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Energy Performance Comparison of Inverter based Variable Refrigerant Flow Unitary AC with Constant Volume Unitary AC

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Abstract

The Variable Refrigerant Flow (VRF) technology has emerged as promising alternative to conventional systems, especially for small residential and commercial buildings which are largely untouched in regard to the energy efficiency of space conditioning systems despite the huge energy saving potential. This study aims to find out whether VRF split system provides an energy efficient and viable retrofit option for this sector. This paper compares the performance of an inverter based VRF Unitary AC with Constant Volume Unitary AC using the field performance testing. Both systems were installed in two geometrically and thermally identical rooms, with 14.5 m^2 floor area each. Observations were made in the months of January to May, the systems were operated from 10 AM to 6 PM, auxiliary heating was also provided to vary the zone internal load conditions; the auxiliary heat load provided by the electrical heaters was 2 kW and 4kW. The results were analyzed and it was found that the VRF technology is energy saving only when it works on part load conditions; minimum (negative) savings were observed when the outdoor temperature was equal to the rated outdoor DBT i.e. when the system was operating at full load conditions while maximum savings i.e. 40% were observed when the outdoor DBT is nearly equal to the indoor set point temperature.

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Keywords: HVAC; Variable Refrigerant Flow; Constant Volume AC; Energy Saving; Part Load

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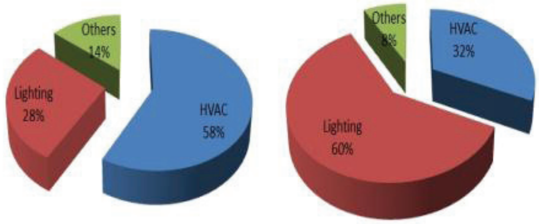
1. Introduction

In the current scenario of energy crisis, researchers are looking for the energy efficient solution for each and every energy consuming technology. The consumption of fossil fuels and the emissions of greenhouse gases associated with energy generation lead to considerable monetary costs and environmental consequences, ACs being the largest energy consumers; an alternative technology solution is a must for the HVAC systems. The VRF technology due to its flexibility and high efficiency in comparison with traditional central air conditioning systems is a promising solution for the HVAC systems. The big difference between VRF systems and conventional HVAC systems is that they adjust cooling/heating output by modulating the refrigerant flow continues with the variable speed compressor.

Nomenclature

HVAC	Heating Ventilation and Air Conditioning	COP	Coefficient of Performance
VRF	Variable Refrigerant Flow	DBT	Dry Bulb Temperature
VAV	Variable Air Volume	1 TR	One tonne of Refrigeration
BEE	Bureau of Energy Efficiency		



Energy Consumption in Residential Sector

Energy Consumption in Commercial Sector

Figure 1 Breakup of Energy consumption in buildings (BEE)

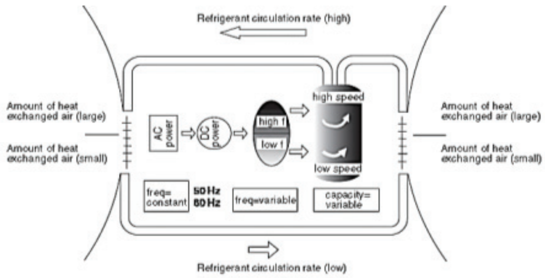


Figure 2 Schematic view of the Inverter Principle (Service Manual Daikin Inverter Pair)

A VRF based unitary AC (Fig. 2) is the modern form of the VRF system where it uses an inverter-driven compressor it can either be a single split system or a multi split system with either one or many indoor units connected to one single outdoor unit. The inverter compressors are capable of changing the speed to follow the variations in the total cooling/heating load as determined by the suction gas pressure measured on the condensing unit. The capacity control range can be as low as 6% to 100%. The ability of a VRF based unitary AC to control the speed of the compressor motor eliminates stop-start cycles. This in turn makes the ACs less prone to breakdowns and cheaper to run. Goetzler et.al. (1) discussed the history and applications of VRF systems and suggested that buildings with multiple cooling/heating zones such as multi-story buildings are best fit for a VRF system. It provides cooling in one zone and heating in another zone by transferring the heat removed from the cooling zone to the heating zone. Shao et al. (2) presented the concepts of frequency at zero refrigerant mass flow rates and the power input at zero frequency, both of which are characteristics of inverter compressors, the authors found that there is an optimal frequency to make COP at the top point, which is usually the basic frequency. Masuda et al. (3) observed that, the refrigerant flow rate for the indoor unit installed to a room with higher cooling load was much more than the other indoor unit which have low load. It was concluded that the VRF could control the refrigerant flow rate of the indoor units individually and respond to the cooling loads. Aynur et al. (4) conducted a field-performance test with a multi-split VRF system in an actual office suite in order to provide real time operational characteristics of the system. Two different control modes (individual and master) were applied to the system. In the individual control mode, all indoor units were controlled by their own individual thermostats located into each zone. In the master control mode, all indoor units were controlled by only one thermostat which was located in the centre of the office suite. It was concluded that the multi-split VRF system in the individual control mode provided better thermal comfort for multiple rooms with higher efficiency compared to the master control mode. Zhou et al. (5) compared the VRF system with two conventional air conditioning units. As part of their analysis, the authors found that the VRF unit is the most energy efficient system. They found that the VRF system was 22.2% more efficient than VAV system. Also the VRF unit was 11.7% more energy efficient than the fan-coil plus fresh air (FPFA) system. Aynur et al (6), does experimental evaluation of the ventilation effect on the performance of a VRV system in cooling mode and compared VRF systems to VAV systems numerically and found that VRF systems can save from 27.1% to 57.9% of energy. Li et al. (7) simulated and experimentally monitored the VRV system on an hourly basis and found that VRV system has higher coefficient of performance than their rating. Zhou et al. (8) investigated the performance of a multi-split VRF system with the EnergyPlus dynamic building energy simulation program. A module for the multi-split VRF system was developed and imported into EnergyPlus. It was found that the COP of the multi-split VRF system increased when the system worked in part load conditions due to the high part load efficiency. Besides, the developed model was used for a comparison study performed in a 10-story office building in Shanghai. It was obtained that the multi-split VRF system saved more than 20% energy compared to a VAV system. This study uses experimental approach which fulfils the objective to investigate the performance of the VRF based unitary AC with respect to a constant volume AC in order to analyse the performance of these systems in different indoor and outdoor conditions. Energy saving potential of VRF system with specific conditions was observed and indicated.

2. Experimental Study:

An experimental setup was developed to measure the performance of an inverter based VRF and conventional split AC Table 1 provides the site location summary. The test setup includes the standard single brick wall building with a fiber cement pitched roof (Table 2). Two identical rooms of the building are fitted with the Split type AC, one with inverter based VRF AC and other with conventional AC. In order to observe the differences between systems more clearly, experiments were conducted and observations were recorded from 11:00 AM to 06:00 PM. Auxiliary heating equipment was started one hour prior to the scheduled observation to achieve stable thermal conditions within the zone.

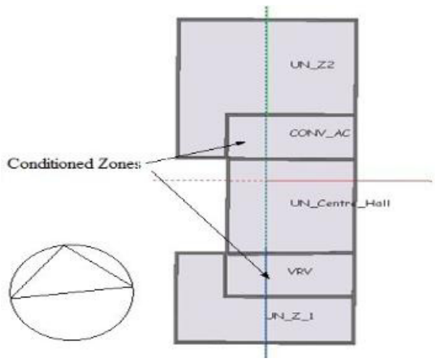


Figure 3 Layout of Building

Figure 4 Experimental Setup Centre for Energy Building

2.1 Equipment's Detail:

Two split AC's are fitted in two zones one being the conventional AC (Table 3) and other an inverter based VRF AC (Table 4). Two electric room heaters were used to provide variable internal load conditions in both conditioned zones (Table 5). Data Acquisition; Readings of Energy consumption, Indoor Temperature, Outdoor Temperature, instantaneous current and voltage and zone surface temperature are taken on hourly basis (Table 6).

Table 1 Site Location Summary

S.No.	Content	Details
1	Weather File	Jaipur-Sanganer
2	Latitude [deg]	26.92°
3	Longitude [deg]	75.82°
4	Elevation [m]	426 m
5	Time Zone	+5:30 GMT
6	Building tilt from North Axis	10°

Table 2 Construction Details

S.No.	Construction	Details
1	Wall	4" Single Brick Wall with Cement Plaster
2	Window	2 mm Clear Glass with Window Blinds
3	Roof	Fiber Cement Pitched Roof with 30^0 Slope
4	False Ceiling	Floor to Ceiling Height 9 ft

Table 3 Constant Volume Split AC Specifications
(Source: Daikin consumer manual FTKD50FVM)

Description	***Unit***	***Model***
Capacity Rated	TR	1.50
COP Rated	-	3.40
Air Circulation	m^3/min	17.50
Operating Voltage	V	230
Running Current Rated	A	6.80
Power Consumption Rated	W	1,530
Star Rating		5 Star

Table 4 VRF based Unitary Split AC Specifications
(Source: Daikin consumer manual FTKD50FVM inverter pair)

Description	***Unit***	***Model***
Capacity Rated (Min.-Max.)	kW	5.20 (1.5-5.9)
COP Rated	-	3.25
Air Circulation	m^3/min	16.80
Operating Voltage	V	230
Running current Rated	A	7.00
Power Consumption Rated (Min. -Max.)	W	1,600 (450-2,300)

Table 5 Heater Specifications
(Source: Usha Consumer Manual Electric Heater**)**

Make and Model	**Usha HC 423**
Heating Application	Air inlet vents
Heater Settings	3 (665W/1330W/2000W)
Power Consumption (W)	2000
Voltage (V)	230

Table 6 Data Acquisition Instruments

Parameter	**Equipment (Accuracy)**
Zone temperature ^{0}C	Fluke 971 temperature humidity meter
Zone Surface temp.^{0}C	Infrared gun (0.01)
Outdoor Temperature ^{0}C	Weather station (MNIT) (0.01)
Energy consumption kWh	Energy meter (0.01)
Instantaneous Current Amp.	Energy meter (0.01)
Instantaneous Voltage V	Energy meter (0.01)

3. Result and Discussion :

Performance data of both VRF and Conventional systems were recorded during months of Jan, Feb and March using different sensors and indicators, results of energy consumption, average indoor temperature and electrical loads were evaluated on daily and hourly basis & plotted for the graphical evaluation. Fig.5 displays the zone average temperature of VRF based unitary AC and conventional AC on Jan 11 with internal heat load of 4 kW with thermostat set point of 23° C. Similar temperature profile is observed for all days.

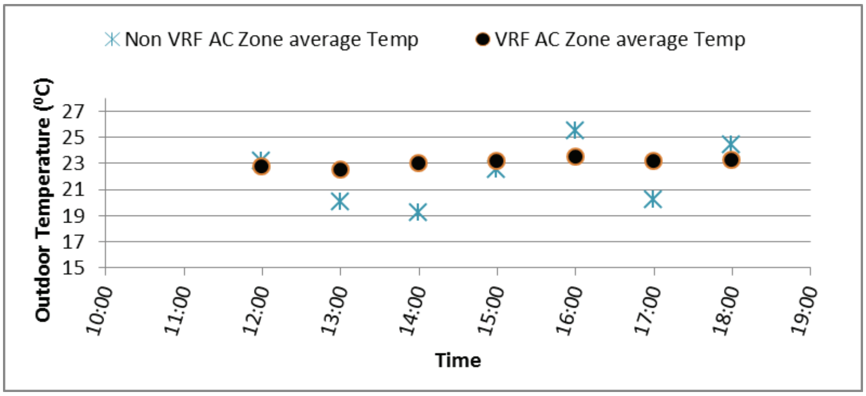


Figure 5 Zone Avg. Temp. Profile of VRF and Conventional AC throughout a Day

From Fig.5 we can conclude that the average zone temperature is more closely met to the set-point by the VRF based unitary AC, whereas fluctuations of the order of ± 2.0 °C are observed with the conventional AC average zone temperature. It suggest that VRF based unitary AC system provide better thermal comfort conditions & in more precise manner than the conventional AC system.

Fig.6 shows graphical representation of energy consumption (kWh) of both AC systems and hourly variations of ambient temperature. Energy consumption of both the AC systems increasing with increase in outdoor temperature, it can be observed that the VRF based unitary AC is more sensitive to the outdoor temperature. At the outdoor temperature of 35 °C (rating condition of both systems) the energy consumption of both AC units is of the same order.

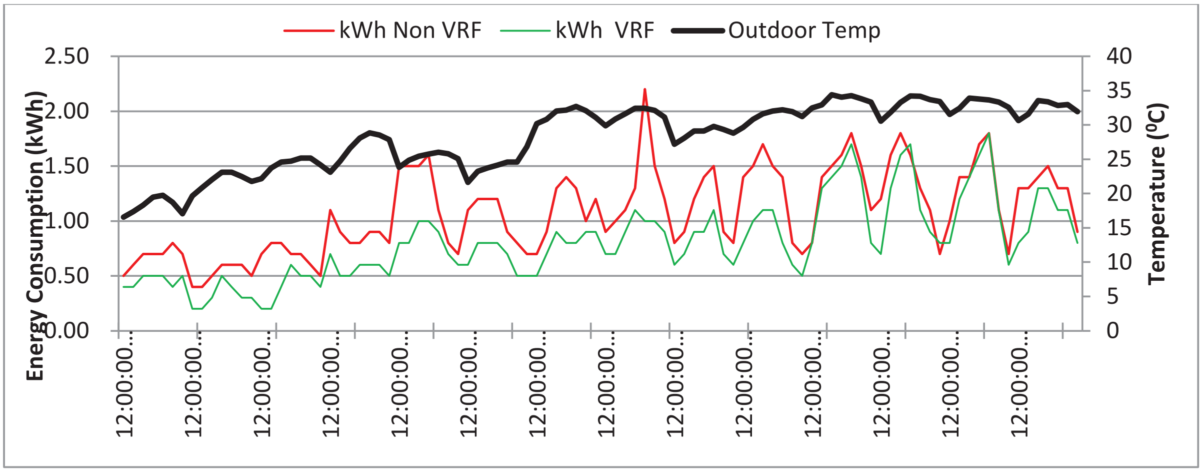


Figure 6 Hourly Variations of Energy Consumption and Outdoor Temperature

Hourly energy saving of VRF based unitary AC with respect to conventional AC is shown in Fig.7 from which it can be concluded that maximum saving occurs when the outdoor temperature is around 23 °C to 25 °C and minimum when outdoor temperature is more than the rated outdoor DBT.

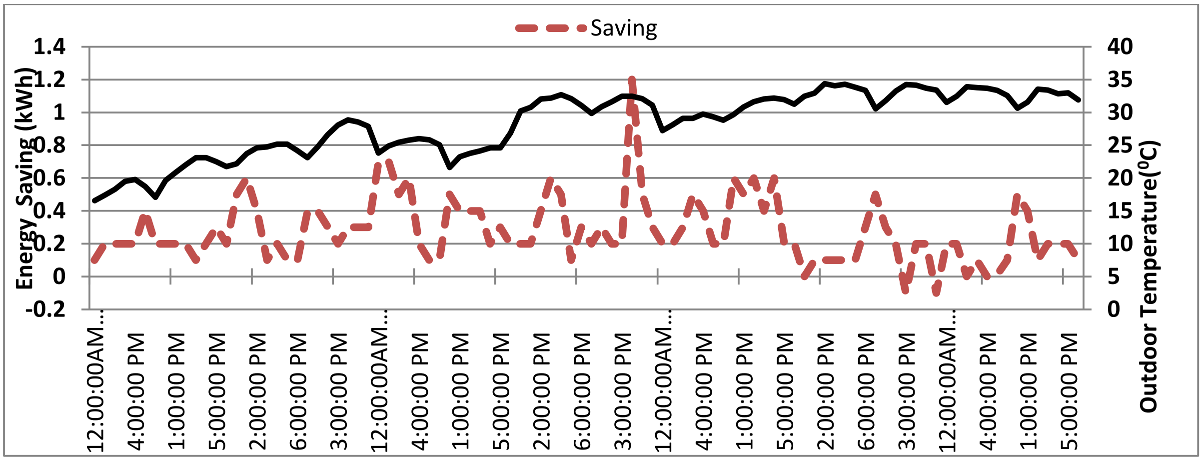


Figure 7 Hourly Saving of VRF AC and Hourly Variations of Outdoor Temperature

A spike in Fig. 6 and Fig. 7 at 4 PM can be seen; at this instant during performance logging a power fluctuation was observed which resulted in the sudden restart of both AC systems. These plots display the ability of VRF based unitary AC to adjust according to the load at startup, whereas a conventional AC system draws more power at startup.

Fig. 8 shows hourly pattern of electrical load for both AC systems, this plot was drawn from the instantaneous readings of voltage and current drawn by AC systems. It shows that the conventional AC cycles between either full capacities or off conditions whereas VRF based unitary AC adjusts its capacity according to the heat load.

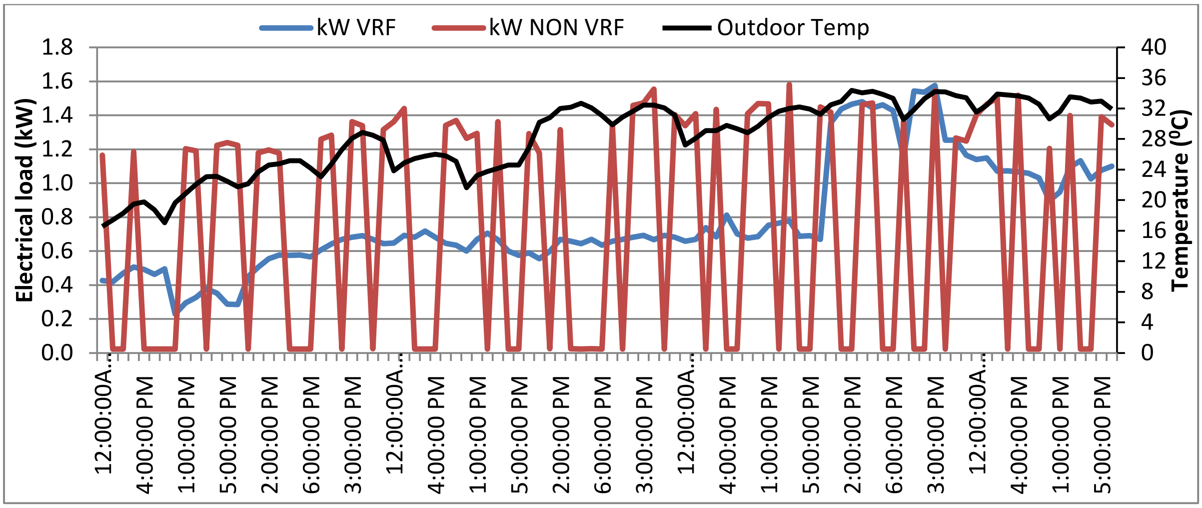


Figure 8 Hourly Variations of Electrical Load of both AC systems and Outdoor Temperature

Fig. 9 displays the daily energy saving of VRF based unitary AC. The saving from VRF based unitary AC is in range of 10-40%. Minimum savings were observed when the outdoor temperature is equal to the rated outdoor DBT i.e. 35 ^{0}C and the systems were operating at nearly full load capacity and maximum savings were observed when the outdoor DBT is nearly equal to the indoor set point temperature and the system loading was at around 40%. Daily energy consumption with daily minimum, maximum and mean temperature can be observed from fig. 9.

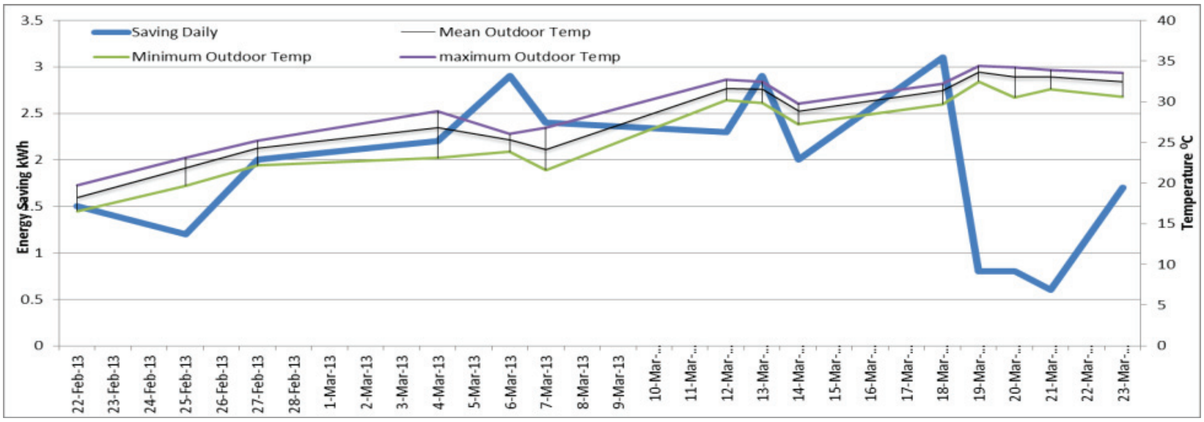


Figure 9 Daily Energy Saving of VRF AC with Mean, Max and Avg. Outdoor Temperature

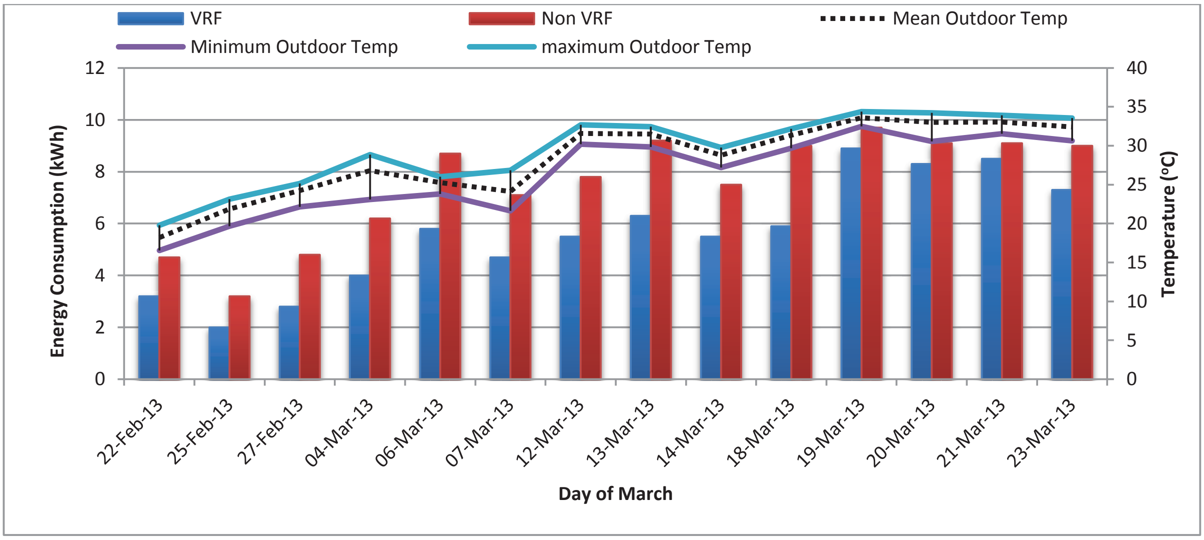
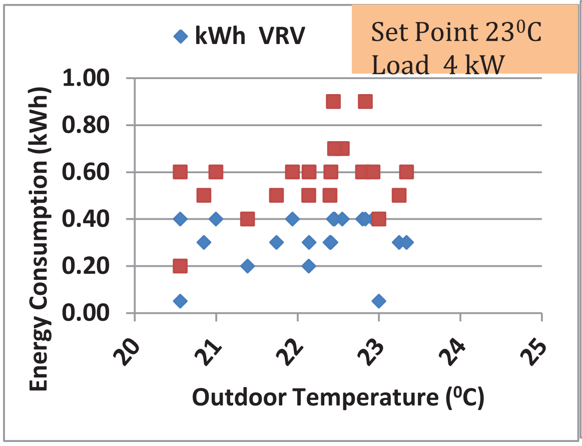


Figure 10 Daily Energy Consumption with Mean, Max and Minimum outdoor Temperature

This graph (Fig.10) is plotted with constant internal heat load and constant set point temperatures for both systems and it can be observed that as the outdoor temperature raises, energy consumption of both the AC systems increases, however the energy consumption of VRF based unitary AC is always smaller, with gradual increase in daily temperature.

Fig. 11 shows performance of both systems against low ambient temperatures with 4 kW internal loads. Energy consumption of constant volume AC is increasing at higher rate with increase in outdoor temperature, as compared to VRF AC. The energy saving from VRF AC consequently decreases at low temperatures reason being that at low loads constant volume AC compressor does not start if the zone temperature is within the temperature band of ±2 ^{0}C from set point whereas VRF AC turns on as soon as the zone temperature crosses the set point temperature. In Fig.12 performance of both the systems is plotted at moderate ambient temperatures ranging from 15 ^{0}C to 35 ^{0}C with equipment load of 2 kW. Maximum energy saving was recorded at around 23-24 ^{0}C. As the ambient temperature increases both the systems shift towards the full capacity and since VRF AC produce energy saving based on the frequency principle (2) , it only gives energy savings at part load conditions, it behaves as a normal AC at full load conditions resulting in no energy savings.



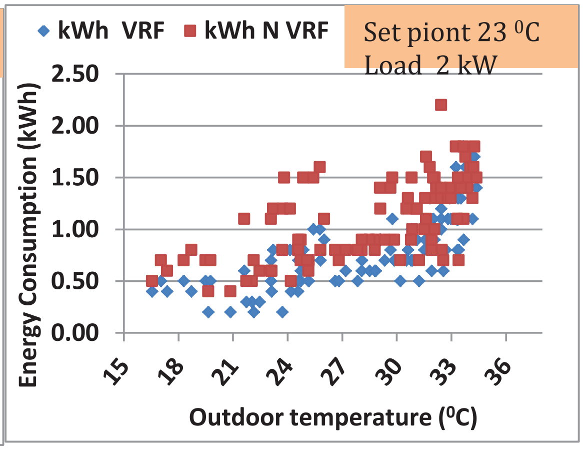


Figure 11 Performance of AC systems at Low Outdoor Temperatures

Figure 12 Performance of AC systems at Moderate Outdoor Temperatures

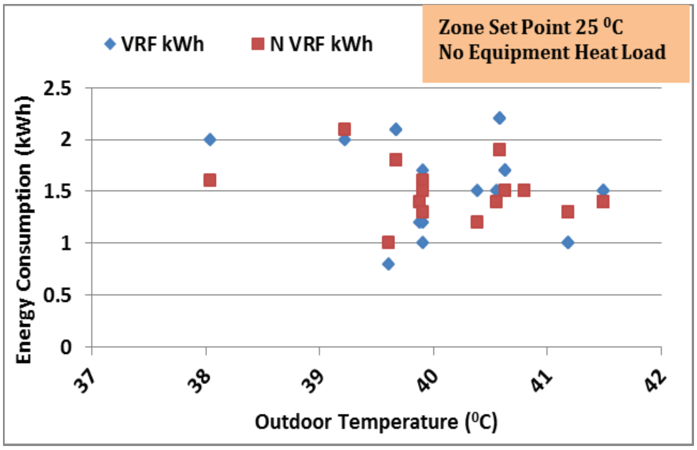


Figure 13 Performance of AC systems at High Outdoor Temperature

Fig. 13 shows the performance of AC systems at high ambient temperatures (full load conditions); VRF AC consumes more energy than constant volume AC due to the fact that VRF AC has an extra component which corresponds to the energy consumption of 3% to 5%. VRF AC is consuming more power at ambient temperature of 38 ^{0}C which is the conditions at the time of startup (morning 11 AM), higher consumption at this point might be due to the capability of the VRF AC to quickly meet the set point temperature at startup, by running at full capacity and then reduce the capacity according to the load.

4. Conclusion

In this study, performance of a variable refrigerant flow (VRF) based unitary AC was compared with a constant volume AC in various ambient conditions. Observations were taken for three different cases viz. low ambient temperatures and high zone internal equipment load, moderate outdoor temperatures and moderate equipment load, high ambient temperature and low equipment load.

Observations were taken for winter set point 23 ^{0}C and summer set point 25 ^{0}C and conclusions were drawn from the tabular and graphical representation of the observations. Energy savings upto 40% were recorded in VRF system at moderate temperature conditions however at high temperature conditions VRF AC consume more power as compared to the constant volume AC. Based on the analysis it can be concluded that

- VRF systems meet the zone set point without significant fluctuations in the zone temperature whereas in constant volume system fluctuations of ±2 ^{0}C were observed. It can be observed that with same set of functional equipment's, the VRF system shows greater precision while the constant volume system show fluctuations.

- VRF AC only gives energy saving at part load conditions, therefore VRF technology must be used only where the AC runs at part load conditions mostly.

- In VRF systems electric consumption only changes when heat load on the system changes and electrical load profile does not fluctuate. Whereas in a constant volume system there is frequent variation in the electric consumption due to its ON OFF cycle operation which also produces harmonics in the electrical signal.

Therefore it can be concluded that VRF technology is emerging as the energy saving technology but its energy saving capability largely depends on the time span when it operates at part load. When working at full load VRF system does not work as energy saving option.

Acknowledgement

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Refrences

[1]. Goetzler, William. Variable refrigerant flow (VRF) systems, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2007; pp. 24-31.

[2]. Shuangquan Shao, et al. Performance representation of variable-speed compressor for inverter air conditioners based on experimental data, International Journal of Refrigeration, 2004; Vol. 27, pp. 805–815.

[3]. M. Masuda, K. Wakahara and K. Matsui. Development of a multi-split system air conditioner for residential use. 2, ASHRAE Transactions, 1991; Vol. 97, pp. 127–131.

[4]. Aynur, Tolga Nurettin, Hwang, Yunho and Radermacher, Reinhard. Field Performance Measurements of a VRV AC/HP System, International Refrigeration and Air Conditioning Conference, 2006; 756.

[5]. Y.P. Zhou, et al. Simulation and experimental validation of the variable-refrigerant-volume (VRV) air-conditioning system in EnergyPlus, Energy and Buildings, 2008; Vol. 40, pp. 1041–1047.

[6]. T.N. Aynur, Y. Hwang and Radermacher. Experimental evaluation of the ventilation effect on the performance of a VRV system in cooling mode—Part I, R. 3, Experimental evaluation HVAC&R Research, 2005;Vol. 46, pp. 373-383.

[7]. Li, Yue Ming and Wu, Jing Yi. Energy simulation and analysis of the heat recovery variable refrigerant flow system in winter, Energy and Buildings, 2010; Vol. 42, pp. 1093–1099.

[8]. Y.P. Zhou, J.Y. Wu a, R.Z. Wang, S. Shiochi. .Energy simulation in the variable refrigerant flow air-conditioning system under cooling conditions, Energy and Buildings , 2007; Vol. 39, pp. 212–220.

[9]. T.N. Aynur, Y. Hwang and Radermacher. Experimental evaluation of the ventilation effect on the performance of a VRV system in cooling mode—Part I., R. 4, Experimental evaluation, HVAC&R Research, 2008;Vol. 14, pp. 615-630.