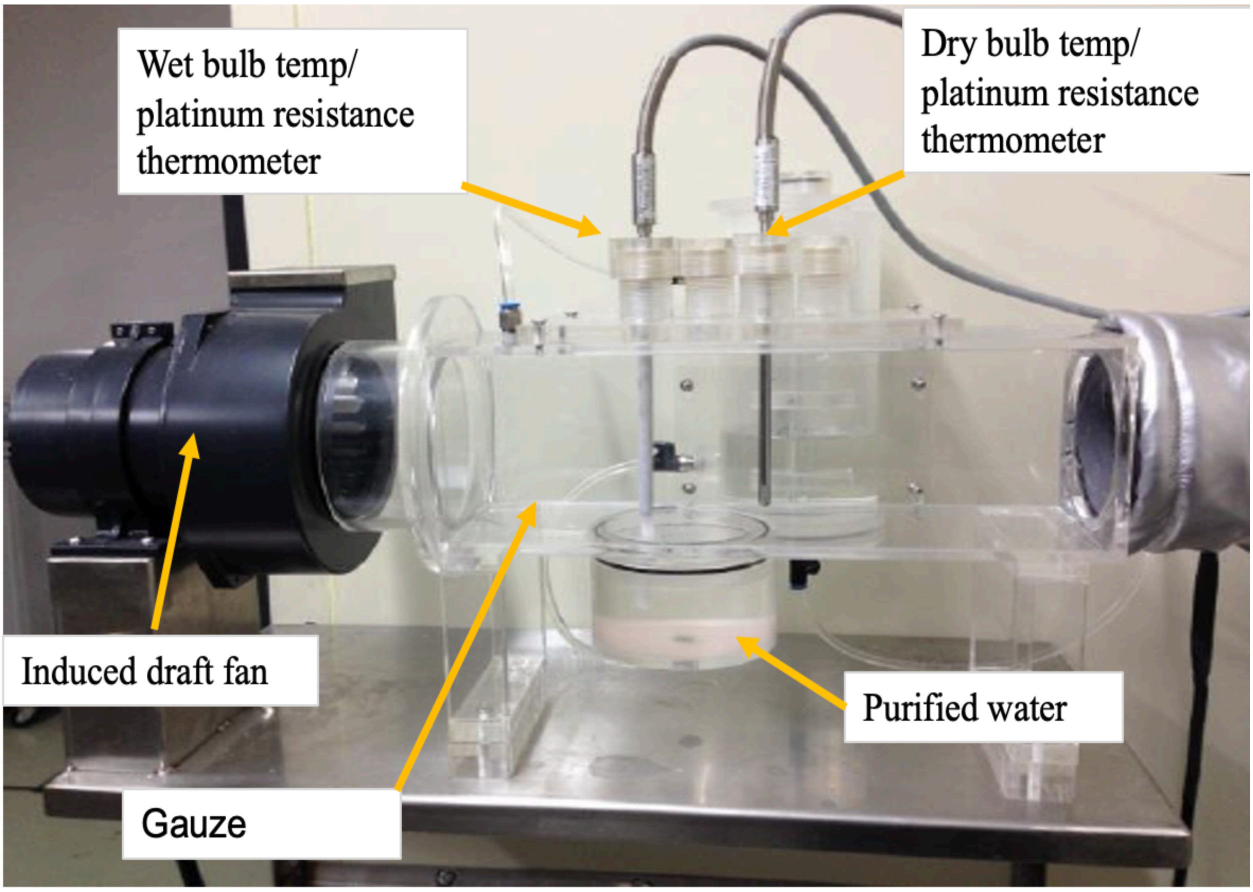


Figure 15. Testing Room Temperature /Humidity Sampling Device

3.8 TOTAL CAPACITY CALCULATION

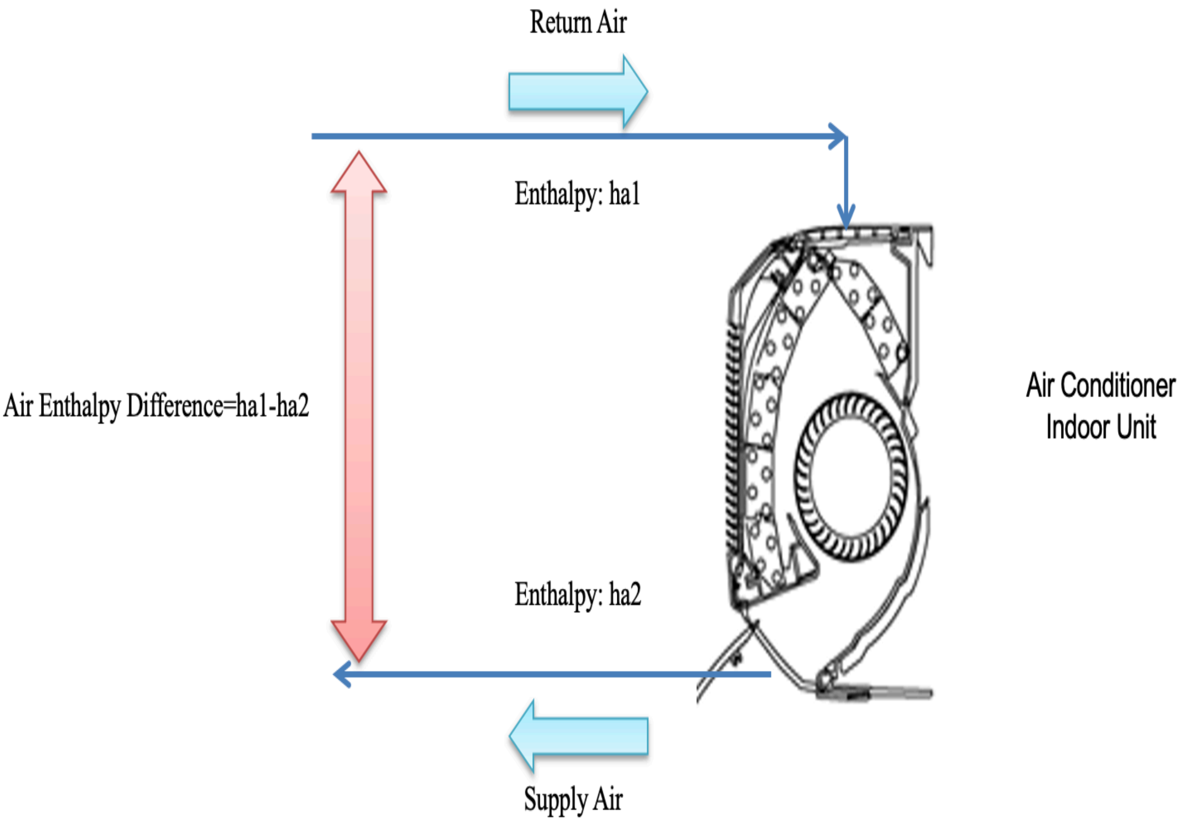


Figure 16. Enthalpy Difference

Cooling Capacity = (Refrigerant Mass Flow Rate) X (ha_1-ha_2)

Where : Enthalpy Difference Between Evaporator Outlet And Inlet = (ha_1-ha_2)

Total Cooling Capacity

$$Q_{tci} = Q_{mi} \times \frac{ha_1 - ha2}{[V \times (1+W)]} \tag{3.7}$$

Where,

Q_{tci}– measured inside total cooling capacity, Watt.
Q_{mi}– air flow rate, m^3/s
ha_1– return Air enthalpy, J/kg
ha_2– supply Air enthalpy, J/kg
V– moister air specific volume,m^3/kg
W– moister air humidity, kg/kg

Sensible Capacity Calculation

$$Q_{sci} = Q_{mi} \times \frac{Cp_a(t_{a1} - t_{a2})}{[V \times (1+W)]} \tag{3.8}$$

Where,

Q_{sci}– sensible capacity, Watt
Q_{mi}– air flow rate, m^3/s
Cp_a– specific heat at constant pressure,
t_{a1}– return Air temperature, °C
t_{a2}– supply Air temperature, °C
V– moister air specific volume,m^3/kg
W– moister air humidity, kg/kg

Latent Capacity Calculation

$$Q_{lci} = K_1 * \frac{Q_{mi}(W_{l1} - W_{i2})}{[V * (1+W)]} = Q_{tci} - Q_{sci} \tag{3.9}$$

Where,

Q_{lci}– latent capacity, Watt
K_1– latent heat of evaporation for water at 15°C, $2.47X10^6$, J/kg
Q_{mi}– air flow rate, m3/s
ta_1– return Air temperature, °C
ta_2– supply Air temperature, °C
V– moister air specific volume, m^3/kg
W– moister air humidity, kg/kg

Additional Measuring Tools

Table 11 Measurement Equipment for RAC Testing

Parameter	Sensor Type	Positioning	Accuracy
Temperature (°C)	T type thermocouple a) Surface Thermocouple	a) Intermediate tube surface b) Immediately before and after main components c) Duct inlet and outlet	±0.5°C
Condenser and evaporator Pressure (Bar)	Bourdon-tube Pressure gauge/ pressure transducer	Compressor Inlet and Compressor Outlet tube	±2.0 %
Condenser Pressure Drop (kPa)	Pressure Differential Transmitter	Pressure on the side of the condenser	±1.0%
Relative humidity	Humidity sensor	Evaporator duct	±2.0%

CHAPTER 4: ANALYSIS OF AIR CONDITIONING SYSTEM

Air cooling systems are a key part of making indoor spaces comfortable for various needs, whether for residential, commercial, or health-related purposes. These complex systems have various mechanical, electrical, and electronics components. These components interact with each other, allowing the exchange of thermal energy throughout the system. Over the years, numerous air conditioning configurations have been developed, and how these components are significantly interconnected influences the system's performance.

"To build a new Air-Conditioning model", the first essential step is calculating the cooling load. This process helps determine the size and capacity of the system's performance elements. While choosing pre-existing parts that fit the desired outcome may seem ideal, it often involves back-calculation based on the required results in practice. Standards and simulation software are used for cooling load calculations, ensuring the system meets the desired performance and efficiency criteria.

The integration and compatibility of the components in an air conditioning system are crucial. Each component serves a specific function, and various parameters affect its behavior. The successful integration of these components ensures smooth operation, high-quality performance, and overall air conditioning system efficiency. By following the appropriate processes and calculations, engineers can design and build effective and reliable air conditioning models that meet the diverse needs of users. The procedure is as follows.

4.1 HEAT EXCHANGER OVERVIEW

One of the crucial parts of an air conditioner is a heat exchanger. In an indoor/outdoor unit, it exchanges heat with a refrigerant; in an outdoor unit, it does the same with outside air and refrigerant.

Figure 17. Indoor/Outdoor Heat Exchange

In the AC system, the idu and odu heat exchangers have different lengths, with the indoor heat exchanger typically ranging from 600 mm to 800 mm and the outdoor heat exchanger ranging from 800 mm to 950 mm.

The heat exchanger is a fin-tube design, where a copper tube for the refrigerant enters an aluminium fin resembling an air plate.

Fin for heat exchange

Various types of fins have been utilized to improve heat exchange efficiency in the development of heat exchangers for air conditioning systems. The initial use of flat aluminium plate fins has evolved into adopting corrugated and slit fins with cut-out's, enhancing heat transfer capabilities. Further improvements were made to the slit shape of the fins, optimizing heat exchange performance. Additionally, efforts to equalize wind speed distribution across the heat exchanger by adjusting fin heights have improved overall heat exchange capacity. Manufacturers continuously refine fin designs, producing more efficient air conditioning systems with enhanced cooling performance and energy efficiency. These advancements in fin technology contribute to the overall effectiveness of heat exchangers, providing greater comfort and environmental benefits.

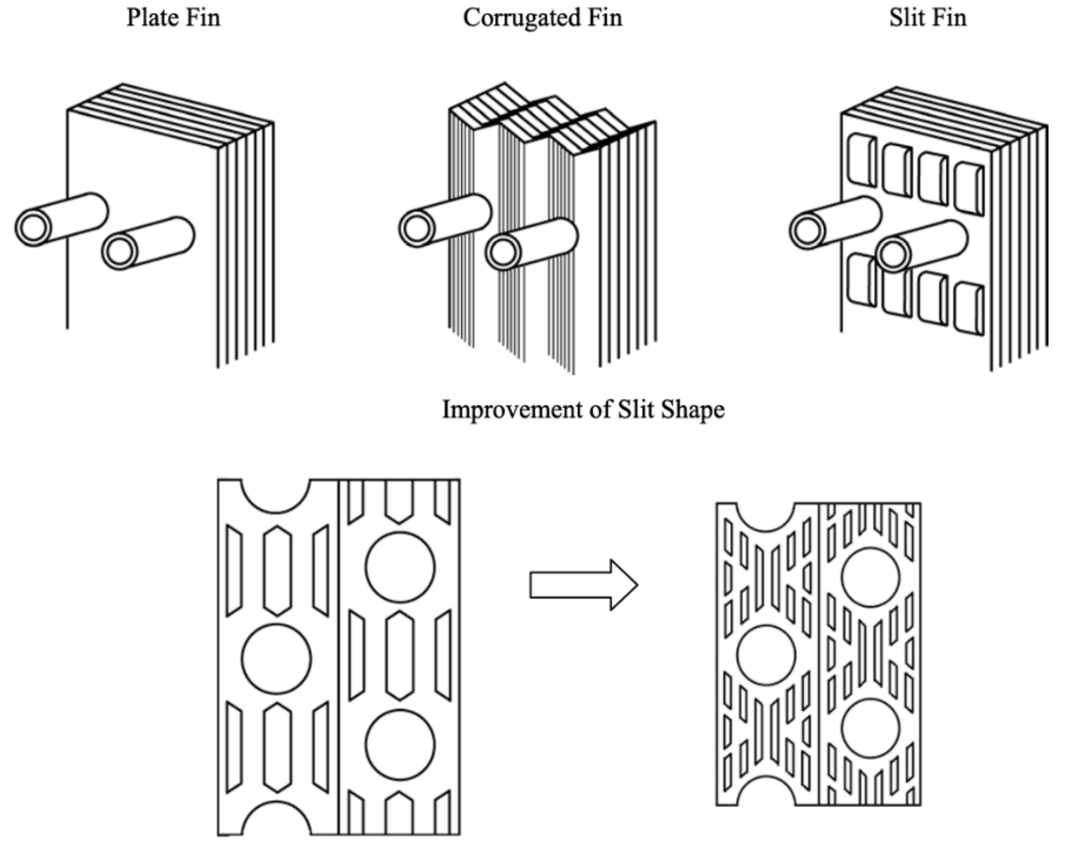


Figure 18. Types of Fins

Copper tube for heat exchange

Initially, a heat exchanger was made out of a completely smooth tube, and the inner surface was not treated in any way. In order to reduce power uses, a tube with an interior groove was designed, and further work was done to optimise the geometry of the groove for better heat exchange.

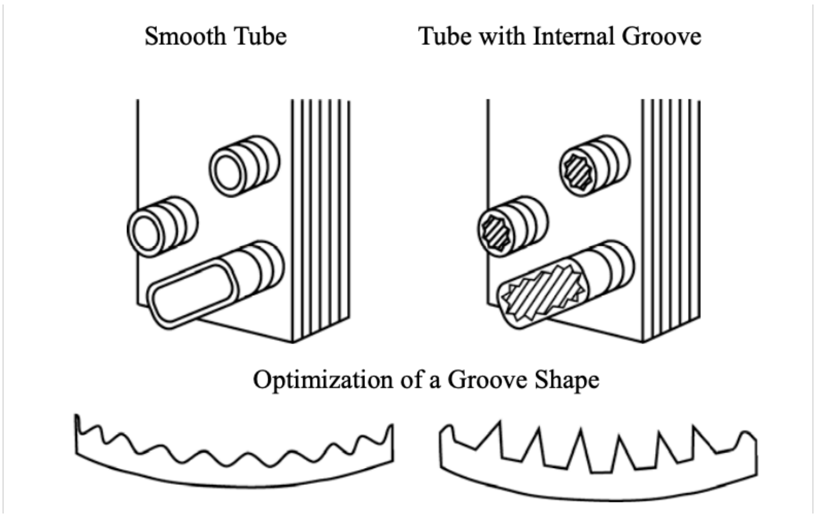


Figure 19. Tubing Design

4.2 COMPRESSOR

High-efficient compression technology is essential for optimizing air. The advancement of high-efficient compression technology in air conditioners has significantly improved compressor performance. Newer and more efficient methods, such as the twin rotary and scroll methods, have replaced traditional rotary compressors. These advancements primarily focus on reducing mechanical loss, achieved by enhancing manufacturing precision and employing control valves to optimize sticking force and minimize sliding loss in scroll compressors. Additionally, improvements in the shape of passages have reduced pressure losses during the suction and discharge processes. As a result of these innovations, air conditioners now achieve higher efficiency and cooling performance, leading to energy savings and improved system effectiveness.

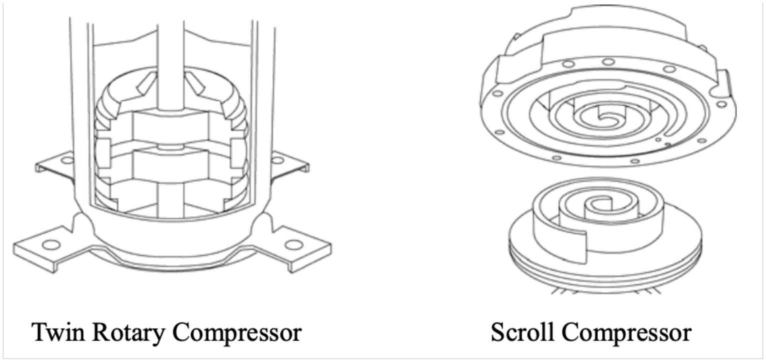


Figure 20. Compressor Types

4.3 PRODUCT CONSTRUCTION & DESIGN

Indoor Unit (IDU)

The indoor unit of an air conditioning system comprises several essential components that collaborate to deliver efficient cooling and proper air distribution. These components work in harmony to create a comfortable indoor environment.At the forefront, the front grill acts as the protective exterior panel of the indoor unit. It shields the internal components from external elements while allowing the free flow of air in and out of the unit. The evaporator assembly is a crucial component responsible for the cooling process. It consists of a coil through which a refrigerant flow. As room air passes over the coil, the refrigerant absorbs heat, cooling the air. This cooled air is then circulated back into the room. The control box houses the electrical components and controls of the indoor unit. Circuit boards, control panels, sensors, and wiring connections are housed within the control box. This control box enables user input and regulates the overall operation of the AC system.The motor assembly is another integral part of the indoor unit, comprising a fan motor and a blower fan. The fan motor powers the rotation of the blower fan, which is responsible for circulating the air within the indoor unit. The motor assembly maintains proper airflow and evenly distributes the cooled air throughout the room.

The decor assembly focuses on the aesthetic aspects of the indoor unit. It includes decorative panels, grilles, and other design elements that enhance the unit's appearance and blend harmoniously with the room decor.

These components provide adequate cooling, regulate temperature, control airflow, and create a visually appealing indoor unit. The front grill ensures protection, the evaporator assembly cools the air, the control box enables user control, the motor assembly facilitates air circulation, and the decor assembly enhances the unit's appearance.

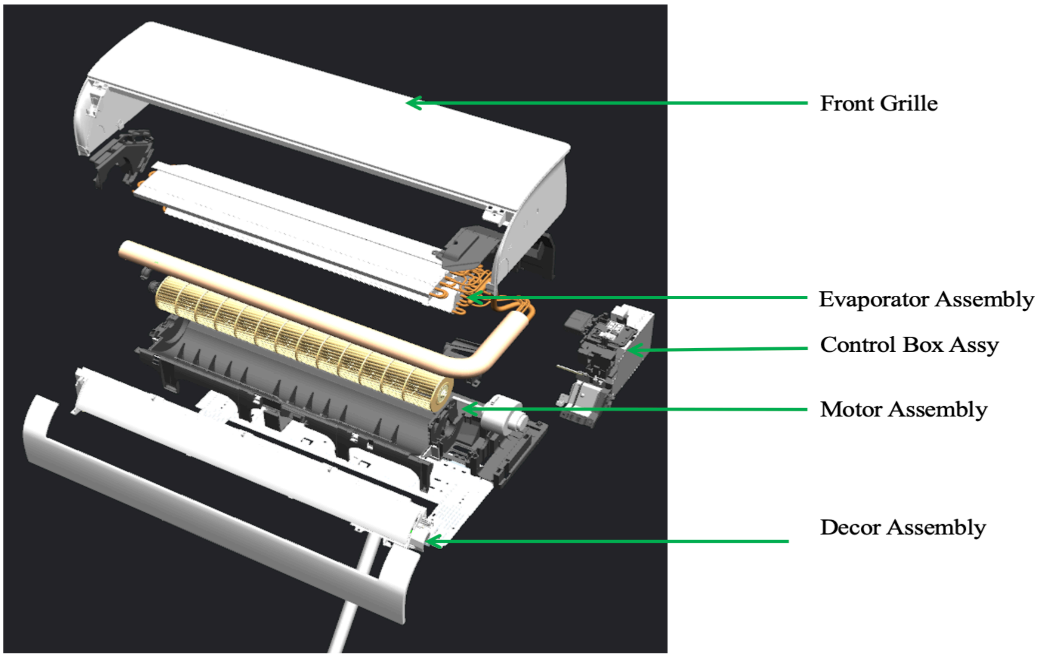


Figure 21. Indoor Unit Assembly

Outdoor Unit (ODU)

The outdoor unit of an AC system consists of several vital components that work together to facilitate the cooling process. These components include the top cover, condenser assembly, control box, compressor assembly, tubing cover, and base pan. The top cover is a protective casing for the outdoor unit, shielding it from external elements such as rain, debris, and UV radiation. The condenser assembly is a critical part of the outdoor unit that transfers heat from the refrigerant to the surrounding air. It comprises a network of coils and fins that facilitate efficient heat exchange, allowing the refrigerant to release heat and cool down. The control box contains various electrical components, including circuit boards and wiring connections. It serves as the command center for the outdoor unit, enabling communication and coordination between different parts of the AC system. The compressor assembly is a key component central to the cooling process. It compresses the refrigerant, increasing its pressure and temperature, and circulates it through the system. This process helps facilitate the heat transfer and cooling cycle.

The tubing cover encloses the refrigerant lines and connecting tubes, protecting them from external factors and ensuring proper insulation. It helps maintain the efficiency of refrigerant flow and prevents energy loss due to heat exchange with the surrounding environment. Finally, the base pan provides a stable foundation for the outdoor unit, supporting its weight and serving as a platform for installation. It also collects and drains condensate generated during the cooling process, preventing water accumulation and potential damage. Together, these components form the outdoor unit of an AC system, working in harmony to facilitate the cooling process and maintain a comfortable indoor environment.

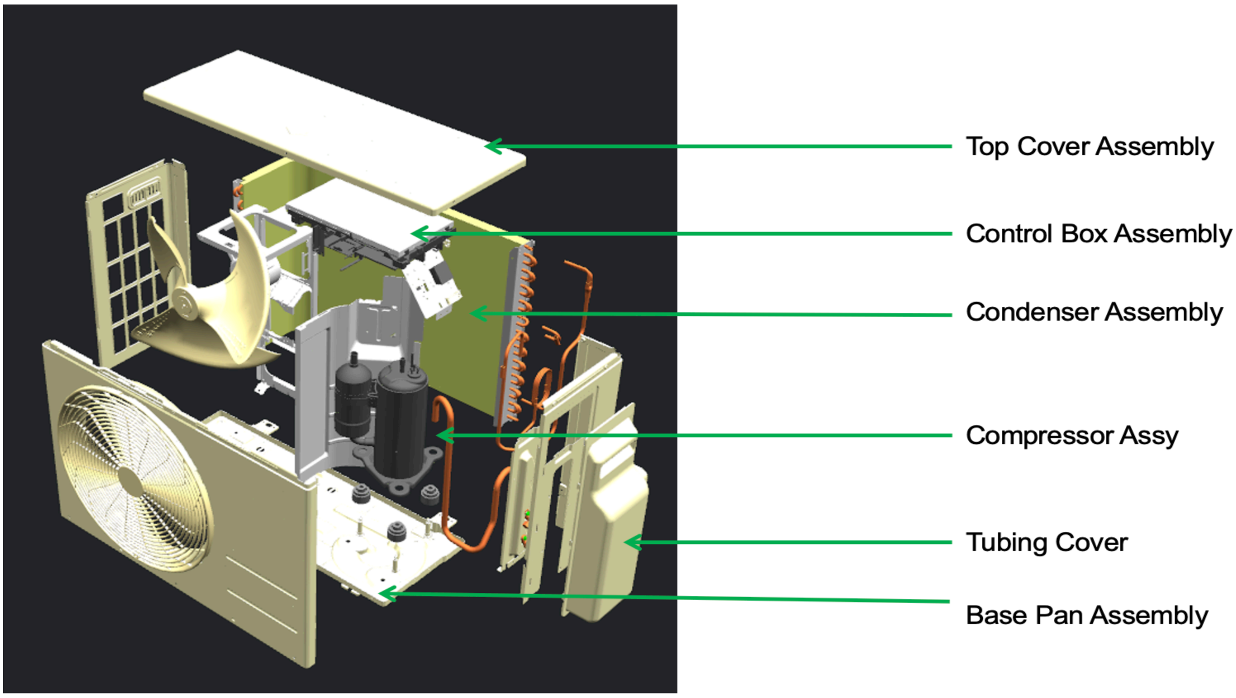


Figure 22. Outdoor unit (odu)

4.4 MAJOR PARTS FUNCTIONALITY

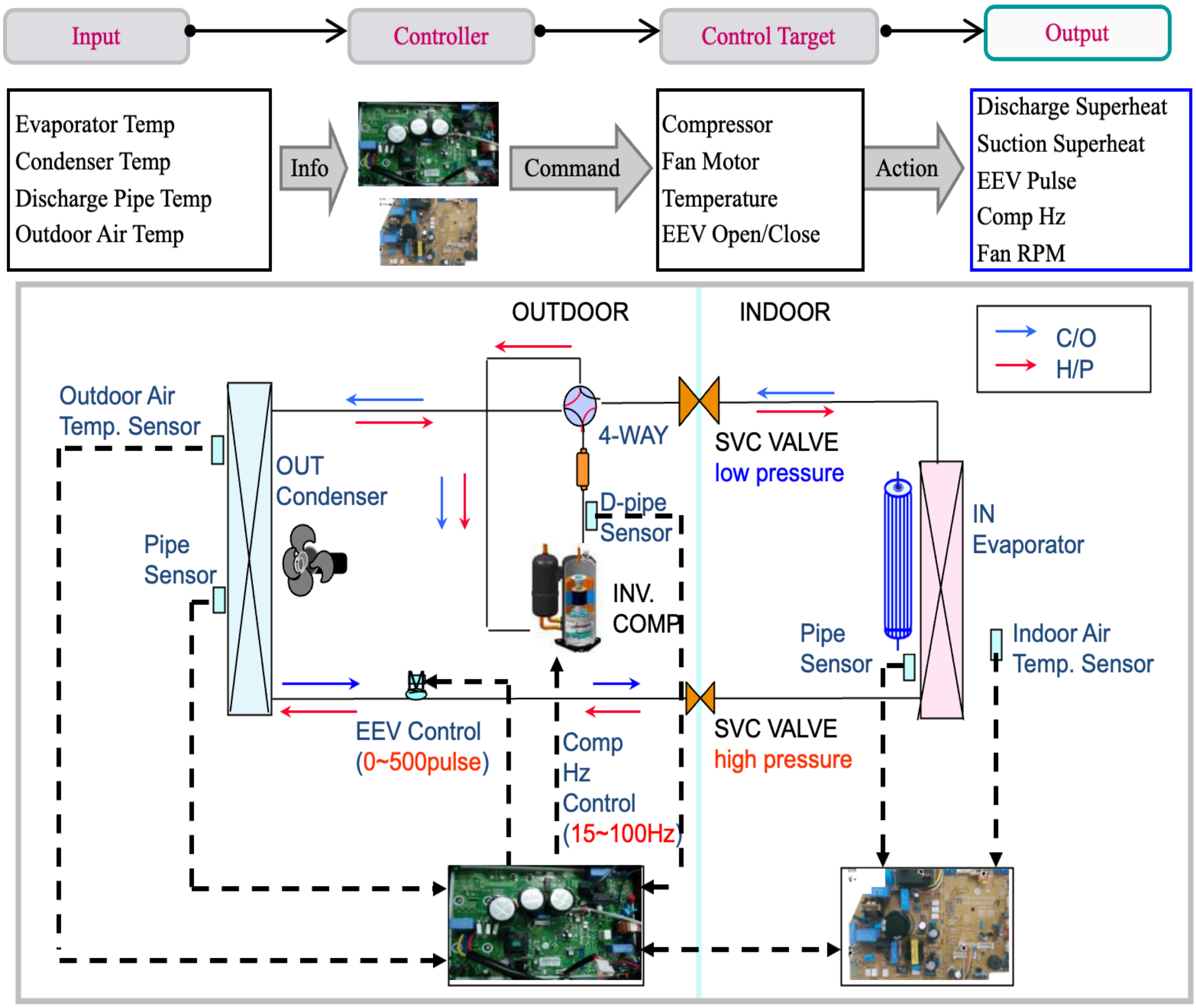


Figure 23. Major parts functionality

Step-by-Step Working of an Air Conditioner:

Input Parameters

- Evaporator Temperature: The refrigerant temperature in the evaporator coil indicates the cooling effect.
- Condenser Temperature: The condenser coil's refrigerant temperature reflects the heat dissipation process.
- Discharge Pipe Temperature: The temperature of the coolant as it exits the compressor, providing insight into the compression process.
- Outdoor Air Temperature: The outside air's temperature affects the overall cooling performance.

Controller

The controller in an air conditioner receives input from various sensors, including temperature sensors in the evaporator, condenser, discharge pipe, and outdoor air. It processes this data to determine the appropriate actions for achieving the desired indoor conditions.

Control Target

The control target of the air conditioner is to maintain the required temperature in the indoor space. The controller continuously monitors the input parameters and adjusts the operation of the system components to achieve the target conditions.

Output

The output of the air conditioner includes various components and actions:

- Compressor: The controller regulates the compressor based on the input parameters and control target. It adjusts the compression ratio to control the cooling ability and power input.
- Fan Motor: The controller controls the fan motor's speed to ensure sufficient airflow for heat transfer in the evaporator and condenser coils.
- Temperature: The controller maintains the desired temperature by modulating the cooling capacity through compressor and fan control.
- EEV (Electronic Expansion and Valve) Open/Close: The controller adjusts the opening or closing of the EEV to regulate the flow of coolant into the evaporator coil.
- Discharge Superheat: The controller monitors the discharge pipe temperature and adjusts the refrigerant flow to maintain the desired superheat value, ensuring optimal compressor performance.
- Suction Superheat: The controller regulates the refrigerant flow into the evaporator coil to maintain the desired superheat value, ensuring efficient cooling.
- EEV Pulse: The controller modulates the opening and closing of the EEV to control refrigerant flow and achieve precise temperature regulation.
- Comp Hz (Compressor Frequency): The controller adjusts the compressor's frequency (speed) to match the cooling demand and maintain the desired temperature.
- Fan RPM (Revolutions Per Minute): The controller regulates the fan motor's speed to control airflow and ensure efficient heat transfer in the evaporator and condenser coils.

CHAPTER 5: RESULT AND DISCUSSION

5.1 16K 5 STAR AC DEVELOPMENT

The sales department of LG submits a request to the Research and Development (R&D) department for the development of a new air conditioning (AC) model. The requested specifications include a 1.5-ton capacity and a 5-star rating under the requirements of the current market.

The term "Ton capacity" refers to the cooling capacity of an air conditioner and is commonly used to indicate the amount of heat an AC unit can remove from a room in one hour. In this context, a 1.5-ton capacity means the AC can remove 1.5 tons (or 18,000 British Thermal Units) of heat per hour, providing efficient cooling for a medium-sized room.

The "ISEER" rating measures an air conditioner's energy efficiency over a typical cooling season in India. It considers factors such as the energy consumed during operation, the cooling capacity, and the performance at different temperature levels. The more ISEER rating, the more energy-efficient the air conditioner is, resulting in lower electricity consumption and reduced environmental impact.

By requesting a new AC model with a 1.5-ton capacity and 5-star rating, the sales department of LG aims to meet the market demand for an energy-efficient air conditioner that provides effective cooling for customers.

“Bureau of Energy Efficiency” (BEE) criteria:

Star rating period from 1st July 2022 to 31st December 2024

Table 12 Star Rating Criteria for Split Air-Conditioner

Split Air-Conditioner ISEER (1st July 2022 - 31st December 2024)		
Stars	Minimum	Maximum
1 Star	3.3	3.49
2 Star	3.5	3.79
3 Star	3.8	4.39
4 Star	4.4	4.99
5 Star	5.0	

To make a 5-star Air-Conditioner, ISEER should be more than 5.00 .

Development plan - We have made a development plan for an AC system with a capacity of approximately 4,600 W, equivalent to 16,000 BTU (16k). Our primary objective is to achieve a high energy efficiency level by targeting an ISEER) rating of 5.20 or higher.

Development trials - In our new development project, we started with a previously developed 5-star model having a cooling capacity of 5000W and an ISEER rating of 4.73. We made specific changes to meet market requirements and comply with the new BEE table for Split models. The cooling capacity was adjusted to 4600W per sales demand, and the ISEER rating was increased to 5.20 to improve energy efficiency. These modifications ensure that the new model aligns with market needs and meets current energy efficiency standards, offering customers an efficient and environmentally friendly cooling solution.

Table 13 Previously developed 5-star model data

To be Filled by the Laboratory/manufacturer				
S No.	Parameters		35°C	29°C
a	Cooling Load			
b	Cooling Capacity	Full Capacity (W)	5000	5385
		Half Capacity (W)	2500	2692.5
c	Power Consumption	Full Capacity (W)	1465	1339.01
		Half Capacity (W)	455	415.87
1	Cooling seasonal total load (CSTL) in kWh		3870.46	
2	cooling seasonal energy consumption (CSEC) in kWh or Electricity Consumption In Units Per Annum		818.81	
3	Indian Seasonal Energy Efficiency Ratio (ISEER- Cooling)		4.73	

Table 14 New development 5-star model desired data

To be Filled by the Laboratory/manufacturer				
S No.	Parameters		35°C	29°C
a	Cooling Load			
b	Cooling Capacity	Full Capacity (W)	4600	4954.2
		Half Capacity (W)	2300	2477.1
c	Power Consumption	Full Capacity (W)	1130	1032.82
		Half Capacity (W)	409	373.82
1	Cooling seasonal total load (CSTL) in kWh		3560.82	
2	cooling seasonal energy consumption (CSEC) in kWh or Electricity Consumption In Units Per Annum		685.26	
3	Indian Seasonal Energy Efficiency Ratio (ISEER- Cooling)		5.20	

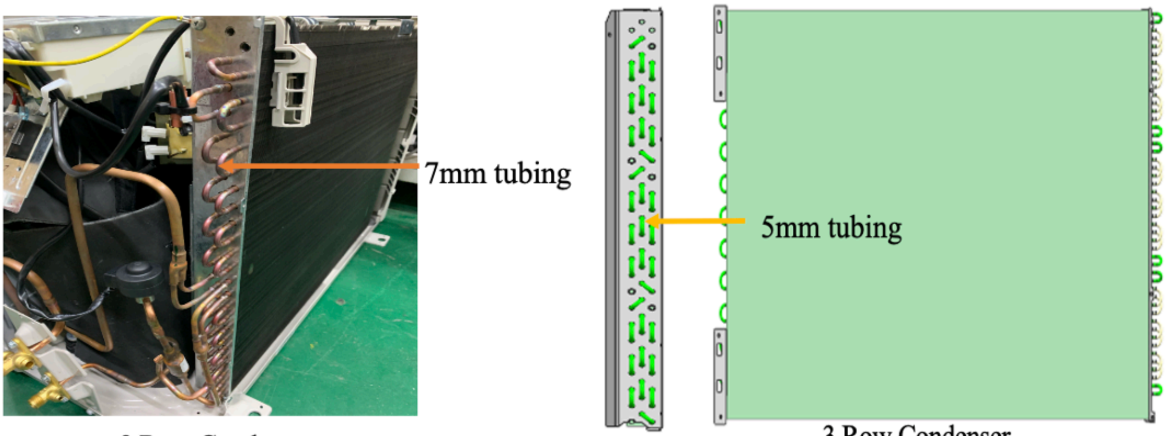
Trials to Achieve ISEER Rating - In our trials to achieve the desired ISEER rating, we conducted various experiments and made specific changes to different air conditioning system components. Here are the details of the trials and modifications:

1. **Compressor Comparison**: During our development trials, we conducted tests using different compressor volumes, specifically 10.2cm^3/rev., 11.5cm^3/rev., and 15.6cm^3/rev. The main objective of this trial was to understand how the compressor volume influences the overall performance and energy efficiency of the air conditioning system. By comparing the results of these tests, we aimed to identify the most suitable compressor compression that would help us achieve our target ISEER rating.

Table 15 Compressor Specification

Specification	Compressor 1	Compressor 2	Compressor 3
Displacement:	10.2 cm^3/rev.	11.5 cm^3/rev.	15.6 cm^3/rev.
Discharge temp.	115°C	115°C	115°C
Suction Pressure:	2.4 MPa	2.4 MPa	2.4 MPa
Discharge Pressure:	4.5 MPa	4.5 MPa	4.5 MPa
Motor: BLDC	6 Pole/1500W	6 Pole/1600W	6 Pole/900W
Motor coil temp.	130°C	130°C	130°C

2. **Condensor Changes**: a. Path Change: We modified the condenser from 2-row to 3-row configurations. This change in the condenser's path aimed to enhance the system's performance by improving heat dissipation and maximising heat transfer efficiency. It was expected to contribute to achieving the desired ISEER rating. b. Condenser Tube Diameter Change: As per the model's specific requirements, we changed the condenser tube diameter from 7mm to 5mm. This adjustment aimed to optimize the heat exchange process and improve energy efficiency, contributing to the overall performance of the AC.



2 Row Condenser

3 Row Condenser

Figure 24. Condenser Front And Sideview

3. **Evaporator**: We modified the evaporator from a 5-path distributor to a 4-path distributor. This trial focused on evaluating the impact of the distributor configuration on cooling performance and energy efficiency. We could determine the optimal path distribution for achieving the desired ISEER rating by comparing the results.

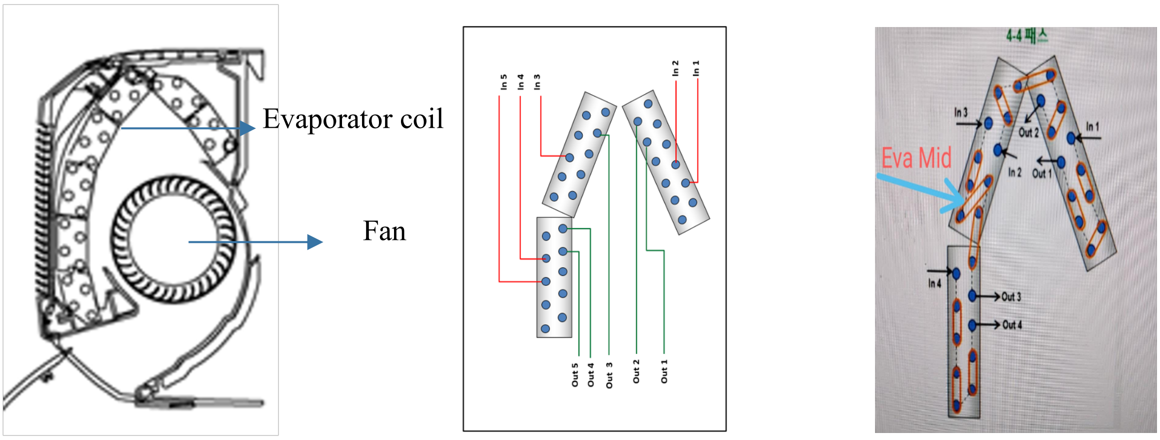


Figure 25. Indoor Unit Side View, (5 In 5 Out) & (4 In 4 Out) path distributor

Through these trials and modifications, we aimed to fine-tune the air conditioning system and optimise its performance to achieve the targeted ISEER rating. By evaluating and implementing these changes, we worked towards improving energy efficiency, heat transfer, and overall system performance, aligning the system with the desired energy efficiency standards.

5.2 TESTING RESULTS AND DISCUSSION

5.2.1 COMPRESSOR TRIALS & COMPARISON

After conducting trials with three different compressors to achieve a target capacity 4600W for the air conditioning system, we determined that Compressor-3 exhibited better energy efficiency in the EER. The EER measures cooling output relative to energy consumption, and Compressor-3 outperformed the other options by achieving a higher EER value. This indicates that Compressor-3 delivers more efficient cooling while consuming less energy. Consequently, we selected Compressor-3 as the optimal choice for the air conditioning system to achieve the desired capacity while maintaining high energy efficiency. By prioritizing a compressor with superior EER performance, we can offer an air conditioning solution that provides efficient cooling and minimises energy consumption, aligning with our goal of attaining the desired ISEER rating.

Table 16 Compressor Trials Results Comparison.

Compressor Trial	Compressor-1	Compressor-2	Compressor-3
Trial No	T1	T2	T3
IDU Ckt	5In 5Out	5In 5Out	5In 5Out
Compressor	15.6 cm^3/rev	11.6 cm^3/rev	10.2 cm^3/rev
Condenser	2R 7mm	2R 7mm	2R 7mm
Type	21FPI	21FPI	21FPI
EEV	1.65mm	1.65mm	1.65mm
IDU Motor	58W	58W	58W
Ref Qty	985gm	985gm	985gm
Capacity Full Load	4612.1W	4651.8W	4622W
%age	100.26%	101.13%	100.48%
Power_ Full Load	1139.6W	1129.4W	1125.4W
Hz	45	45	45
Discharge Temperature Td	75°C	81°C	77°C
ODU RPM	950	950	950
IDU RPM	1600	1650	1650
Capacity Half Load	2207.1W	2192.9W	2210.7W
%age	47.98%	47.67%	48.06%
Power Half Load	407.1W	400.5W	399.6W
Hz	18	18	18
Discharge Temperature Td	60°C	63°C	61°C
ODU RPM	840	840	840
IDU RPM	1500	1450	1450
ISEER	5.09	5.16	5.18

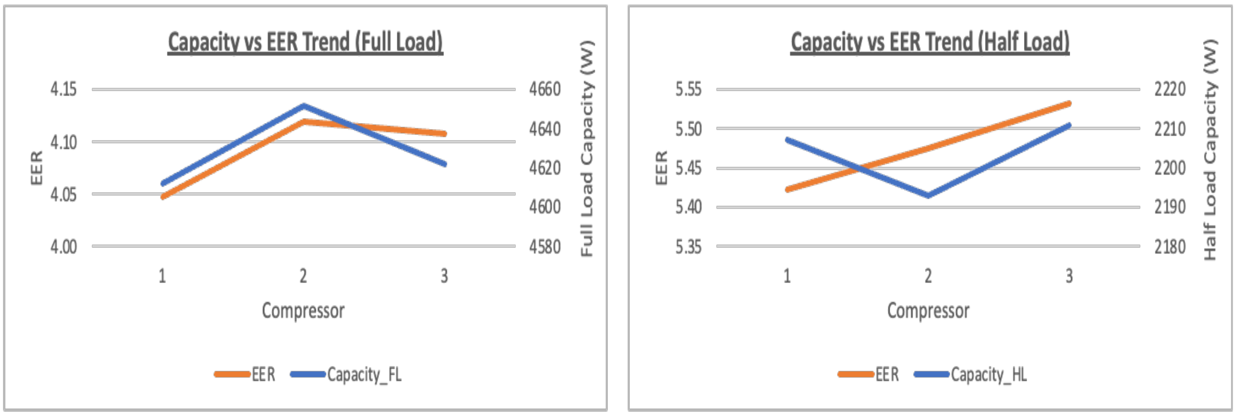


Figure 26. Cooling Capacity vs EER Trend for Compressor Trials

5.2.2 SYSTEM OPTIMIZATION WITH COMPRESSOR

We investigated the air conditioning system's performance during the system optimization process by varying the compressor frequency (Hz) and the electronic expansion valve (EEV) opening. The compressor frequency ranged from 15 Hz to 100 Hz, while the EEV opening varied from 0 to 500. After thorough analysis, we discovered the best results through system optimization. At Full load capacity, we achieved a cooling capacity of 4622W with the compressor running at 45 Hz and an EEV opening of 210. For half load capacity, the system delivered 2210.70W with the compressor operating at 18 Hz and an EEV opening of 98. The corresponding power usage at total load capacity was measured at 1125.4W, while half load capacity resulted in power usage of 399.6W. Although these optimization efforts resulted in an ISEER of 5.18, which is commendable, our desired target was an ISEER of 5.20.

Table 17 Compressor Frequency and EEV plus optimization

Trial	HALF LOAD 18Hz, 102eev 840 RPM, 985GM GAS	HALF LOAD 18Hz, 98eev 840 RPM, 985GM GAS	HALF LOAD 18Hz, 96eev 840 RPM, 985GM GAS
Freq	18	18	18
Capacity (W)	2,170.00	2,210.70	2,230.00
Power	398.00	399.60	405.00
EER	5.452	5.532	5.506
Td	58	61	63

Trial	FULL LOAD 45Hz, 210eev 840 RPM, 985GM GAS	FULL LOAD 45Hz, 206eev 840 RPM, 985GM GAS	FULL LOAD 45Hz, 204eev 840 RPM, 985GM GAS
Freq	45	45	45
Capacity (W)	4,622.00	4,630.00	4,628.00
Power	1,125.40	1,128.00	1,131.00
EER	4.107	4.105	4.092
Td	77	79	81

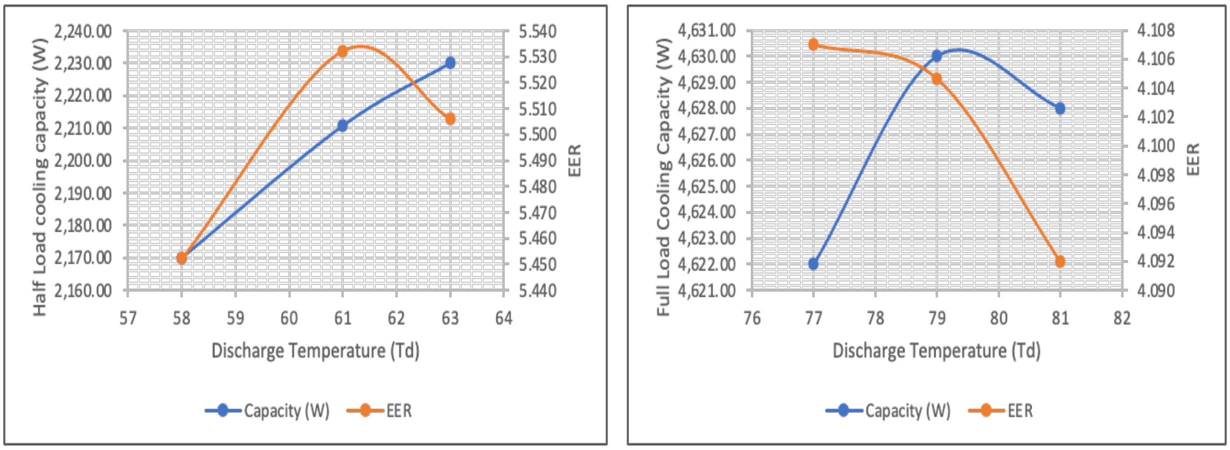
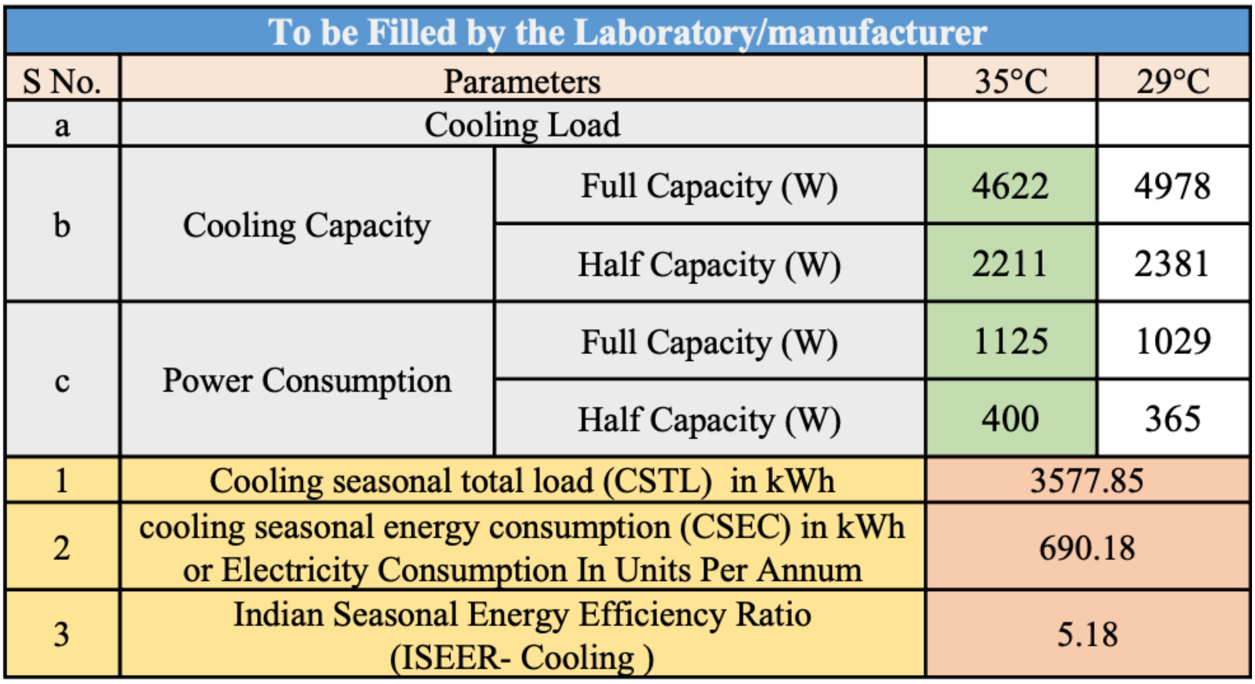


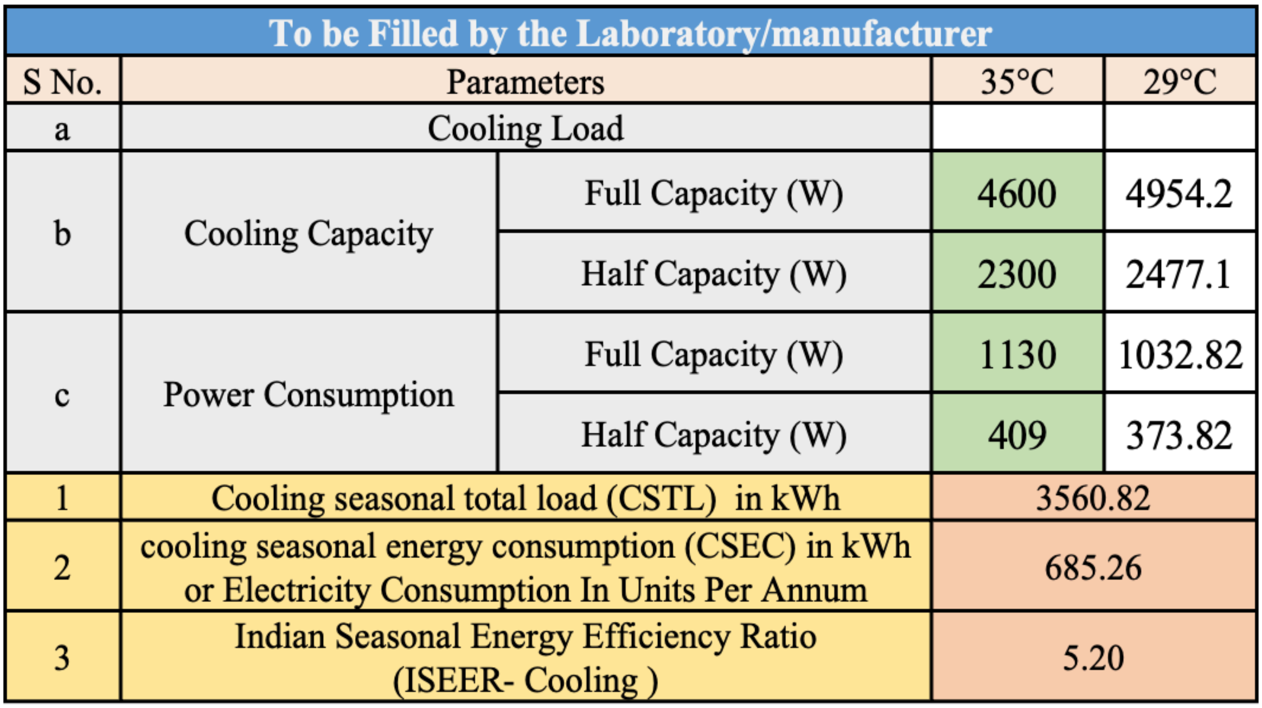
Figure 27. Cooling Capacity vs EER (Half and Full Load)

Table 18 Achieved ISEER



To be Filled by the Laboratory/manufacturer				
S No.	Parameters		35°C	29°C
a	Cooling Load			
b	Cooling Capacity	Full Capacity (W)	4622	4978
		Half Capacity (W)	2211	2381
c	Power Consumption	Full Capacity (W)	1125	1029
		Half Capacity (W)	400	365
1	Cooling seasonal total load (CSTL) in kWh		3577.85	
2	cooling seasonal energy consumption (CSEC) in kWh or Electricity Consumption In Units Per Annum		690.18	
3	Indian Seasonal Energy Efficiency Ratio (ISEER- Cooling)		5.18	

Table 19 Desired ISEER



To be Filled by the Laboratory/manufacturer				
S No.	Parameters		35°C	29°C
a	Cooling Load			
b	Cooling Capacity	Full Capacity (W)	4600	4954.2
		Half Capacity (W)	2300	2477.1
c	Power Consumption	Full Capacity (W)	1130	1032.82
		Half Capacity (W)	409	373.82
1	Cooling seasonal total load (CSTL) in kWh		3560.82	
2	cooling seasonal energy consumption (CSEC) in kWh or Electricity Consumption In Units Per Annum		685.26	
3	Indian Seasonal Energy Efficiency Ratio (ISEER- Cooling)		5.20	

To meet the desired ISEER rating, it is evident that further modifications to the system are necessary. These modifications will allow us to achieve the desired ISEER of 5.20

5.2.3 ELECTRONICALLY CONTROLLED EXPANSION VALVE (EEV)

An EEV (Electronic Expansion Valve) is used in refrigeration and air conditioning systems to precisely control refrigerant flow, enabling efficient and accurate regulation of the system's cooling capacity. Unlike traditional capillary tubes, an EEV can adjust the degree of throttling based on electronic signals, making it highly adaptable to different operating conditions.

The working principle of an EEV involves an electronically controlled valve that responds to signals from a microcomputer or electronic controller. When the system detects the need for cooling, the microcomputer sends an electronic signal to the EEV, instructing it to adjust the refrigerant flow rate. The EEV then uses a pulse motor to rotate and convert the rotation into up-and-down motion, which adjusts the gap between the valve and the valve seat. This action controls the opening and closing of the valve, determining the degree of refrigerant throttling.

As the compressor's operating conditions change, such as varying its number of revolutions in an inverter air conditioner, the microcomputer continuously sends signals to the EEV, allowing it to respond in real time and maintain precise control over the refrigerant flow. By accurately regulating the refrigerant flow, the EEV ensures that the air conditioning system maintains optimal cooling performance, energy efficiency, and temperature and humidity control, contributing to enhanced comfort and reduced energy consumption. EEVs have become increasingly common in modern air conditioning systems and provide efficient and adaptive refrigerant flow control, leading to improved overall system performance.

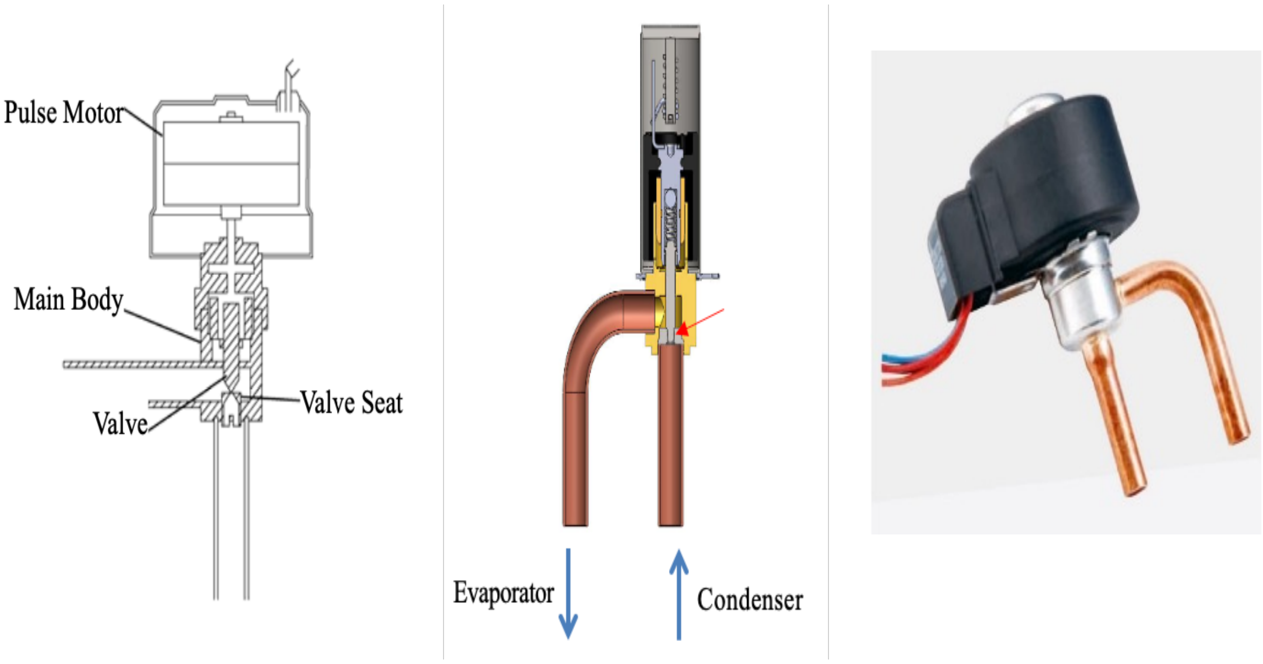


Figure 28. Electronically Controlled Expansion Valve

5.2.4 CONDENSER TRIALS AND COMPARISON

Table 20 Condenser Trials Results Comparison

Condenser	Condenser 1	Condenser 2	Condenser 3
Trial No	T1	T2	T3
IDU Circuit	5In 5Out	5In 5Out	5In 5Out
Compressor	10.2 cm^3/rev	10.2 cm^3/rev	10.2 cm^3/rev
Condenser	2R 7mm	2R 7mm + 6 Hair Pin (2.5Row)	3R 5mm
Type	21FPI	21FPI	21FPI
EEV	1.65mm	1.65mm	1.65mm
IDU Motor	58W	58W	58W
Ref Qty	985	985	700
Full Load Capacity	4622W	4610W	4610W
%age	100.48%	100.2%	100.28%
Full Load Power	1125.4W	1155W	1117.5W
Hz	45	44	68
Discharge Temperature Td	77°C	75°C	76°C
ODU RPM	950	950	950
IDU RPM	1450	1450	1450
Half Load Capacity	2210.7W	2240.2W	2355W
%age	48.06%	48.70%	52.26%
Half Load Power	399.6W	420.2W	428.9W
Hz	18	18	29
Discharge Temperature Td	61°C	60°C	60°C
ODU RPM	750	750	800
IDU RPM	1450	1450	1450
ISEER	5.18	5.01	5.20

By modifying the condenser circuit from a 2-row configuration with a 7mm tube diameter to a 3-row design with a 5mm tube diameter, we successfully achieved the desired ISEER rating of 5.20. This adjustment was made to optimize the heat exchange process and improve energy efficiency in the air conditioning system. The change in condenser circuit design allowed for enhanced heat transfer and increased efficiency, improving overall performance. With the modified configuration of the condenser circuit, we obtained the targeted ISEER rating, indicating the successful accomplishment of our energy efficiency goals.

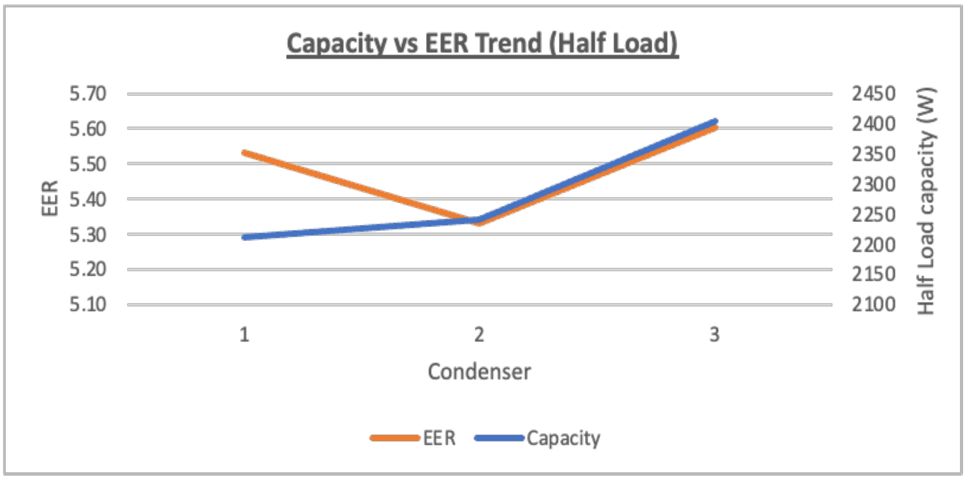


Figure 29. Cooling Capacity vs EER (Full Load)

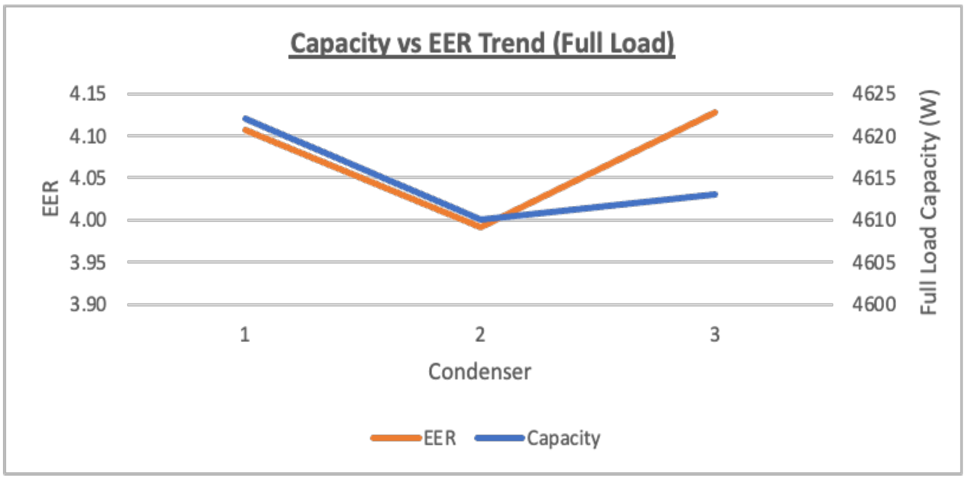


Figure 30. Cooling Capacity vs EER (Half Load)

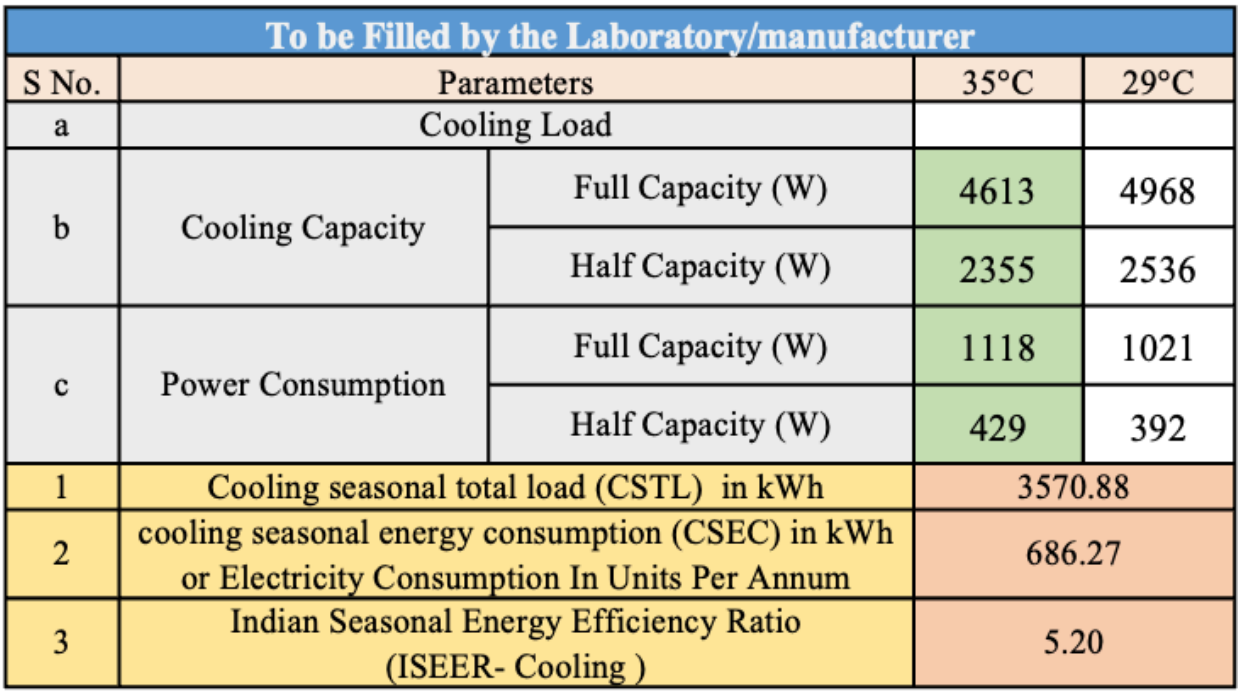
5.2.4. EVAPORATOR PATH COMPARISON

The decision to switch from a 5-in-5 out path configuration to a 4 in 4 out path configuration for the evaporator circuit resulted in improved cooling capacity and ISEER value. This improvement was primarily due to the reduced pressure drop and heat loss achieved with the modified configuration. The 4 in 4 out path design allowed for a more efficient refrigerant flow, enhancing cooling capacity and performance. The reduced pressure drops also minimized heat loss within the evaporator circuit, improving energy efficiency. The reduced pressure drops and minimised heat loss contributed to an enhanced ISEER value, reflecting the air conditioning system's improved efficiency. Modifying the evaporator circuit design yielded better cooling capacity and ISEER value by reducing pressure drop and heat loss, ultimately enhancing the system's efficiency and performance.

Table 21 Evaporator Path Result Comparison

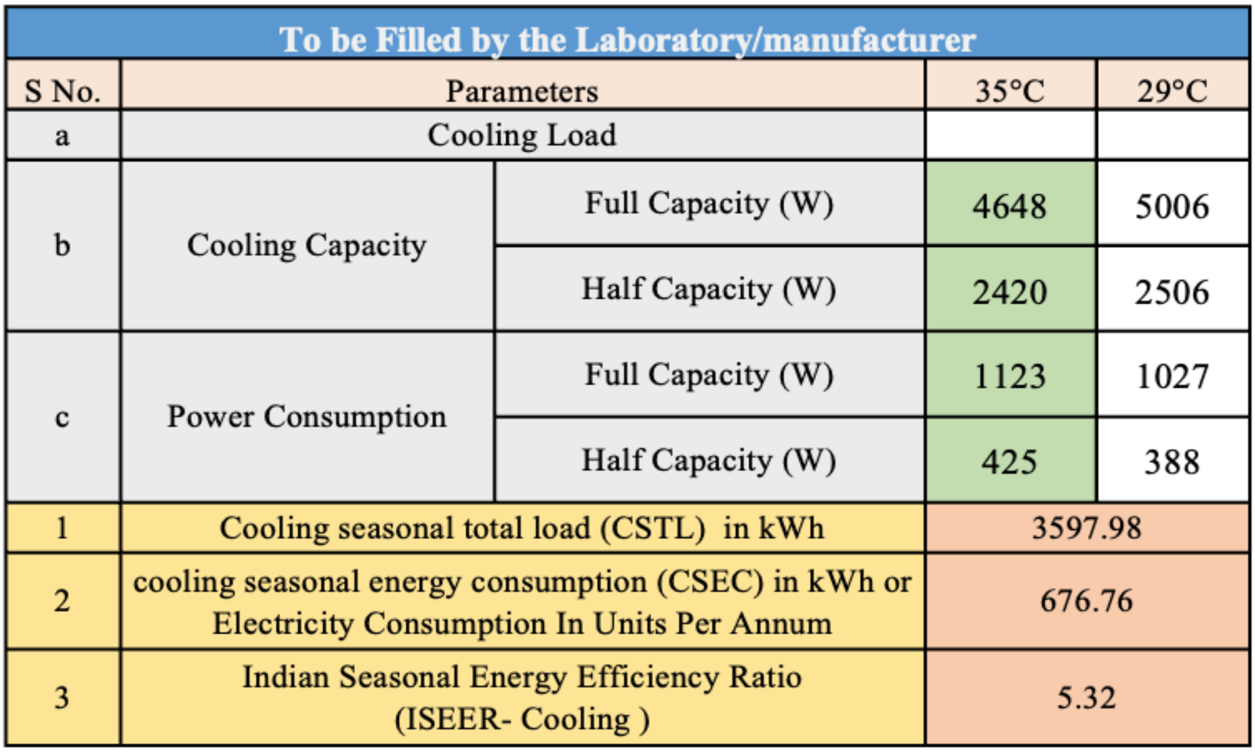
Evaporator	**Circuit 1**	**Circuit 2**
Trial No	T3	T4
IDU Circuit	5In 5Out	4In 4Out
Compressor	10.2 cm^3/rev	10.2 cm^3/rev
Condenser	3R 5mm	3R 5mm
Type	21FPI	21FPI
EEV	1.65mm	1.65mm
IDU Motor	58W	58W
Ref Qty	700	700
Full Load Capacity	4613W	4648W
%age	100.28%	101.05%
Full Load Power	1117.5W	1123.2W
Hz	68	68
Discharge Temperature Td	76°C	74°C
ODU RPM	950	950
IDU RPM	1450	1450
Half Load Capacity	2355W	2420W
%age	52.26%	52.6%
Half Load Power	428.9W	424.5W
Hz	29	29
Discharge Temperature Td	60°C	57°C
ODU RPM	800	800
IDU RPM	1450	1450
ISEER	5.20	5.32

Table 22 ISEER Value For 5 in 5 out Evaporator Circuit



To be Filled by the Laboratory/manufacturer				
S No.	Parameters		35°C	29°C
a	Cooling Load			
b	Cooling Capacity	Full Capacity (W)	4613	4968
		Half Capacity (W)	2355	2536
c	Power Consumption	Full Capacity (W)	1118	1021
		Half Capacity (W)	429	392
1	Cooling seasonal total load (CSTL) in kWh		3570.88	
2	cooling seasonal energy consumption (CSEC) in kWh or Electricity Consumption In Units Per Annum		686.27	
3	Indian Seasonal Energy Efficiency Ratio (ISEER- Cooling)		5.20	

Table 23 ISEER Value For 4 in 4 out Evaporator Circuit



To be Filled by the Laboratory/manufacturer				
S No.	Parameters		35°C	29°C
a	Cooling Load			
b	Cooling Capacity	Full Capacity (W)	4648	5006
		Half Capacity (W)	2420	2506
c	Power Consumption	Full Capacity (W)	1123	1027
		Half Capacity (W)	425	388
1	Cooling seasonal total load (CSTL) in kWh		3597.98	
2	cooling seasonal energy consumption (CSEC) in kWh or Electricity Consumption In Units Per Annum		676.76	
3	Indian Seasonal Energy Efficiency Ratio (ISEER- Cooling)		5.32	

CHAPTER 6: CONCLUSIONS AND FUTURE SCOPE

Conclusions

In conclusion, the development process has provided valuable insights and critical learnings for improving the efficiency and performance of air conditioning systems. Some of the critical points identified are:

1. Compressor selection is crucial for air conditioner design, as it directly affects power consumption and energy efficiency. Choosing a smaller volume compressor during the initial stages of model development offers several advantages. Firstly, smaller compressors consume less power, improving energy efficiency and lowering electricity costs. Secondly, using a smaller compressor allows for better matching of the cooling capacity to the specific requirements of the air conditioner, preventing inefficient short cycling and improving humidity control. Operating the compressor closer to its optimal capacity enhances efficiency, reduces strain on components, and increases the system's reliability. In conclusion, starting with a smaller volume compressor enables better power reduction, efficiency, consistent operation, enhanced humidity control, and longer compressor life. By selecting the appropriate compressor size, air conditioning systems can achieve the desired Energy Efficiency Ratio (EER) and provide cost-effective cooling solutions to consumers.

2. Condenser path optimization is essential for enhancing the performance of AC systems. The condenser's role is to release the heat absorbed from indoor air to the outdoor environment. A condenser with a 5mm tube diameter achieves more efficient heat transfer due to increased surface area contact between the refrigerant and the surrounding air.
   Furthermore, the 5mm tube-diameter condenser design optimizes refrigerant flow and reduces pressure losses during heat exchange. This leads to better cooling performance and increased energy efficiency.

3. Path balancing in indoor units (IDUs) is a crucial aspect of air conditioning system design, impacting capacity performance and overall efficiency. Our investigations revealed that a 4-path circuit configuration in the IDU outperformed a 5-path circuit in terms of cooling capacity. Achieving path balancing ensures equal airflow distribution across all refrigerant paths, optimizing cooling performance and preventing inefficiencies. Future focus on path balancing aims to enhance efficiency further. Using a condenser with a 5mm tube diameter and a 4-path circuit configuration achieved higher cooling capacity and improved energy efficiency, providing increased comfort and reduced energy consumption for users. Optimizing the condenser path and achieving path balancing is critical for effective cooling solutions and meeting customer needs.

FUTURE SCOPE

1. Advanced Heat Exchangers: Integrating advanced heat exchangers, such as micro-channel heat exchangers, can provide superior heat exchange efficiency and reduce refrigerant charge. Further research and development in this area can significantly improve system efficiency.
2. Advanced Compressors: Changing from reciprocating compressors to rotary compressors, such as dual inverter compressors, may reduce the power needed to run the system while increasing the rate at which it cools. Continuous technological advancement in compressors has the potential to contribute to improvements in energy efficiency.
3. Electronic Expansion Valves (EEV): Electronic expansion valves offer increased modulation capabilities, allowing for precise refrigerant flow control based on variable-capacity requirements. Further advancements in EEV technology can optimise system performance.
4. High-Efficiency Motors: Electrically commutated motors (ECM) with higher efficiencies can replace traditional engines, reducing energy consumption. Incorporating aerodynamic component design can further enhance fan energy efficiency.

The upcoming India Cooling Action Plan, initiated by the Government of India, provides an opportunity to integrate efforts in technology, manufacturing, efficiency, and environmental considerations. This holistic approach and supportive government policies can encourage innovation and research in the air conditioning industry, leading to more power-efficient and environmentally friendly cooling solutions.

In summary, the development process has highlighted the importance of various technological interventions, market transformation through policies, and operational interventions in achieving higher efficiency and performance in air conditioning systems. The identified future scope areas provide a roadmap for further advancements in technology and practices to meet evolving energy efficiency goals and sustainability requirements.

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