



Use of VRF Systems in Tall & Large Commercial Buildings

Part 4

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This is the 4th article in the series explaining the VRF technologies and their increasingly diverse applications. In the first article, I explained how the Copeland Scroll works and the principle behind the operation of the Digital Scroll technology. I concluded the article by explaining some of the key advantages of the Digital Scroll technology. In the second article, I provided a more detailed analysis and comparison between the DC inverter and Digital Scroll. I discussed the challenges of measuring the energy efficiency of VRF systems and talked about the advances that are happening on the Digital Scroll platform – namely, equipping the Digital

Scroll compressor with enhanced vapor injection technology. In the 3rd article, I explained how the electronic controller works in a VRF system. System design engineers have always been confronted with

a very complicated logic to drive VRF systems due to the various parameters that need to be managed and so, I explained the control logic in a very simple way. In this article, we are going to talk more about

About the Author

Arup Majumdar has a B. Tech in mechanical engineering from the Indian Institute of Technology, Kanpur and an MBA from the Indian Institute of Management, Ahmedabad. Arup has been instrumental in introducing the Digital Scroll technology to multiple OEMs spread across Asia, Middle East, Europe and North America and establishing this technology as a strong alternate to the incumbent Japanese inverter. He has been awarded the Emerson Technology Award for his contribution to establishing this technology globally. Arup is a regular speaker on modulated technologies in various industrial forums globally and has written several technical articles on this topic. He can be reached at Arup.Majumdar@emerson.com

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Chart 1: Examples of large commercial VRF applications

the diverse applications of VRF systems and specially focus on tall buildings and large commercial spaces. Traditionally, large commercial buildings have been air conditioned by chillers of various types, but now we have an increasing phenomenon of VRF being applied in such applications.

As can be seen from Chart #1, VRF has been applied for some really tall buildings and large spaces, like the Beijing Spaceflight Museum. Large spaces with high ceiling heights had been a limitation of VRF but that has been overcome through usage of the hybrid system. We will explain the hybrid a/c system through a case study in Korea.

In any building, there are two variations that happen to the a/c load demand. The first relates to the variations that occur during any day. Typically, in any commercial building, there is a base load and there is an element of variable load. This is especially true for the space that is on the periphery of the building. When the sun's heat comes in to the building, one side of the building picks up more heat load and when the sun moves to the other side, the load is shifted. This means that the spaces that are on the periphery of the building see a cooling demand pattern that is more variable than what is needed by the center of the office where the demand is more stable.

The second variation relates to the demand changes depending on the ambient temperature of the year. A study of the cooling load was done for an office space in Tokyo, Japan and Chart #2 shows the cooling demand for the summer season.

The chart clearly shows that the a/c system works at the 100% point for a very short period of time during the year. Most of the time, the machine is operating between the 30% - 75% load. Traditionally, a central

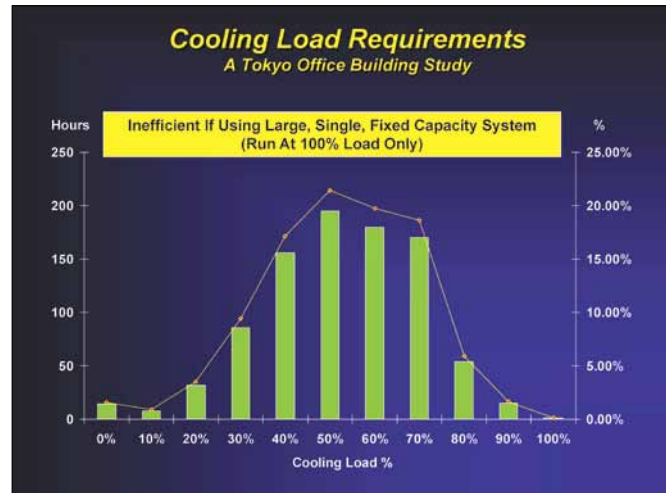


Chart 2: Cooling demand by hours for the season

air conditioning system consisting of air-cooled / water-cooled chillers with air handling units (AHUs) was considered the ideal choice for air conditioning large areas including tall buildings. The conventional choice of equipment for cooling and heating applications are:

Chiller:

- Centrifugal chiller (above 400 TR) with boiler
- Screw chiller (100 – 400 TR) with boiler
- Air cooled heat pump modular chillers (under 100TR)

Air Side Equipment:

- AHU with high velocity duct system, in which one AHU can serve several floors by using high velocity main ducts.
- AHU with low velocity duct system, in which one or more AHUs are installed for each floor.
- AHU with low velocity duct system along with fan coil units (FCU) to handle smaller areas/zones.

Using the above equipment, central air conditioning

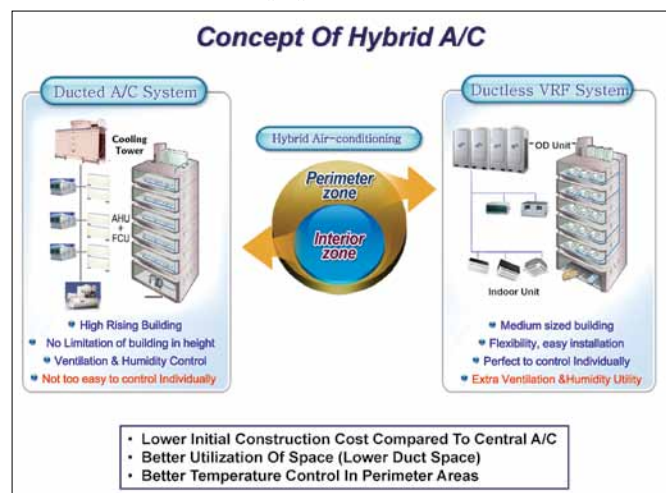


Chart 3: Hybrid system combines chillers and VRF

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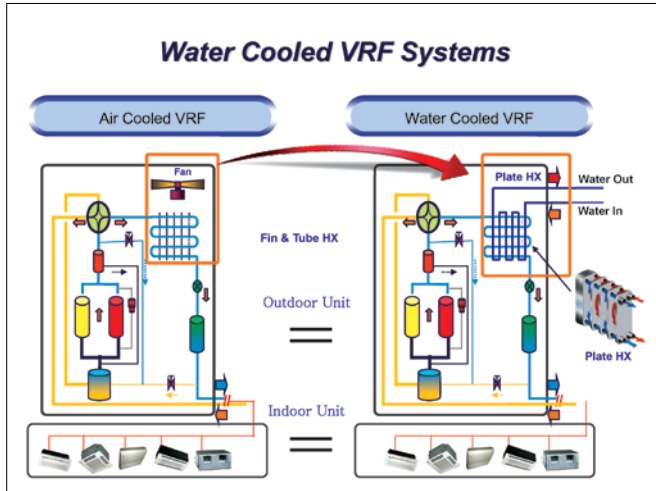


Chart 4: Air Cooled and water cooled VRF system configuration

systems have proven over a period of time their advantages such as: easier fresh air management, equipment centralized in plant rooms, good efficiencies for water cooled systems, etc. However, there are some issues which are not addressed by the central chilled water system and these are:

- Handling variable load – It is generally believed that chillers with an adequate diversity factor can handle variable loads effectively. Even though there are variables of “water flow”, “air quantity” etc, which can be controlled, there is a limitation on how much the chillers can adjust to the fluctuating load – on a daily and also seasonal basis.
- Effective Room Temperature Control – Temperature can be controlled within +/- 1.5°C which is many times not adequate. Also, zone-wise temperature control is not feasible unless additional variable air volume terminals are installed.
- Flexibility – Since several areas are being serviced



Chart 6: Equipment selection for Building R4



Chart 5: Google earth image of two buildings in Suwon City

by one AHU, partial air conditioning is not possible. The system is not flexible enough to permit a part of the space to be cooled/ heated. Even when the space is serviced by an FCU terminal, the user can turn on the individual remote controller, but the chiller and chilled water pumps would have to run, adversely affecting the power consumption.

- Energy Billing – In case of the chilled water system, individual customer billing for the electricity energy used by HVAC system is complicated. Special instrumentation like a Btu meter is required.

The VRF system, on the other hand, is able to handle the variable load very effectively, can maintain room temperature within a very tight tolerance, is flexible and zoned energy billing is possible.

Let us now explain the concept of hybrid a/c. Hybrid a/c system uses a mix of both chiller and VRF systems to get the benefits of both technologies. Chart #3 explains this concept of the hybrid system. In a hybrid system, the chiller is used to handle the base load of the building and the VRF is used to handle the fluctuating load. The building interior typically has a more constant load and the chiller is used for that space and the periphery of the building (which sees more variable load) is handled by the VRF.

When applying hybrid systems, sometimes the space constraint becomes significant and it is not always possible to install air cooled VRF. In cases where such constraints are there, water cooled VRF is an option and Chart #4 explains the system layout for the water cooled VRF systems for large commercial spaces.

Case Study 1: Hybrid A/C

Suwon City, a city about an hours’ drive from Seoul, South Korea, is the headquarters for Samsung Electronics. There are several tall buildings in the city

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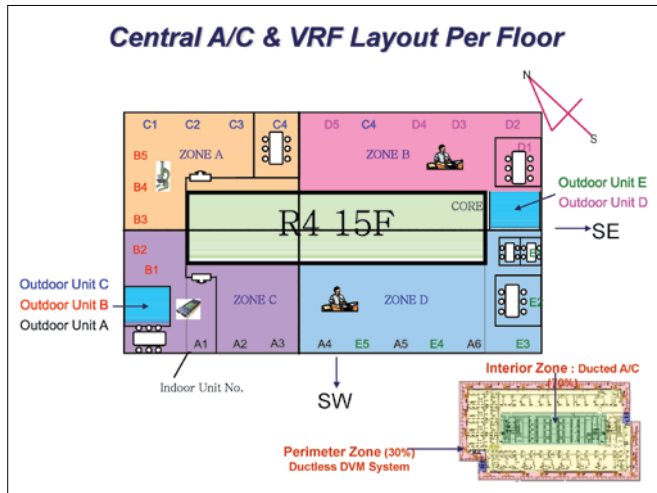


Chart 7: Layout of indoor and outdoor units of the VRF

that have offices and laboratories for different Samsung divisions. Chart #5 shows the Google earth image on two buildings that are the subject of this case study.

There are two buildings R3 and R4. R3 uses the conventional chiller system while building R4 uses the hybrid system. Let us explain the architecture of building R4 in more details. This is 42 storey commercial building and occupies a floor space of over 214,000m². This building used a combination of VRF and chiller and Chart #6 shows the details of the equipment selection.

To better understand how the equipments are placed, let us look at the layout in Floor #15 in Chart #7. There is an inner core as shown by the light green zone and the chiller is used to a/c that space. This is the region of the building where the cooling load is fairly even. Around the periphery of the floor, we can see all the VRF machines being placed. There are five outdoor units that are labeled from A-E and the indoor units with labels of A1, A2 etc, and these machines are all installed around the periphery of the building.

The cost analysis for this project has been done versus the R3 building (that only uses the traditional chiller system). The cost and savings data are shown in Chart #8. There is a savings of 17% on the initial construction cost (the higher cost of VRF versus lesser ducting etc have all been factored in this calculation) and 6% on running costs. On a life cycle cost calculation, there is a savings of 12% in building R4 versus building R3.

Case Study 2: Tall Building

For large commercial spaces and especially tall buildings – three major objections have been raised for the usage of VRF systems. Table 1 summarizes the objections and the technical solutions used to address them.

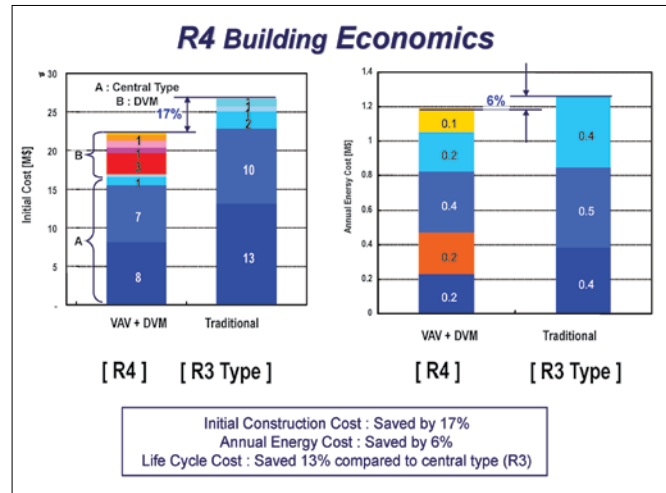


Chart 8: Operating and life cycle cost calculations

<p>Fresh air intake: Indoor units of VRF machines being direct expansion system are not easily adaptable for fresh air intake. This is relatively simpler to handle in a conventional chiller system where fresh air AHU or fresh air duct can be provided.</p>	<p>Two options are available. Fresh air indoor units are available and they can be appropriately sized and installed in the ducting system to provide the required quantity of fresh air. Alternately, a “Heat Recovery Ventilator” can be used to provide fresh air and exhaust stale air simultaneously.</p>
<p>Refrigerant pipe length/Elevation limitation: The length of refrigerant piping determines the amount of pressure losses and consequent cooling capacity loss. Most manufacturers specify a maximum pipe length around 100 – 150 meters. Also, there is a restriction on the elevation difference between the Outdoor Unit and the indoor unit (normally 50 meters). With a chiller system, there are no such issues on pressure losses.</p>	<p>Condensing Units can be placed on each floor or alternate floors on the periphery of the building. To ensure the aesthetics of the building, louvers can be provided from top to bottom for the building. It is therefore important to involve the architect in the initial stages of the construction. This CDU arrangement can reduce the length of the interconnecting piping and restrict the elevation difference to a manageable height.</p>
<p>Short circuit of hot air from the CDU's: As the CDU's are located one above the other throughout the height of the building, there is a great chance for the hot air discharge from the CDU at the lower floors to enter the air intake in the higher floors and create short cycling. This short circuiting would definitely hurt the cooling performance. Also in tall buildings, the natural wind pressure changes with elevation and that can potentially cause less than optimal air flow to the condenser and hurt the cooling performance.</p>	<p>This issue can be addressed by installing well designed louvered grill on the outside of the building and a short discharge air duct on the CDU. Computational Fluid Dynamics (CFD) simulations need to be done to ensure that there is no short cycling of hot air and also to assess that wind pressure at higher elevations do not adversely affect the performance of the units.</p>

Table 1 : Objections and technical solutions in tall buildings.

Tongji United Plaza in Shanghai, China is a large commercial building and is the second case study to show the application of VRF. Chart #9 shows an aerial view of the Tongji plaza. This is a large complex that houses offices, hotels, conference rooms and restaurants. The total construction area is 181, 403m² and consists of 4 blocks:

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Chart 9: Tongji United Plaza, Shanghai China

Block B	22 floors office 3 floors Skirt Bldg.	<ul style="list-style-type: none"> • Offices • Banks • Food Court
Block C	11 floors	<ul style="list-style-type: none"> • Apartment type offices
Block D	10 floors	<ul style="list-style-type: none"> • Hotel
Block E	3 floors	<ul style="list-style-type: none"> • Shopping complex • Restaurant

The choice of a/c systems installed in this complex is similar to the hybrid system mentioned in the first case. There are however some additional considerations taken into account – like designing the right type of louvers for the outdoor units and also the CFD analysis, and that will be covered in this article.

Table 2 explains the a/c equipment choices:

Block B	1st Floor	<ul style="list-style-type: none"> • Fire Protection Control Center • Computer Room • Bank 	<ul style="list-style-type: none"> • Digital Scroll VRF System • 44 Sets Of 8-44HP CDU • Fresh Air Unit Located at each floor
	2nd Floor	<ul style="list-style-type: none"> • Bank 	
	4th – 22nd Floor	<ul style="list-style-type: none"> • Offices/Conference Room 	
	1st Floor	<ul style="list-style-type: none"> • Lobby/ Restaurant 	<ul style="list-style-type: none"> • 3 sets of air cooled heat pump chillers 480 KW • 1 set of air cooled heat pump 365 KW • Chillers located on roof of main building
	2nd Floor	<ul style="list-style-type: none"> • Restaurant 	
	4th – 22nd Floor	<ul style="list-style-type: none"> • Offices/ Conference room 	

Table 2 : Equipment choices in Block B

The other blocks of C, D and E have a similar equipment selection and so we are not providing further details. Where we will get into more details are: the location of the VRF machines, the louver design and the CFD analysis done to understand the heat dissipation from the outdoor units.

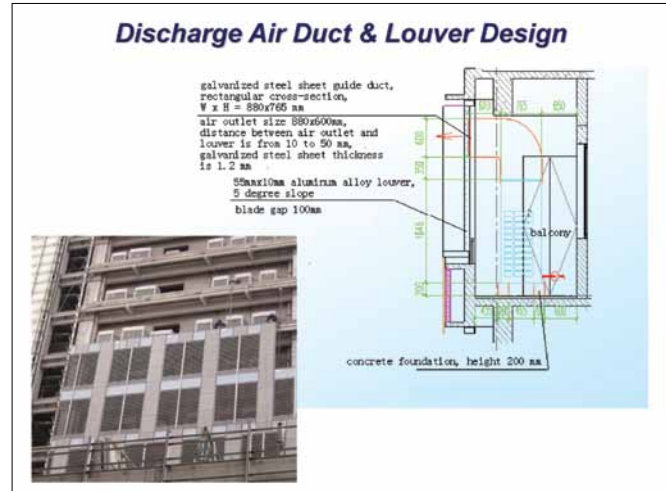


Chart 10: Louver design and discharge air duct layout

1. Outdoor unit location: As requested by the HVAC designer, the architect has provided the outdoor unit installation platform on each floor to ensure that the efficiency-drops due to long pipe length is avoided (the maximum distance between the outdoor and indoor is about 40 meters).

2. Louver design: To facilitate the outdoor unit's discharge air, the CDUs have L shaped discharge air deflection ducts. These ducts ensure that the vertical air discharge from the CDU is deflected in the horizontal direction. The louver design and the building façade is shown in Chart #10.

The key design point of the guide duct design is to ensure an optimal discharge air duct velocity – to control noise, and also to reduce the static pressure loss. The duct discharge air velocity is kept in the range of 4.9 – 5.4 m/sec.

3. Computational Fluid Dynamics (CFD) analysis: The temperature mapping was done for several conditions and two of them are given here. The temperature mapping was done for a 10m/s wind speed and the temperature spectrum is shown in Chart #11.

Both the above situations (wind flow from either direction) indicate that the return air temperature is below 40°C and that will ensure uninterrupted operation of the machines.

Another simulation was done with a lower wind velocity of 1 m/sec. Chart #12 shows the simulation results.

Similar CFD analysis has to be done for the weather patterns encountered by the building. The analysis done for Tongji Plaza confirmed that even though there was a 1-2°C increase in the temperature in the upper floors of the building due to the heat dissipation, the system

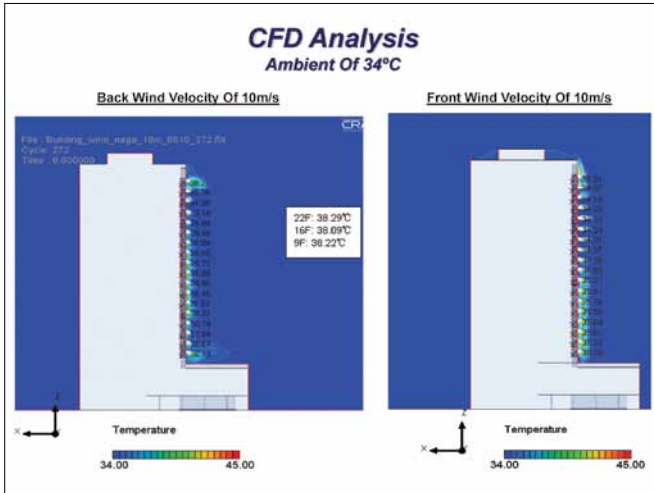


Chart 11: CFD analysis for wind velocity of 10m/sec

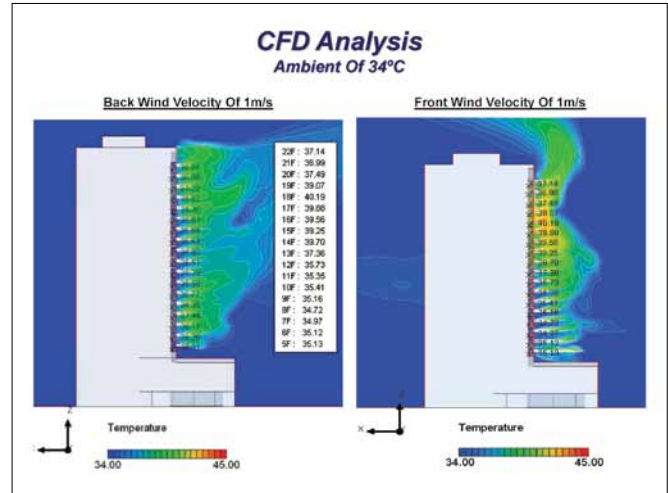


Chart 12: CFD analysis with wind velocity of 1m/sec

continues to function normally and delivers the required cooling/heating.

Conclusion

VRF is now being increasingly applied for large commercial spaces and tall buildings. In such large buildings, it makes economic sense to have a hybrid system – combining the benefits of the VRF technology and also using the traditional chiller system. The

chiller is used for the base load and the VRF for the varying load. The two case studies have documented data on the life cost advantage of using such kinds of hybrid systems. For tall buildings, CFD analysis has to be done to ensure that short cycling of hot air does not occur on the top floors. As long as sufficient design precautions are taken, VRF can comfortably be applied for large commercial spaces. ❖

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