3E Analysis for Comparative Evaluation between Variable Refrigerant Flow System and Fixed Speed Air Conditioning System

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Abstract: Presently, thermal comfort requirements are increasing at a faster rate. Several technologies are available in market to choose from. A cost benefit analysis of technologies is always helpful from the consumer point of view to select the correct cooling system. It is very important to note that energy and environmental assessments are also necessary to be considered along with economics. Hence this work is carried out to propose a clear picture of comparison between two mostly used air-conditioning systems i.e. fixed speed split air conditioning system and variable refrigerant flow system. It is proved that variable refrigerant flow system is advantageous over conventional fixed speed split air-conditioning system. However, it is also noted that small households and shops did not found this appropriate due to high fixed cost and maintenance cost.
This work is made to compare the above mentioned systems for different capacities and number of operating hours, keeping nature of load as similar under standard ambient condition. The main variables are system capacity, working hours, years of operation, total cost (initial cost +operational cost+ maintenance cost), power saving, life span, space saving etc. The Results shows that hours of usage dominates over sizing of the unit on the basis of energy, economic and environmental analysis.

Keywords: Variable Refrigerant Flow System; Split Air Conditioning System; Energy; Economic.

1. INTRODUCTION

1.1 Variable Refrigerant Flow System

It is an air-conditioning system where there is one outdoor unit or module of outdoor units with multiple numbers of indoor units. In other words Variable Refrigerant Flow (VRF) is an air-conditioning system configuration where there is one condensing unit operating with multiple evaporating units to achieve the goal of controlling of temperature, humidity, air-flow, air-filtering, ventilation of a given confined space while a suitable refrigerant is flowing through the system by the help of compressors & expansion devices.

The term Variable Refrigerant Flow (VRF) basically means ability of the system to control the flow of the amount of the refrigerant flowing to multiple evaporators (indoor units) based on the heat load demand & capacities of evaporators connected to single condensing unit (outdoor units) or module of condensing units (outdoor units) of appropriate capacity with the help of compressors & expansion devices. The main goal of this VRF system is to achieve the customized controlling of temperature (heating or cooling), humidity, air flow, air-filtering, ventilation etc. as per desired level of comfort in different zones of given confined space. As Rahul Khatri et al [1] explained that VRF system is proving very good energy saving during part load condition.

With higher efficiency & better controllability VRF system can help in achieving the sustainable design of air-conditioning of a building/ space/ zones. As Pijale IM et al [2] explained that VRF system consumes less than 20% Energy than conventional fixed speed split air-conditioners based on the outdoor air temperature condition on daily basis/hourly basis. However designing of VRF system is little more complicated & requires additional works comparing to the conventional split air-conditioners or direct expansion (DX) system. It is noticeable that VRF system also operates on the direct expansion (DX) principle, which means that heat is transferred to or from the space directly by circulating refrigerant to evaporators located near or within the conditioned space. Refrigerant flow control is the major challenge of VRF system & variable flow of refrigerant is the key to advantages (like power savings, precise cooling, and temperature controlling etc.). As Ammi Amarnath et al [3] explained that VRF system is having good zone controlling by not conditioning the unoccupied zones.

Normally an outdoor unit consists of compressors & condenser while indoor unit consists of evaporator & expansion device. Both outdoor &

indoor units are connected with each other with appropriate size of properly insulated copper tubes or pipes running between them. And a mesh of communication or transmission cable is laid through appropriate conduit pipes to connect all indoor units with outdoor unit or module of outdoor units for controlling or commands transmission purpose. However a suitable refrigerant (R410A) is flowing into the system through the insulated copper tubes or pipes. As Roba Saab et al [4] VRF system can modulate the frequency on part load condition as per requirement while Fixed speed air-conditioners works either on full load or No load condition.

VRF system/technology was developed & designed by the air-conditioning company Daikin Industries, Japan. As Daikin Industries, Japan got this technology patented with the name of Variable Refrigerant Volume (VRV) system, so the other manufactures use the term Variable Refrigerant Flow (VRF) system. In fact VRV or VRF both are the same system.

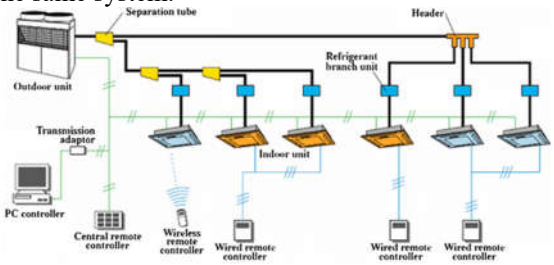

Figure 1.1: A typical diagram of VRF air-conditioning System

1.2 Fixed Speed Split Type Air Conditioning System

It is an air conditioning system where there is one indoor unit connected with one separate dedicated outdoor unit. Indoor unit is connected with outdoor unit with the set of copper pipes & power and communication cables. Indoor unit is placed inside the room/area, which is to be air conditioned, while the outdoor unit is mounted either on rooftop or wall outside in ambient. That's why it is called split type air conditioner system. Indoor unit consists of mainly evaporating coil (cooling coil), expansion device(mostly metering device/capillary) printed circuit board (PCBs) blower & air filters while the Outdoor unit consists of compressor, condenser(heat exchanger), condenser fan(propeller fan) & printed circuit boards(PCBs).

Compressor can be rotary type or scroll type. The rotational speed of the compressor i.e. rotation per minute (RPM) remains constant as per standard rated RPM. This type of compressor either runs at full load (100% loading-ON) condition or no load (0% loading-OFF) condition as per the air conditioning load requirement of the inside/room condition. As soon as the set temperature of the indoor unit is being achieved inside the room, the compressor goes for cut off with a fluctuation of +/- 2 degC. Again when the room temperature becomes more than the +2 degC of set temperature of indoor unit, the compressor starts running on full load condition. This is how it goes with the help of microprocessors/printed circuit boards. There can be single or multiple compressor in an outdoor unit. But COP of Fixed speed Split air-conditioning system is lesser than VRF System under similar condition. As author Dongsu Kim [5] explained that VRF system has got better energy saving energy potential for all season/weather comparing to fixed speed Split Air-conditioning Stem.

The Indoor unit can be of various type for split type air conditioning system like Hi-Wall/Wall mounted type, Cassette type, Ducted type & Concealed type indoor units etc. However there will be a separate dedicated outdoor unit for each indoor unit, both are connected to each other with set of copper piping & communication wiring. Power cable may be separate or combined for indoor & outdoor unit depending upon the capacity & type of split air conditioning unit.

2. MATERIALS & METHODS

Materials used in this project work are the data sources like products catalogues, price list, installation manuals & technical data sheet. The methods that are used in the cost analysis & comparison process among VRF Air-conditioning System & Fixed Speed Split Air-conditioners are based on variables like working hours, capacity of system, efficiency, initial cost, operational cost, maintenance cost, space saving etc.

Data sources that are used in this project work as material are as followings:

a. Product Catalogues of VRF Air-conditioning System of reputed companies/manufactures
b. Product Catalogues of Fixed Speed Split Air-conditioning System of reputed companies/manufactures like- Hitachi, Fujitsu General, Daikin & Samsung.
c. Technical Data sheet of reputed companies like- Hitachi, Fujitsu General, Daikin, Samsung & LG.
d. Installation Manuals of reputed companies
e. Price List of equipment of reputed companies.
f. Installation material/service cost from reputed Dealers.
g. Pictures of equipment taken from sites.

Methods used for Cost Analysis & Comparison: We are using market survey/market research as a tool for data collection for the analysis & comparison of cost among VRF System & Fixed Speed Split Type Air-conditioning system. In the process of our market survey/market research, we

have collected data from various reputed Original Equipment Manufacturer (OEM) companies like- Hitachi, Fujitsu General, Daikin, LG Electronics & Samsung.

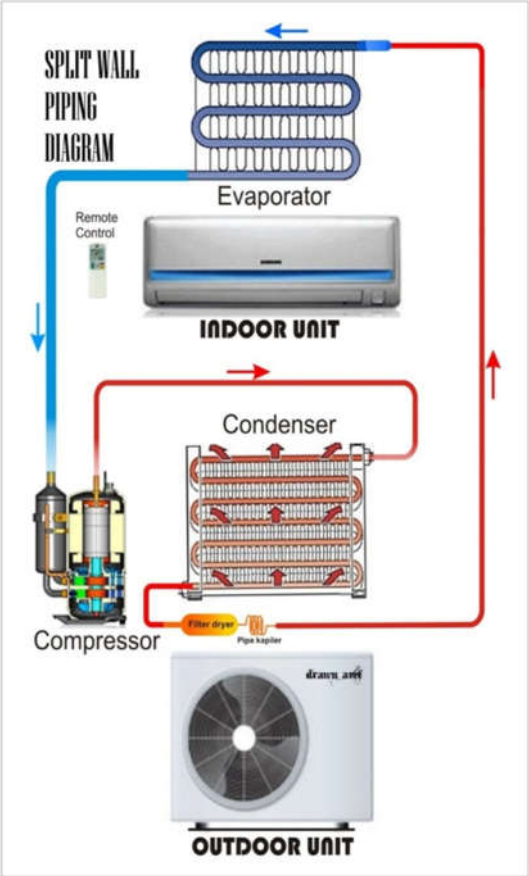

Figure 1. 2 : Typical diagram of Split Air-Conditioning System

All Calculations have been done based on considering the several variables & factors like working hour, initial cost, operating cost, maintenance cost, life span, efficiency, space saving etc. for both VRF Air-conditioning System & Fixed Speed Split Air-conditioning System.

We are explaining the same by using separate excel sheet for our all calculations using the data/information collected from our market survey. We are using graphical method for proper analysis & cost comparison between VRF system & Fixed speed Split Air-conditioners.

The Excel sheet & graphs are attached in the separate sheets for reference. The mathematical equation used for cost analysis for VRF air-conditioning system & Fixed Speed Split type Air-Conditioning System is explained below as well.

Materials/data sources used are mainly product catalogue, technical data book, installation manuals, price lists, site photographs for VRF system & fixed speed split air-conditioning system for reputed Original Equipment Manufacturer (OEM) companies. Methods used to carry out the project work is mainly market research/survey done for data collection for VRF system & Fixed Speed Split Air-Conditioning System. Evaluation & Comparison have been done by using graphs & charts for total cost, total power consumption, total equivalent CO2 Emission based on number of working hours, capacity of system, number of years of operation etc.

Details of Cost Analysis and Comparison of VRF Air Conditioning System & Fixed Speed Split Type Air conditioning System.

The Cost of any Air Conditioning system consists of the following components:

a. Cost of Equipment.
b. Cost of Installation of Equipment.
c. Cost of Operation of Equipment.
d. Cost of regular Maintenance/preventive Maintenance service of Equipment.
e. Cost of Spares parts mainly Compressor, PCB, and Motors etc.

Mainly the above costs can be broadly considered under three categories:

1. Initial Cost: This consists of basic cost of equipment plus basic cost of installation for the equipment at site.
2. Operation Cost: This is the running cost of the equipment during working hours as per required load conditions.
3. Maintenance Cost: This consists of the cost of regular and preventive maintenance service of equipment plus the cost of spare parts on annual basis.

Life Span (Total Number of Years of Operation of Air-Conditioning System): It is the average working life cycle of any Air-Conditioning System. The Average life of VRF Air-conditioning system is approximately 25- 30 years, while the average life of Normal Fixed Speed Split type Air Conditioning system is approximately 10-15 years along with proper regular maintenance of both the air conditioning system.

We have considered life span of VRF air conditioning system as 30 years, while the life span of Fixed Speed type split air conditioning system is considered 15 years for all the analysis.

Space Saving/Building Elevation: The Space saving & Building Elevation are also important factors of consideration & decision making. As the overall foot print area taken by VRF System Outdoor units are lower than that of the Fixed Speed Split Air-conditioning System. We can have space saving with VRF system in comparison to Fixed Speed Split AC system. As the number of outdoor units in case of VRF system is very less than the number of outdoor units in case of Fixed

speed Split Air-conditioning system for a given capacity of system above 10HP.

Building Elevation will remain intact/undisturbed by using VRF System as the number of Outdoor units in case of VRF system is very less than that of the Fixed Speed Split Air-Conditioning System. And the Outdoor units of VRF system can easily be kept onto the rooftop even for high rise buildings without disturbing the Elevation of the building.

As VRF system can operate & support the actual length between Outdoor unit & farthest indoor unit around 150 meters easily, while Fixed Speed Air-Conditioners can operate & support the actual length between Outdoor unit & indoor unit around 15 meters only. So the Building elevation might get disturbed for mid-size & high rise building while using Fixed Speed Split type Air-Conditioning System.

We have analyzed the cost comparison for VRF air-conditioning system & Fixed Speed Split type air-conditioning system based on the following factors/variables:

1. Initial cost (cost of equipment + cost of installation)
2. Operation cost.
3. Maintenance cost.
4. Working hours/Running hours
5. Power consumption/power saving
6. Life Span (Total Number of Years of operation of Air-Conditioning System)
7. Capacity of System
8. Space saving/Building Elevation

The above variables can again be further classified into two categories:

Independent Variables

1. Working hour/ running hour of Air-Conditioning system
2. Capacity of Air-Conditioning System.

Dependent Variables

1. Initial Cost (Equipment + Installation)
2. Operational Cost
3. Maintenance Cost
4. Life Span of Air-conditioning system.
5. Space Saving/Building Elevation

We have done our Cost analysis calculation considering all the independent variables & dependent variables for developing the mathematical equation & obtaining the desired criteria of for selecting the best Air-Conditioning System for an application amongst VRF System & Fixed Speed Split type Air-conditioning System.

The same is explained below in detail.

Based on Capacity of Air-Conditioning System: We have taken the Capacity of Air-Conditioning System as followings for our Cost Optimization Calculations:

1. 10 HP of system capacity
2. 20 HP of system capacity
3. 50 HP of system capacity
4. 80 HP of system capacity
5. 100 HP of system capacity
6. 200 HP of system capacity
7. 300 HP of system capacity

Based on Working Hour: We have taken the working hours/running hours of Air-conditioning system as followings for our Cost Optimization Calculations:

1. For 6 hours of working
2. For 8 hours of working
3. For 10 hours of working
4. For 12 hours of working
5. For 15 hours of working

This way we have done the cost calculation, analysis & comparison for VRF Air-conditioning system & Fixed Speed Split Air-conditioning system by using excel sheet & graphs. For details excel sheets attached in this report can be referred. The mathematical equation is explained below.

Mathematical Equation Developed for Cost Analysis:

Total Cost Difference/Saving (S) = ((Initial Cost of VRF System per unit(Icv)- Initial Cost of Fixed Speed Split AC System per unit(Ics)) x (Capacity of System(C)) + (Operational Cost of VRF System per Unit(Ocv) - Operational Cost of Fixed Speed Split AC per Unit(Ocs)) x (Capacity of System(C)) x (Number of Working Hours (H) per day) x (Days of Operation in a Year(D)) x (Number of Years of Operation(Y)) + (Maintenance Cost of VRF System (Mcv)-Maintenance Cost of Fixed Speed Split AC(Mcs)) x Capacity of System(C) x (Number of Years of Operation(Y)).

S= (Icv-Ics) x C+ (Ocv-Ocs) x C x H x D x Y + (Mcv-Mcs) x C x Y

Assumptions that are taken for Cost Calculation Analysis & Comparison: There are certain assumptions which are taken into the consideration for the Cost analysis & optimization calculation as mentioned below:

1. Life Span (Total Years of Operation): The average life span for VRF Air-Conditioning System is taken for 30 Years, while the average life span for Fixed Speed Split Air-Conditioning System is taken 15 Years.
2. Number of Days of operation in a Year: The Air-conditioning system is supposed to run an average for 8 months (=240days) in a Year for cooling only.
3. The Working hour/Running Hour Per Day for Air-Conditioning System: It is taken 6 hours, 8 hours, 10 hours, 12 hours & 15 hours per day for calculation & cost analysis.
4. The Capacity of Air-Conditioning System: It is taken 10HP, 20 HP, 50 HP, 80 HP, 100 HP, 200 HP & 300 HP.

5. The Cost of Electricity: It is assumed Rs.7/ per kWh of electricity consumed.
6. The Years of Operation has been taken as 1 Year, 5 Years, 8 Years, 10 Years, 12 Years & 15 Years for calculations.
7. 1 HP of Cooling/Heating = 0.8 TR of Cooling/Heating as per Market standard.
8. Basic Unit for Air-conditioning capacity has been considered HP for all calculations.
9. Comparison is done for cooling only case. Fixed Speed Split AC is cooling only type, while VRF system can have both cooling & heating operation, but we have done analysis & comparison for cooling operation only.
10. VRF system with Hi-Wall type indoor units has been considered against the Fixed Speed Wall Mounted type Split Air-conditioners for comparison. Both the system works on Green Gas refrigerant R410A.
11. The current rate of inflation has been considered @ 5% for cost/price appreciation.
12. The average emission of CO_2 is 0.98 Kg against the production of 1 kWh of electricity.

Based on the above assumptions all the calculations have been done in the excel sheet for Cost Analysis & Comparison for VRF Air-Conditioning System & Fixed Speed Split type Air-Conditioning System for selecting the best Air-Conditioning System for an application.

3. RESULT & DISCUSSION

Cost Comparison result can be explained based Air-Conditioning System capacity & Working hours/running hours of Air-Conditioning System. We are explaining the results of our detailed cost comparison analysis for each case considered herewith based of Capacity of Air-Conditioning System & Working hour/Running Hour of Air-Conditioning System as per followings:

3.1 For 10 HP Capacity

The Result for 10 HP Capacity Air-conditioning system is explained below based on the working hour/running hour of the Air-conditioning system:

3.1.1 For 6 hours of working

The analysis of cost for 6 hours operational 10HP VRF and Fixes Speed Split AC system is shown in figure 1. It is observed that Fixed Speed Split Air-Conditioning System is a better choice than VRF Air-conditioning System. As the working hour is very limited & the cost saving is negligible at even end of 15 years of operations, it is advised to use split ac system as the initial cost of split ac system is very low as compared to VRF air conditioning system.

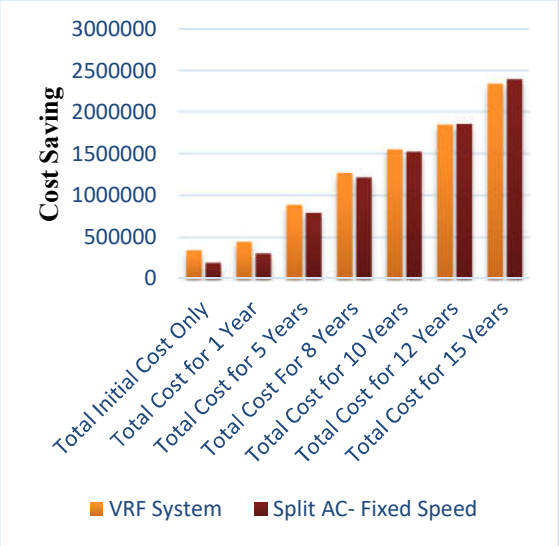

Figure 3. 1 : Total Cost (INR) chart for VRF vs Split AC

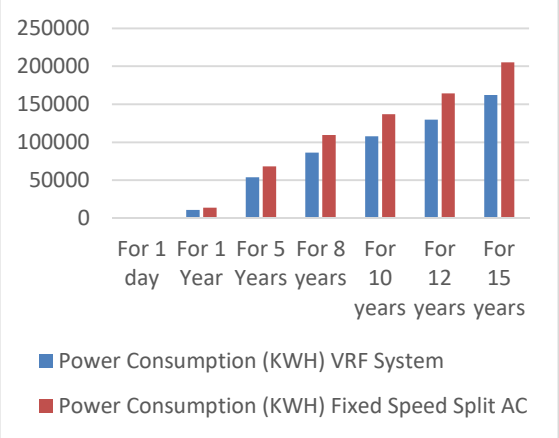

Figure 3. 2 : Power Consumption Chart (kWh) for VRF vs Split AC

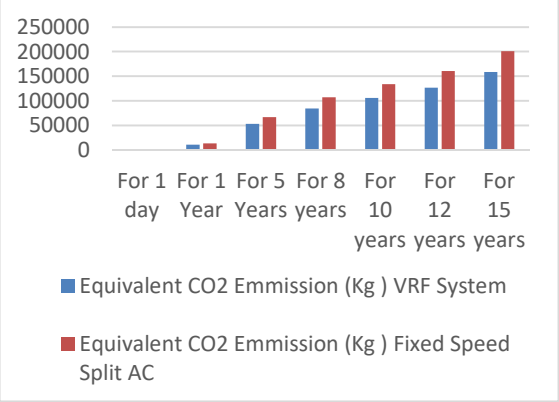

Figure 3. 1 : Equivalent CO2 Emission (Kg) Chart for VRF vs Split AC

Payback Period for differential investment- The Payback for differential investment is not achieved even after 15 years of operation. So investment on VRF system is not good choice in this case for 6 hours of operation per day.

Result: Fixed Speed Split AC System is better choice than the VRF System.

3.1.2 For 8 hours of working

As the working hour is still less, so based on cost comparison analysis it is observed Fixed Speed Split Air-Conditioning System is a better choice than VRF Air-conditioning System for an application for 10 HP Capacity of Air-Conditioning System. The cost saving is NOT appreciable even after 15 Years of operation. And the initial investment is higher in case of VRF system than the Fixed Speed Split Air-Conditioners. So Fixed Speed Split AC is a better choice. The Graph is attached below in figure 3.4

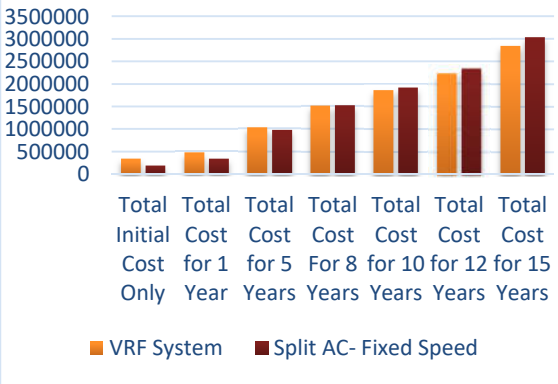

Figure 3. 4 : Total Cost (INR) chart for VRF vs Split AC

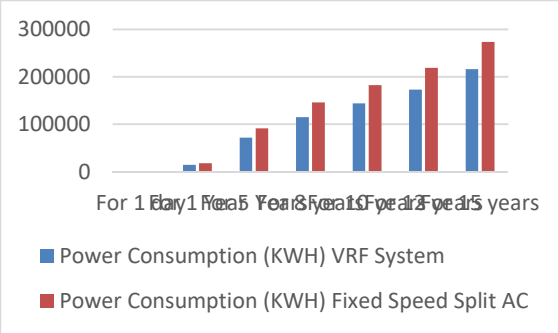

Figure 3. 5 : Power Consumption (kWh) chart for VRF vs Split AC

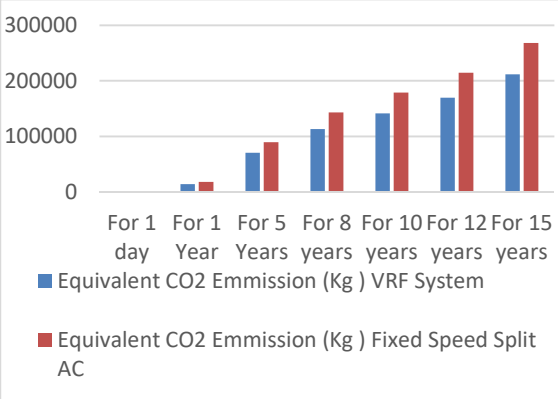

Figure 3. 6 : Equivalent CO_2 Emission (kg) chart for VRF vs Split AC

Payback Period for differential investment: The Payback period for differential investment is around 14 Years, which is again a big period, so investment on VRF system is not a good choice. Fixed Speed Split Air-conditioners are better choice for 8 hours of working per day.

Result: Fixed Speed Split AC System is better option than the VRF System.

3.1.3 For 10 hours of working

As the working hour is good enough, so based on cost comparison analysis it is observed VRF System could be better choice than Fixed Speed Split Air-conditioning System for an application for 10 HP Capacity of Air-Conditioning System for longer span of usages. As the cost saving starts after 8 years of operations & total saving to be done till 15 years of operation is decent enough more than 7%. So it is advised to opt for VRF system for longer span of usages, else Fixed Speed Split AC is a better option. The Graph is attached below in figure 3.

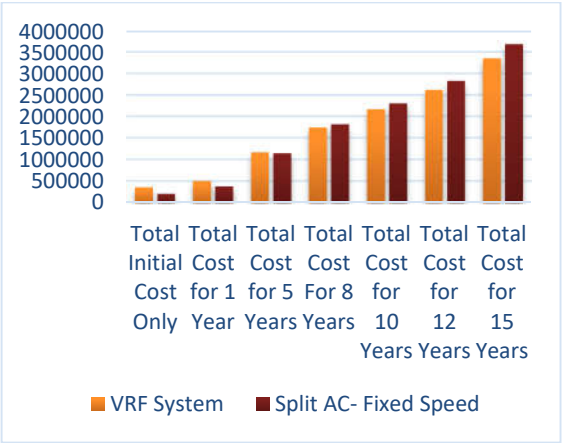

Figure 3. 7: Total Cost (INR) chart for VRF vs Split AC

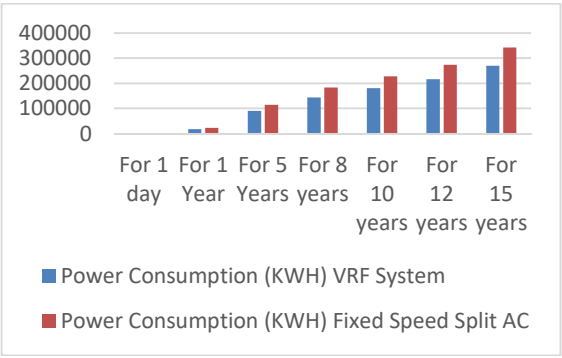

Figure 3. 8 : Power Consumption (kWh) chart for VRF vs Split AC

Payback Period for differential investment: The Payback period for differential investment is 11 years, which is still a bigger period & not decent enough to invest on VRF system, so fixed speed

Split Air-Conditioners are better choice for 10 hours of Operation per day.

Result: VRF system is a better option for longer span of usages than Fixed Speed Split Air-conditioners, while Fixed Speed Split AC is better choice for smaller span.

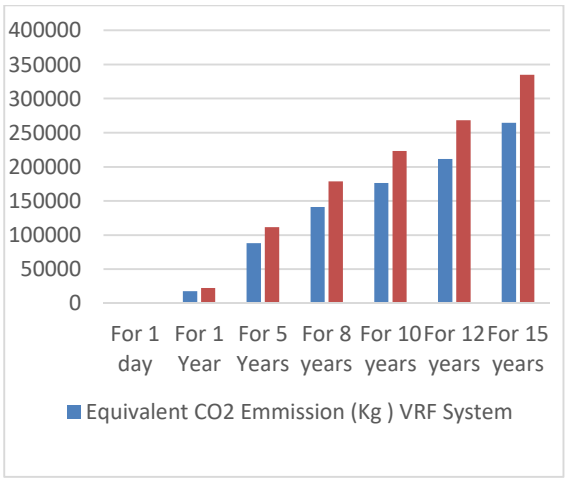

Figure 3. 9: Equivalent CO_2 emission (Kg) Chart for VRF vs Split AC

3.1.4 For 12 hours of working

As the working hour is high enough, so based on cost comparison analysis it is observed that VRF Air-Conditioning System is a better option than the Fixed Speed Split Air-Conditioning System for an application for 10 HP of Capacity of Air-Conditioning System. As the cost saving starts after the 5th year of operation, and the total cost saving to be done till 15th years of operation is good enough more than 9%. So it is advised to opt for VRF system. The Graph is attached below in figure 3.10.

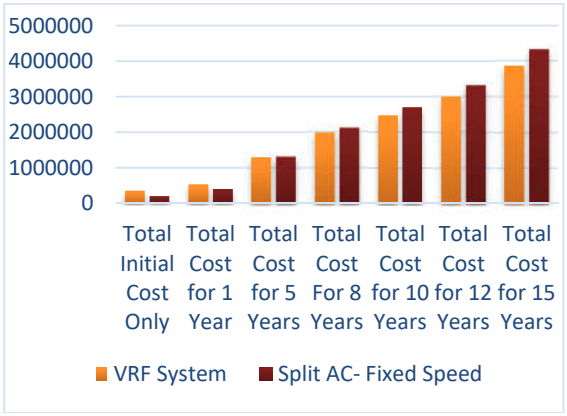

Figure 3. 10: Total Cost (INR) chart for VRF vs Split AC

Payback Period for differential investment: The payback period for differential investment is decent 9 Years. So VRF system is a better choice for air-conditioning for 12 hours of operation per day.

Result: VRF System is a better choice than Fixed Split AC System.

3.1.5 For 15 hours of working

As the working hour is very high, so based on cost comparison analysis it is observed that VRF Air-Conditioning System is surely a better choice than the Fixed Speed Split Air-Conditioning System for an application of 10 HP air-conditioning system. As the cost saving starts after the 5th Years of operations & total cost saving to be done till 15th years of operation is very good more than 11%. So it is advised to opt for VRF system. The Graph is attached below in figure 5.

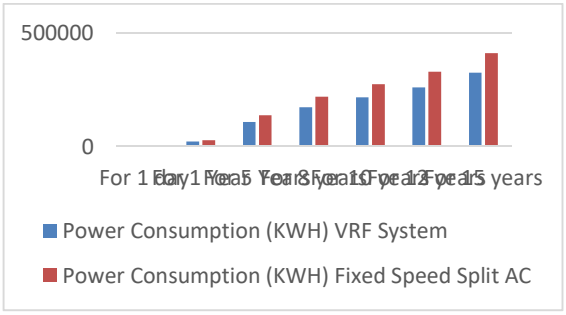

Figure 3. 11: Power Consumption (Kwh) chart for VRF vs Split AC

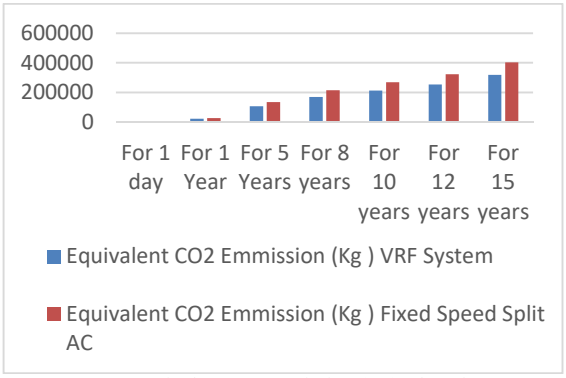

Figure 3. 12: Equivalent CO2 Emission (Kg) Chart for VRF vs Split AC

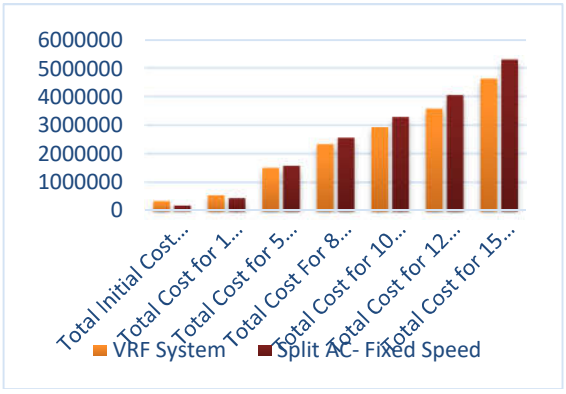

Figure 3. 13 : Total Cost (INR) chart for VRF vs Split AC

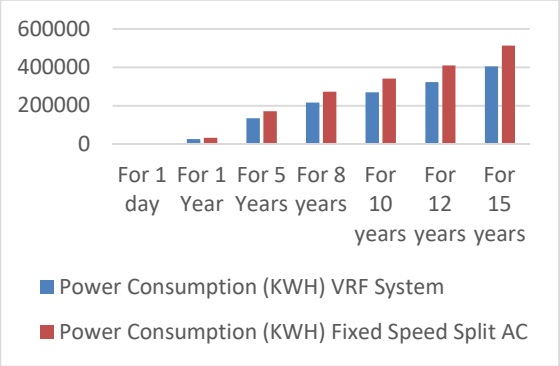

Figure 3. 14: Power Consumption (kWh) chart for VRF vs Split AC

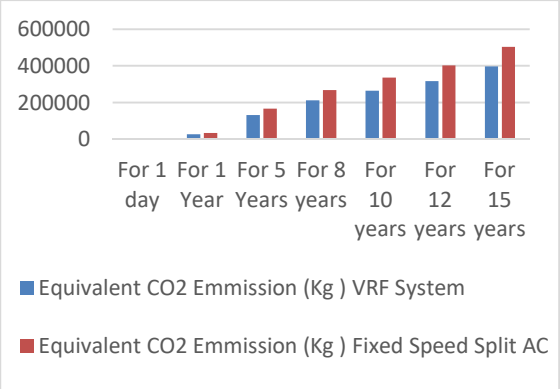

Figure 3. 15: Equivalent CO_2 Emission (Kg) chart for VRF vs Split AC

Payback Period for differential investment: The Payback period is very good 7 Years for differential investment in case of using VRF system. So here VRF air-conditioning system is surely a better choice for 15 hours of operation per day.
Result: VRF System is surely a better choice than Fixed Speed Split AC System.

4. CONCLUSION & FUTURE SCOPE

The conclusion based on the dissertation report is mentioned below.

a. The initial cost (cost of equipment + cost of installation) of VRF air conditioning system is higher than that of the Fixed speed split type air-conditioner.
b. The cost of operation is cheaper for VRF system than that of the Fixed speed split type air-conditioning system, as Power consumption for VRF system is lesser than that of the Fixed speed split type air-conditioning system.
c. The cost of annual maintenance is higher for VRF system that of the Fixed speed split type air-conditioning system. The cost of spare parts are covered under comprehensive annual maintenance cost.
d. If the average running time/working time of air-conditioning system is less than or equal to 8 hours per day- Fixed Speed Split Air-conditioners are better choice than VRF system in terms of initial investment, cost optimization & value for money.
e. If the average running time/working time of air-conditioning system is equal to or greater than 12 hours per day- VRF System is always a better option than Fixed speed Split Air-conditioners in terms of better power saving & longer average life, which makes VRF most cost effective & value for money.
f. In short for small & mid-size households where the air-conditioning system capacity is up to 50HP & the hours of operation/working is up to 10 hours a day- Fixed Speed Split Air-conditioners are value for money & better than VRF system in terms of less initial investment & cost optimization for short term of usages up to 10 years.
g. VRF system is more efficient & environment friendly based on low electricity consumption & thereby equivalent CO2 emission can be reduced to environment.
h. The overall foot print area of Outdoor units are lesser in case of VRF Air-conditioning system comparing to the Fixed speed Split Air-conditioning System. Space Saving is there with VRF system on the roof top. As number of VRF outdoor units are very less comparing to the number of outdoor units of Fixed speed Split Air-conditioners.
i. The building elevation is not being disturbed by using VRF air-conditioning system, as the number of Outdoor units are very less and can be kept over the roof top very easily, as they can support and work easily around 150 meters of actual distance between outdoor unit & farthest indoor unit. However in case of Fixed Speed Split AC- building elevation may be disturbed if all the outdoor units are not installed over the rooftop, as the maximum actual distance supported by Fixed Speed Split Air-conditioners between outdoor unit & indoor unit is around 15 meters only.
j. VRF Air-conditioning System is very suitable for high rise buildings without disturbing the elevation of the building, while Fixed Speed Split Air-conditioners are useful for small domestic/commercial application in small sized buildings.
k. In Short for Commercial/Industrial Application VRF System is always a good choice and highly recommended due to its heavy duty working capacity, power saving, longer life span, easy to operate & maintenance process.

For Domestic/Household Application Fixed Speed Split Air-conditioning System can be better

option if the Working hour is limited up to 10 hours & System Capacity is limited up to 50 HP due to its low initial cost, simple to operate & ease of maintenance.

The analysis done here is between VRF Air-conditioning system with Wall mounted type indoor units & Normal Fixed Speed Split Air-Conditioners (3-star rated Wall Mounted-cooling only). All the calculations & analysis have been done for cooling only operations.

The similar kind of analysis can be done & elaborated further for the VRF system vs Invert Split Air-conditioners or VRF system vs Hot and Cold Split Air-conditioners. Both Cooling & Heating operation can be considered for analysis.
The similar type of analysis can be done further for VRF system vs individual Ducted type or Cassette type Split air-conditioners for further application. The future scope of work is quite there to broaden the results & conclusions.

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