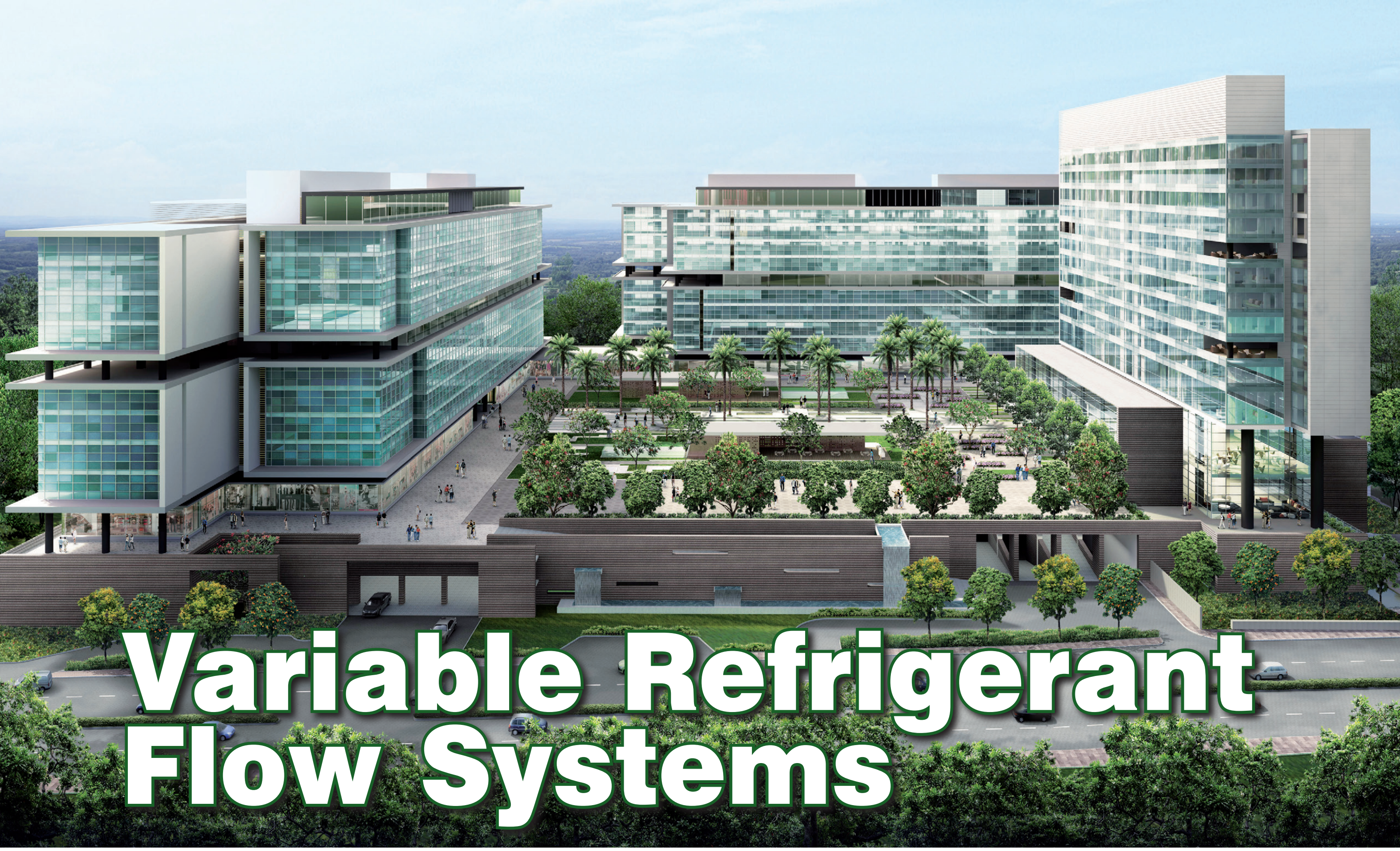

Variable Refrigerant Flow Systems

Tech Park – 2, Pune uses a total of 3,966 TR VRF systems for HVAC

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Introduction

Variable Refrigerant Flow (VRF) systems were introduced in India almost 30 years ago in the early 1980s, and one of the first installations was at the residence of Habil Khorakiwala, founder of Wockhardt Limited, in Mumbai. I believe the system is still functioning properly.

Initially the use of VRF was limited due to high cost. The scenario changed when a large number of manufacturers jumped into the fray. Currently, due to intense competition, VRF costs are comparable to conventional central plants for comfort cooling applications, and lower in some cases due to duty benefits. Over a period of time, the technology has become more and more acceptable and owners, erectors, operators, and maintenance staff have grown familiar with it, so much so that now, tens of thousands of tons of equipment is being installed every year and this segment is on a high growth trajectory.

The term VRV (Variable Refrigerant Volume), though synonymous with VRF systems, is the registered trade name for Daikin products that use variable refrigerant flow. VRF is the generic term widely used by other manufacturers.

Initially these systems used R-22 refrigerant. With the imminent phase out of R-22, alternate refrigerants were introduced. All manufacturers currently offer systems with R 410A.

VRF systems have the inherent characteristic of lower than proportional operating power consumption at part loads. For example, at 50% load, the IkW/RT is lower than 50% of full load. Thus, it scores over chilled water plants, which have large parasitic power usage. In a central plant, power usage other than for operating chillers can be clubbed as parasitic power, and includes power requirement for condenser water pumps, chilled water pumps, cooling tower fans, water treatment systems, fill up, system pressurization, etc. Under part load conditions, the pumps and other drive motors have to be operating, and though the chillers can unload to some extent, the additional power for other motors is generally constant even when there are load variations due to usage or seasonal and diurnal variations.

Principles of Operation

VRF systems are direct expansion type, in which the refrigerant is circulated in the indoor units to achieve cooling. A standard DX system has five components,

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namely; a fixed speed compressor, an air cooled condenser, a DX evaporator coil, and an expansion device, which is either a capillary tube or a thermostatic expansion valve. All these components are connected by refrigerant piping to form a circuit. The fifth component is the temperature control device, in this case a thermostat. The system is cycled on-off to maintain the indoor temperature around the set point.

Because of hysteresis in the control circuit, the system is switched off when the room temperature reaches below the set point and is switched on above the set point. Thus, the temperature is maintained within a certain band, with the bandwidth depending on system inertia. (Hysteresis is the difference in the value of the process; in this case the temperature difference between the set point and the change-over from on to off, or vice versa. This is the resultant of the inertia in the sensing element, and the difference required to change the existing condition of the contacts.)

In VRF systems, the components are similar but with some notable differences. The compressors have some form of capacity control. Either the speed of the compressor can be varied by incorporating a Variable Speed Drive (VSD), as in inverter units that are typical among the Japanese brands, or by fast loading and unloading of compressors, as in Digital Scroll compressors popularized by Emerson. Air cooled condensers use variable speed fans. The cooling coil of the indoor unit is very similar to standard units.

The expansion device is an Electronic Expansion Valve (EEV), which can sense inlet liquid temperature as well as gas outlet temperatures of the coil, and air temperature at the inlet and outlet of the coil. Based on the control scheme, the EEV opening is adjusted in very fine steps to maintain the room temperature, while maintaining suction superheat at the minimum stable level at the DX coil outlet.

The control device incorporates a pressure sensing device at the suction of the compressor, along with several other sensors. At the heart of the control scheme resides a microprocessor, which can accept inputs from the EEVs, all sensors, indoor units and compressors, and based on the special algorithm for that unit, give signals to control the capacity of the compressor by varying the speed or loading pattern, and switch on or off additional compressors so as to maintain the targeted suction pressure at the compressors.

As loads on indoor units increase, the room temperature will start to rise. This is sensed by the EEV and it is opened to admit exactly the required quantity of refrigerant that will maintain the superheat constant. With the rise in cooling load and the wider opening of the EEVs, the suction pressure tends to increase. This increase is relayed to the microprocessor along with the percentage opening of the EEV and the capacity of the IDU. The microprocessor then initiates a signal to increase the capacity of the compressor by increasing its speed or increasing the on time for the loaded part of the compressor.

If the loads on IDUs decrease, the reverse process starts and the compressor capacity is reduced. After a "wait and watch" period, the microprocessor again goes through the process to check and maintain the suction pressure constant. This way, the cooling capacity is matched to the required cooling load.

At part loads, with the use of the full available area of the air cooled condensers and the control of the fans speeds, the lowest possible condenser pressure is achieved. Further, at part loads, the suction pressure also rises, leading to reduction in the lift of the compressors that leads to lower power requirements. Therefore, at part loads the IkW/RT reduces dramatically.

As the values of various important parameters like pressures, temperatures, valve opening, room temperatures, on/off status and ambient conditions are logged at the microprocessor at fixed intervals, these values can be downloaded to assess the performance of the system at all times. This is a very powerful tool for the operators and the maintenance staff to keep the systems functioning properly.

Further, A VRF outdoor unit can be connected to a large number of indoor units. This also facilitates load diversity at part load conditions.

All this makes VRF systems very efficient at part loads. As most systems operate at part loads for nearly 99% of the operating time, better part load IkW/RT translates into lower overall power consumption.

Equipment for VRF

A typical schematic of the VRF system is represented in *Figure 1*, where one outdoor unit is connected by refrigerant piping (both liquid line and suction line) to a large number of indoor units.

The major components are:

1. Compressor, generally scroll or rotary type. The compressor can be fixed speed or variable speed depending on the design, and compressor capacity can be varied by changing its speed, as in compressors controlled by Variable Frequency Drives (VFDs). Both scroll and rotary compressors can be with variable speed, while scroll compressors can also achieve capacity control by rapid loading and unloading.
2. Air cooled condenser with fans.
3. A variety of DX indoor units in various configurations and capacities.
4. Interconnecting refrigerant piping for conveying liquid refrigerant to IDUs and suction line.

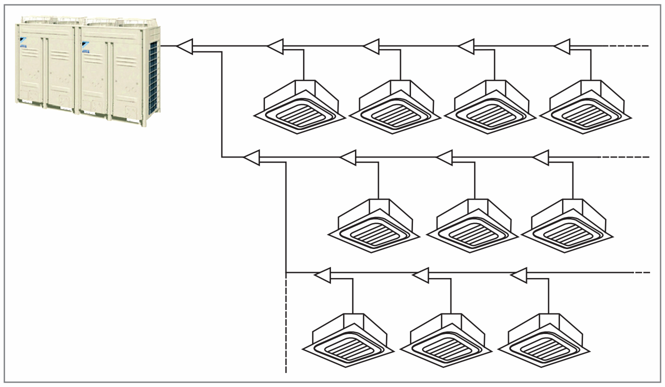

Figure 1: Typical schematic of a VRF system

5. EEV, which can measure liquid inlet temperature and gas outlet temperature, and modulate steplessly (or with a large number of steps between open and close), to maintain low levels of superheat.
6. Electronic control system for sensing the number of IDUs which are functional, the percentage of opening of individual expansion valves, suction pressure, and temperatures and pressures in the refrigeration circuit and to signal the compressor, fan etc. to be sequenced or loaded/ unloaded or to vary their speed in order to maintain design or set points.

Typically, outdoor units comprising of compressors, air cooled condensers, air circulating fans, refrigerant piping and controls are assembled. Sensitive components like the eletricals and electronics are suitably enclosed from the elements in one compact unit. Unit capacities generally vary from 8 HP to 20 HP depending on the design of individual manufacturers. It is possible to add parallel ODUs for increase in unit capacity and generally 3 or 4 modules can be clubbed together to form a larger unit.

The indoor units comprising of filter, fan and DX coil units can take many shapes and sizes, from ceiling mounted units to hideaways to ducted units. Typical indoor unit configurations are; Wall mounted split unit, One way cassette, Two way cassette, Four way cassette, Ceiling suspended unit and Ductable unit.

Addition of AHUs to IDUs

As these VRF units evolved logically from split units, their IDUs were generally very similar and had the issue of low cfm/RT, which made them suited for comfort applications. These units could not be used for applications where the cfm to RT ratio was higher, due to their inherent limitation of air flow rates. With more applications being called for, manufacturers have come up with different models using AHUs as the latest addition.

AHUs have the advantage of being able to match the cfm as well as loads, and the filtration requirements demanded by specific applications.

See *Figure 2* for a typical schematic diagram of an AHU coupled to VRFs.

The size or capacity of AHUs available to be coupled to ODUs can be from the smallest air flow rate of 2,000 cfm and 8RT to bigger units upto 50,000 cfm and 100RT. However, the size of compatible electronic expansion devices is limited and generally varies from 8 RT to 16 RT in some cases. For connecting to larger capacity AHUs, multiple units of expansion devices or kits are required to be connected in parallel.

VRF Applications

Some applications are listed below, though the list is not exhaustive:

- Residences
- Offices and IT Spaces
- Hospitals
- Malls and Showrooms
- Hotels
- Resorts

These typical applications are discussed in the following sections.

Residences

VRF air conditioning is an ideal solution for residences. Generally in a residence, all the areas served by a common system are never occupied or used simultaneously. The bed rooms would generally be occupied during the nights, while the common areas like family rooms, dining area and drawing halls would be occupied at various times during the day, with varying occupant loads, offering large diversities in AC cooling loads. The cooling loads can further vary due to the diurnal as well as seasonal variations in ambient conditions.

All in all, there would be large variations in the cooling loads over the full 24 hours in a day, as well as from day to day and season to season. VRFs address this variation very nicely by matching the cooling capacity to the required cooling load.

Offices and IT Spaces

In any medium sized or large office or IT space, it is generally noticed that the staff do not clock in simultaneously, but the office gets occupied over a period of time. Offices may get fully occupied over an hour. The staff also leaves at different times resulting in variations in occupancy. Further, all the staff is not generally present at all times or even at peak occupancy, and all heat generating equipment like computers, printers, fax machines, copiers and UPS, which generate heat due to the use of electrical power, are not used 100% at all times. The use of lighting and levels of illumination required also vary. Again, the ambient conditions contribute to variations in cooling loads depending on the time of the day and season, leading to loads which are not at peak and are not constant. VRFs are very effective in dealing with such variations.

Hospitals

Hospitals have certain areas which require air conditioning on a 24x7 basis, like patient rooms, 24 hour nursing stations, casualty areas, ICUs, and certain rooms which house critical

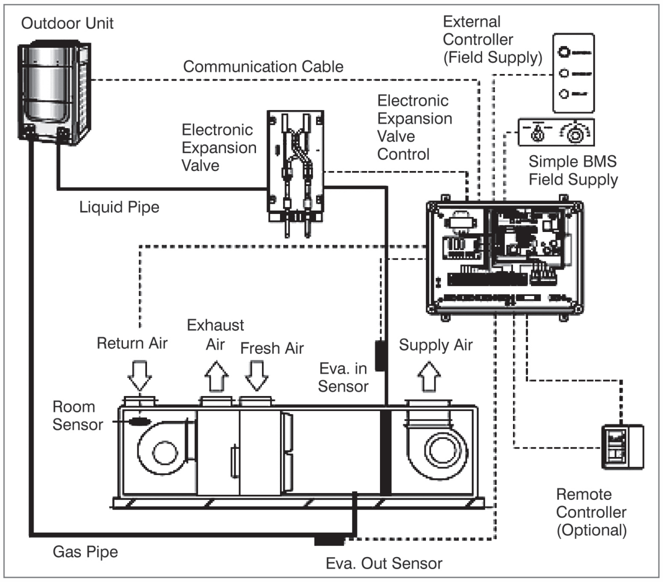

Figure 2: Schematic of AHU in a VRF system

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equipment, and certain critical areas such as blood banks and bone marrow transplantation areas. There are other areas that are not conditioned for all the 24 hours, like office and administration areas, maintenance areas, diagnostics, consultation rooms, entrance lobbies, day care sections and test labs. In India, some operation theaters are conditioned only when required.

In hospitals, there are specific requirements for fresh air supply, which is generally higher than normal AC applications, and some clean or sterile areas require a higher level of filtration and recirculation rate to maintain the required indoor conditions.

Due to this, the standard or prevalent type of indoor units associated with VRFs, which offer low cfm/RT, cannot be used. Further, due to the inherent limitation of small capacity indoor units, the filtration levels required in certain areas in hospitals could not be effectively addressed. Due to this, VRFs were used only for patient rooms and consultant rooms, and were not used for other areas. With the introduction of AHUs, which operate in conjunction with VRF outdoor units and offer the same advantages of control, it is now possible to cater to any air flow rate, at any pressure, which can address the higher pressure drops associated with the higher level of filtration required in certain areas. It is now feasible to use VRFs in almost any application in a hospital.

Malls and Showrooms

Malls are another segment in which VRFs can be used effectively. In a typical mall, there are some common areas which include corridors, food courts, public areas, entrance lobbies etc., and there are defined enclosed areas for small shops and bigger anchors.

The shops and anchors are usually conditioned with independent cooling units with their own controls which allow them to start and stop their equipment according to their own schedules, as well as to set the required temperatures and to exercise control on the system. The common areas are generally under the control of the common operators. The schedules of operation for these areas are generally the same as the opening and closing times of the mall, with fixed temperature set points.

However, the loads in the shops and anchors vary with the number of shoppers. Shopper density varies with the type of shop, the time of day and perhaps the season and the merchandise being marketed. The internal loads also vary depending on the use. Shops selling high value items like watches and jewellery generally have higher lighting levels. Loads in common areas vary with footfall and as per the time of day and the season. VRFs are well suited for such load variations.

Till some time back, VRFs were not very popular with interior designers due to the need to install a large number of small capacity units for the common areas. However, with the introduction of AHUs coupled to VRF ODUs, this issue has been addressed and interior designers can use grills and diffusers to suit their designs.

Hotels

A fair sized hotel would generally consist of many public areas such as lobbies, meeting rooms, banquet halls and restaurants, as well as guest rooms for the temporary residents travelling for business or pleasure. Public spaces are at lower levels while the guest rooms are normally at higher levels. The guest rooms are arranged around a common corridor at each floor level.

A look at the usage indicates that guest rooms are partially occupied during the daytime but are fully occupied from the evening onwards. The public areas, on the other hand, are functional and occupied during the daytime. Accordingly, load patterns for the rooms vary with the load being the maximum in early evenings, while peak loads for the public areas occur in the late afternoons or late evenings. Meeting rooms would be unused by late evening, but the banquets, restaurants and bars would be occupied from late evening onwards. Because of these variable loads, a VRF system works out to be the most efficient while meeting the varied temperature requirements of each room.

Here again, in the earlier days the public areas could not be served efficiently by VRFs due to the large loads and consequent requirement of a large numbers of IDUs, with their impact on the interiors. With the use of AHUs coupled to VRF ODUs, this problem has been addressed and air outlets can be designed to suit the interior decorator's requirements.

Resorts

Resorts by nature are very similar to hotels in their usage. However there are vast differences in their layouts. The public areas are located centrally, and are clubbed or connected together with open passages or corridors. The residential areas are spread out with one or two storey buildings separated by gardens or other landscape.

Individual VRF systems for each area are the ideal solution as they can take care of load variations, and only power supply needs to be provided to each unit, with the individual units being totally independent for switching on or off as well as for individual control as per guest requirement. VRFs avoid the shortfalls of a chilled water system – extensive piping carrying chilled water, with pipes routed underground, leading to corrosion both from inside and outside.

Fresh Air

One of the perceived drawbacks of VRFs was that there was no possibility of providing fresh air to IDUS. This is not correct, as the provision for fresh air in AHUs and ductable units is the same as in any other system – it can be supplied by ducts and fans if the indoor equipment is located in a room or enclosure. For the smaller ceiling mounted units like cassettes, there is a provision in the unit for connecting a fresh air duct.

The best method is to provide a small dedicated fan for fresh air with a small distribution network of ducting terminating in each IDU/cassette. In order to avoid air balancing issues, it is possible to used automatic duct flow controllers at the terminals. These units are now settable within a range.

VRF Options

With higher market penetration of VRF systems, VRF outdoor units are also available as water cooled units. These can be used if adequate water of the correct quality is available. Needless to mention, water cooled VRF units are more energy efficient than air cooled units.

Some manufacturers also offer floor standing units, similar to

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Package Units, as IDUs, which can be used for larger areas such as large halls, and if some floor space is available.

Recently, a couple of manufacturers have introduced VRF Units with integrated hot water generation systems. These units require different control units, which can sense the requirement of hot water and act as heat pumps or AC Units as per requirement. They are energy efficient and ideal for residences and hotels, where both hot water and air conditioning are required simultaneously.

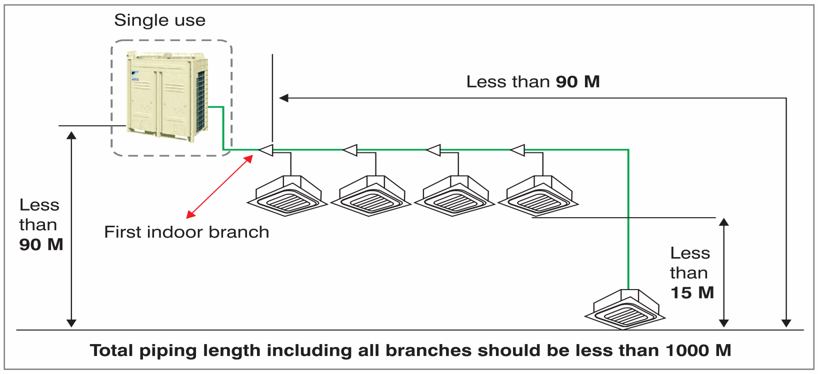

Figure 3: Limitations on pipe lengths

Installation Limitations

Even though VRF systems can be used for various applications, some of which have been mentioned above, these systems have to be applied within the limitations of the equipment in terms of sizes, pipe lengths, etc. Outdoor units can cover capacity ranges from 5 HP to 54 HP for some makes, while other makes can offer 80 HP units.

One module of outdoor unit can be connected to or serve upto 64 indoor units, while the ratio of installed capacity of IDUs to ODUs can vary from 50% to 200%.

The limitations on piping lengths are generally upto 165m of pipe or 190m of equivalent length to the farthest unit. The total length of piping can be as high as 1000m. In the worst case, the ODUs can be located 90m above the lowest ODU. If the ODU is located below the IDUs, the level difference is limited to 40m. The difference in levels of multiple IDUs connected to one ODU can be no more than 15m.

There are limitations on the external static pressure of condenser fans which, with special settings, can go upto 78Pa.

Case Study: A Very Large IT Park

The builders of a large Software/IT Park EON *(Figure 4)*, covering four buildings, each of one million sq ft area, opted for VRF systems. The total installed cooling capacity is in excess of 15,000 HP (around 13,000 RT). The yearly power consumption figure for VRF systems was simulated to be lower than conventional chilled water systems. This was a major deciding factor.

The other issues which drove the decision towards VRF were:

- As the location was in a declared SEZ, no duties or taxes were applicable. Hence, with a large component of imported equipment, the initial cost of VRF was found to be lower than chilled water plants, which have a large component of local materials.

Figure 4: Software Park at EON Special Economic Zone, Kharadi, Pune

- Another major factor in opting for air cooled systems was the scarcity of water.
- Further, these buildings were for multi-tenant use. With the incorporation of VRF units, the systems could be purchased as and when required by the occupants/owners. This gave the leeway to the builders to invest as and when needed, unlike in central chilled water plants where all piping etc. has to be installed upfront.
- For central chilled water plants, AC usage has to be measured through BTU meters, and proportional allocation for power usage of the main plant is to done. Allocation of proportional power usage has to include other costs as well for water usage, treatment etc. for the purpose of total billing. Other than this being cumbersome, the accuracy of BTU meters, and maintaining their accuracy over a period of time, is questionable, especially with corrosion of pipes, non clear water flows, air pockets or micro bubbles travelling with the chilled water, leading to incorrect measurements of water flow.
- In VRF plants, billing for the use of AC systems is simple and accurate, as you just need to install electrical energy meters.

The experience with the operation and maintenance of this large plant is generally good.

Failure rates and downtime are small. The figures are readily available for nearly 10,000 HP, served by 3290 compressors installed in 2007 and 2008:

IDU failures	:	Nil
Gas leaks	:	3 systems of 54 HP (i.e. 0.6 leaks per year)
HP/LP switch failures	:	9 (i.e. 1.8 units per year)
Compressor burn-outs	:	40 (i.e. 8 per year or 0.24% per year)

These figures are really encouraging and indicate what a good installation can achieve.

Conclusion

A large number of manufacturers are pushing VRF systems due to their inherent advantage of low power consumption, especially at part loads. Leading manufacturers are investing in VRF technology, given its high potential for growth. The initial disadvantages of VRF systems have been addressed by the manufacturers, leading to wider acceptance among the users. As a result, this segment is outgrowing the overall HVAC market. ❖