Design of VRF System with Customised AHU in Conjunction with Variable Evaporating Temperature

A VRF outdoor unit

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Introduction

In the Indian HVAC industry, during the past 15 to 20 years, a combination of air-cooled condensing unit (CDU) with split type ductable indoor units or customised AHU has been very popular.

Condensing unit selection has been based on ARI guidelines (Standard Operating Conditions), shown in *Table 1*.

Table 1: ARI guidelines for CDU selection

S. No.	Description	Details
1	Evaporating temperature	7.2°C/45°F
2	Condensing temperature	54.4°C/130°F
3	Superheat	11.1°K/20°F
4	Sub-cooling	8.3°K/15°F

Evaporating temperature of the system is 7.2°C, operating frequency is 50 Hz, and fixed speed condenser fan is operating as per the ambient temperature. Evaporating temperature cannot be changed because of fixed operating system parameters.

Nowadays, it is a practice to install air conditioning systems in almost all commercial buildings, hospitals, hotels, industrial establishments, office premises, residential complexes, etc. The user, today, is more demanding than ever and looks for a cost effective and energy efficient solution with no compromise on indoor environmental conditions, ease of installation, maintenance and operation of HVAC equipment. While designing the HVAC system for a large size project, the user desires to save money, space and installation time with flexibility in installation and operation.

To meet such system requirements, Variable Refrigerant Flow (VRF) system and Chilled Water system are the options available. In many of the HVAC applications (e.g. auditorium, laboratory, OT, NICU, SICU, pharmaceutical manufacturing, public area, sport complex and theatre), the standard VRF indoor units do not suit the technical requirements, hence the

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user has to opt for Air Handling Units. Two energy efficient options are available: standard chilled water system connected to an AHU, and a VRF ODU connected to an AHU.

An air distribution system with AHU can deliver cool air with the required quality of filtered clean air, humidity, 100% cooled fresh air and can suit the customised requirement of static pressure with precise control carried out by an EC fan or variable frequency drive motor. A large volume of air can be handled with multiple air handling units, which can carry out the air distribution through grills, diffusers, etc. to suit the architectural interior design requirement.

Variable Refrigerant Flow

VRF technology is available with full DC inverter scroll compressor using R-410A high pressure refrigerant. R-410A is a blend of HFCs with zero Ozone Depletion Potential (ODP). VRF technology allows cooling and heating, ensuring various desired indoor conditions in all seasons with the help of Electronic Expansion Valve (EEV) controlled variable refrigerant flow. Refrigerant flow is based on the following parameters:

- Ambient condition
- Condensing temperature
- Indoor air quality
- Inside room condition
- Refrigerant evaporative temperature

Brief Description of VRF Operating System

A VRF outdoor unit operates with microprocessor controller, which is integrated with the following:

- Cumulative suction temperature of indoor units.
- Suction superheat.
- Compressor suction pressure.
- Compressor discharge pressure.
- Discharge superheat.
- Ambient condition.
- Condenser fan speed as per ambient temperature.
- Electronic expansion valve (EEV) provided at the evaporator coil.
- EEV/TXV is controlled by ΔT between the inlet and outlet of the coil apart from signals from return air sensor. The check point is to maintain the superheat, which also ensures compressor safety from liquid compression.
- Quality of air controlled is very precise as the EEV/TXV is not controlled by only one feedback but from multiple sensors.
- Microprocessor controller design and parameters may vary from manufacturer to manufacturer.

Compressor Operating Frequency and Speed

DC inverter compressors are available with 2 pole/4 pole/6 pole compressor drive motor. The compressor speed increases or decreases with changing operating frequency. The relation between the number of poles of compressor drive motor, operating frequency and compressor speed is given in *Table 2*.

Table 2: Relation between operating frequency, number of poles and compressor RPM

Operating Frequency (Hz)	Compressor Speed with 2 Pole Drive Motor (RPM)	Compressor Speed with 4 Pole Drive Motor (RPM)	Compressor Speed with 6 Pole Drive Motor (RPM)
50	3000	1500	1000
60	3600	1800	1200
90	5400	2700	1800
120	7200	3600	2400
150	9000	4500	3000

An analysis of *Table 2* shows that:

- With 2 pole compressor drive motor at 150Hz operating frequency, compressor RPM is 9000, which is very high compared to 4 pole and 6 pole motor.
- With 6 pole compressor drive motor at 150Hz operating frequency, compressor RPM is 3000, which is quite low compare to 2 pole and 4 pole motor.

The advantage with 6 pole compressor drive motor is the lowest power consumption due to lowest speed; the additional advantages of low speed compressor are longer life, minimum vibration and less noise.

So, one should select the outdoor unit scroll compressor with the largest number of poles.

This data is applicable to DC inverter condenser fan also.

Whenever operation at full capacity is not required, VRF system shares the heat load among the installed units and, thus, manages to reduce the DC inverter compressor and condenser fan speed. Inverter compressor efficiency levels are further optimized at partial load, reducing energy consumption and also increasing the entire system efficiency.

Accessories for VRF ODU and AHU Connectivity

AHU Kit

The AHU Control Kit is an essential part of the VRF circuit and AHU evaporator coil. The kit mainly comprises of the following:

- Temperature sensor for refrigerant gas pipe.
- Temperature sensor for refrigerant liquid pipe.
- Temperature sensor for supply air.

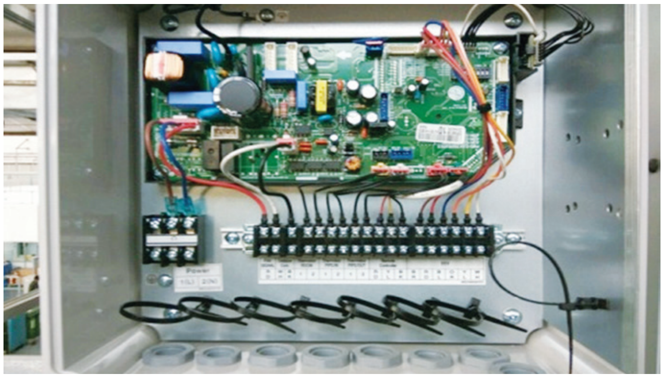

Photo 1: AHU kit (inside view)

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- Temperature sensor for return air.
- Communication PCB.
- DI/DO ports for external contacts.
- Communication through remote control.

Expansion Valve Kit

It contains the Electronic Expansion Valve depending on evaporator coil capacity.

Remote Controller

The remote controller should be wired/centralized.

AHU Fan Drive Motor Starter

AHU should have its own starter. However, it can be interlocked with the AHU controller for start through remote control.

Photo 2: EEV kit

ODU and AHU Configurations

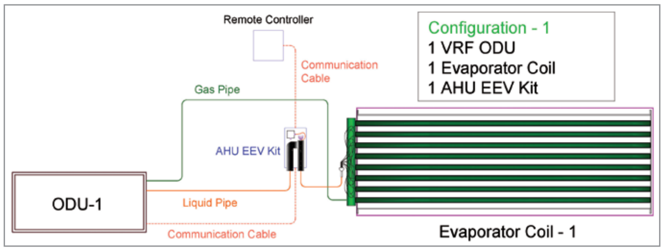

Figure 1: Configuration of one ODU, one evaporator coil and one AHU kit

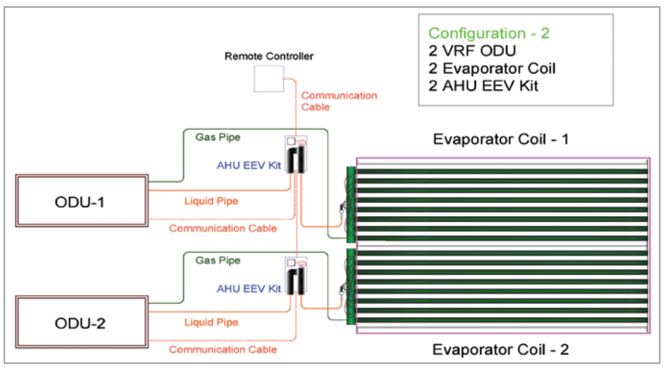

Figure 2: Configuration of two ODUs, two evaporator coils and two AHU kits

Photo 3: AHU control kit for two ODUs

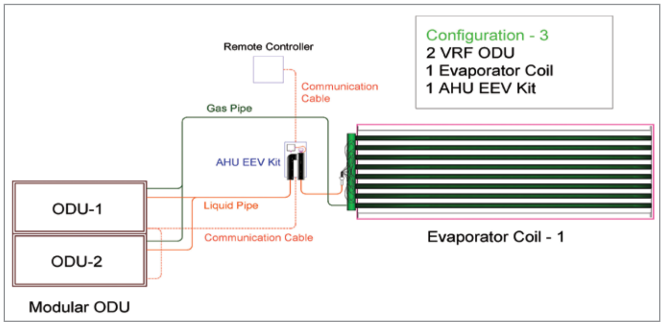

Figure 3: Configuration of two ODUs, one evaporator coil and one AHU kit

Photo 4: AHU control kit for three ODUs, three evaporator coils and three AHUs

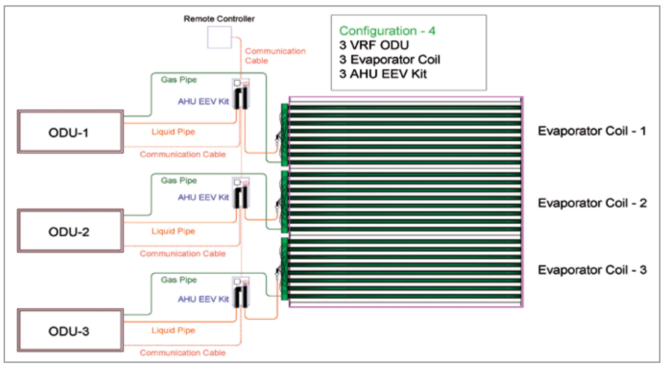

Figure 4: Configuration of three ODUs, three evaporator coils and three AHU kits

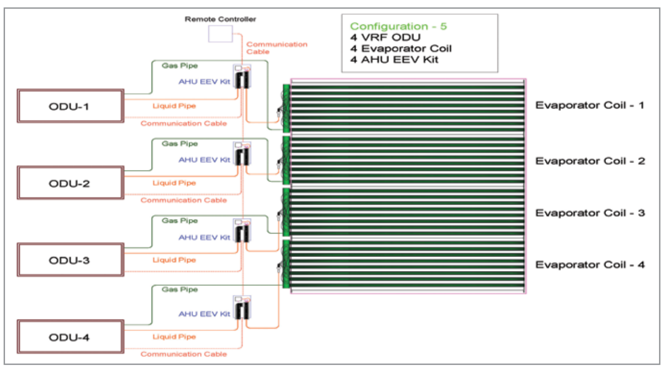

Figure 5: Configuration of four ODUs, four evaporator coils and four AHU kits

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This combination is based on AHU kit with EEV 20 HP capacity maximum available with multiple combination. The evaporator coil should be intertwined type. It is difficult to manufacture an intertwined coil with more than 4 coil sets.

Selection of AHU and DX Evaporator Coil

The evaporative temperature and refrigerant flow are controlled as per cooling and heating capacity requirement of the area. The evaporative temperature varies with inside room condition and ambient condition. The EEV provides precise control of refrigerant flow to the inlet of AHU DX evaporator coil, which operates and adjusts the evaporative temperature automatically to achieve the refrigeration circuit performance and highest energy efficiency at partial load.

Photo 5: Thermal break air handling unit

The AHU evaporator cooling coil is selected on the basis of following data:

- AHU coil selection varies with the manufacturer. The basic parameters that need to be met are velocity across the coil (maximum 2.5 m/s), number of rows deep (preferably 4~6 RD), and volume of the coil. Since the AHU is a third party arrangement and additional refrigerant capacity is based on cooling coil capacity, the above parameters are matched as per the manufacturer's guide.
- AHU kit, which consists of the electronic/thermal expansion valve (EEV/TXV) for refrigerant flow and a controller for communication between AHU and VRF ODU, comes in multiple capacities from 2~16 TR. Each EEV/TXV should be connected to individual distributor of the coil for smooth refrigerant flow.
- VRF system manufacturer selects the dehumidified air quantity as 400 cfm (maximum) per TR air conditioning load.
- In case dehumidified air quantity is more than 400 cfm/TR, the designed evaporative temperature will get increased, resulting in higher inside room temperature and reducing the cooling efficiency of evaporator coil.
- The increase in the evaporative temperature will affect the system Apparatus Dew Point (ADP), and the ADP will also increase. ADP selection is a part of system design.

The HVAC designer/ VRF unit manufacturer should provide the following minimum data to the AHU manufacturer to design the evaporator coil:

- Ambient condition
- Evaporator coil capacity in kW
- Fresh air supply quantity and dehumidified air quantity
- Total air quantity (fresh air supply quantity + dehumidified air quantity) to evaporator coil in cfm
- Evaporator 'IN' temperature (°C)
- Coil superheat
- Return air temperature to evaporator coil
- Return air relative humidity to evaporator coil
- Evaporator coil outlet air temperature
- Air temperature (return air temperature + fresh air temperature) to evaporator coil 'IN'
- AC system ADP and Effective Sensible Heat Factor (ESHF) as per heat load calculation
- Total capacity of evaporator coil (sensible load + latent load)
- Maximum saturated discharge temperature
- Air velocity across the evaporator coil 'IN'
- Face area of evaporator coil
- Number of rows
- Type of refrigerant
- Number of distributors
- Number of evaporator coils in one AHU (applicable for multiple ODUs connected to intertwined coils)

Minimum Check Points for Evaporator Coil Selection

The following points need to be verified by the HVAC designer and VRF system manufacturer:

- ADP of evaporator coil should be considered around 50~52°F (10-11°C)
- Total cooling capacity of evaporator coil (TR)
- Sensible and latent cooling capacity (TR)
- Effective Sensible Heat Ratio (ESHR)
- Total dehumidified air quantity
- Dry bulb inlet temperature to the coil 'IN'
- Dry bulb outlet temperature at the coil 'OUT'
- Evaporator coil 'OUT' relative humidity
- Saturated suction temperature of refrigerant (SST)
- Saturated discharge temperature SDT
- Face velocity and coil face area of evaporator coil
- Test pressure of evaporator coil for R-410A should be 600 psi

Limitation for Evaporating Temperature Selection

VRF equipment manufacturer selects the evaporating temperature for the cooling system considering the following data:

- ADP around 50~52°F (10-11°C)
- Condensing temperature not to exceed 54.4°C for Indian climate
- Scroll compressor suction pressure operating range in the range of 790 kPa to maximum 950 kPa

VRF system for comfort application at or above 10°C evaporating temperature does not work satisfactorily, as the corresponding compressor suction pressure is above 995 kPa. The safe working zone of evaporating temperature for an AHU application is 5.0°C to 8.8°C; however, it may vary from manufacturer to manufacturer. If

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this configuration (evaporating temperature and scroll compressor suction pressure) is not managed adequately, it puts additional stress on the AC plant infrastructure, resulting in an increased risk of system failure. Hence safety parameters of the VRF system do not allow operation beyond the range mention above.

The VRF system principally works within the range of 2°C to 5°C superheat. In case inside room cooling capacity requirement drops, EEV will control the required refrigerant flow across the evaporator coil to maintain the desired ΔT, i.e. less than 5°C. In a scenario where the evaporating temperature of the refrigerant increases and refrigerant flow varies automatically, this cycle tries to maintain 5°C ΔT and the desired room temperature also.

In case of compressor failure, the evaporating temperature may increase and ΔT may go above 5°C; however, it should be noted that stepless modulation gives the right evaporating temperature and precise capacity control.

The manufacturer selects the evaporating temperature suitable for their equipment and operating system software. The following evaporating temperatures are indicative and only for guidance:

Configuration 1

Evaporator entering temperature: 7°C

Evaporator leaving temperature: 9°C

ΔT: 2°C

Configuration 2

Evaporator entering temperature: 5°C

Evaporator leaving temperature: 8.2°C

ΔT: 3.2°C

Configuration 3

Evaporator entering temperature: 6°C

Evaporator leaving temperature: 8.5°C

ΔT: 2.5°C

The following three case studies will give a fair idea about the characteristics of a DC inverter compressor at various evaporating temperatures and operating frequencies.

Case Study 1

Condensing temperature: 54.4°C

Operating frequency: 50 Hz

Refrigerant: R-410A

Compressor model: Danfoss VSH088m

Table 3: DC inverter compressor characteristics at 50 Hz

Evaporating Temperature (°C)	Scroll Compressor Suction Pressure (kPa)	Compressor Capacity at 50 Hz (kW)	Compressor Input Power (kW)	IkW/TR
5.0	842	19.60	7.717	1.38
6.6	890	20.72	7.742	1.31
7.2	907	21.16	7.751	1.29
7.7	920	21.54	7.759	1.27
8.3	935	22.0	7.769	1.24
8.8	950	22.4	7.770	1.22
9.4	974	22.85	7.786	1.20
10	995	23.33	7.795	1.18

Case Study 2

Condensing Temperature: 54.4°C

Operating Frequency: 75 Hz

Refrigerant: R-410A

Compressor model: Danfoss VSH088

Table 4: DC inverter compressor characteristics at 75 Hz

Evaporating Temperature (°C)	Scroll Compressor Suction Pressure (kPa)	Compressor Capacity at 75 Hz (kW)	Compressor Input Power (kW)	IkW/TR
5.0	842	30.37	11.60	1.34
6.6	890	32.13	11.66	1.28
7.2	907	32.80	11.68	1.25
7.7	920	33.38	11.70	1.23
8.3	935	34.08	11.72	1.21
8.8	950	34.67	11.74	1.19
9.4	974	35.39	11.76	1.17
10.0	995	36.13	11.78	1.15

Case Study 3

Condensing Temperature: 54.4°C

Operating Frequency: 90 Hz

Refrigerant: R-410A

Compressor model: Danfoss VSH088

Table 5: DC inverter compressor characteristics at 90Hz

Evaporating Temperature (°C)	Scroll Compressor Suction Pressure (kPa)	Compressor Capacity at 90 Hz (kW)	Compressor Input Power (kW)	IkW/TR
5.0	842	35.96	14.02	1.37
6.6	890	38.07	14.10	1.30
7.2	907	38.88	14.13	1.28
7.7	920	39.57	14.15	1.26
8.3	935	40.41	14.18	1.23
8.8	950	41.11	14.20	1.21
9.4	974	41.98	14.23	1.19
10.0	995	42.85	14.26	1.17

Summary

Table 3 to *5* show that:

- if evaporating temperature and operating frequency increase, scroll compressor suction pressure as well as compressor capacity increases correspondingly;
- if evaporating temperature increases, compressor IkW/TR decreases accordingly;
- compressor suction pressure is not affected by variation in operating frequency;
- however, compressor discharge pressure is independently controlled by microprocessor based controller, by controlling condenser fan motor speed according to ambient temperature; and
- suction pressure and evaporative temperature vary automatically due to variation in inside load and condensing temperature.

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Compressor Capacity vs. Condensing Temperature

Operating frequency: 90 Hz

Evaporative temperature: 8.3°C

Compressor model: Danfoss VSH088

Table 6: Compressor characteristics vs. condensing temperature

Condensing Temperature °C	Scroll Compressor Suction Pressure (kPa)	Compressor Capacity at 90 Hz (kW)	Compressor Input Power (kW)	IkW/TR
54.4	935	40.97	14.27	1.22
50.0	935	43.81	13.17	1.06
43.0	935	47.97	11.65	0.85
35.0	935	52.22	10.03	0.68

- At higher ambient/condensing temperature, the compressor capacity is low and vice versa.
- Condensing temperature is directly related to ambient temperature. VRF outdoor unit should be selected for maximum 54.4°C condensing temperature as per Indian climate.
- Condensing temperature will be low in winter; hence, VRF ODU will work at low condensing temperature in winter, resulting in electrical energy saving.
- VRF system can work as a Heat Pump in cold climate areas, where ambient temperature is below 15°C.
- Refrigerant temperature will be higher in heating mode due to the reverse cycle of refrigerant circuit, and lower in cooling mode.

Superheat and Sub-cooling with Variable Condensing Temperature via BLDC Condenser Fan and Constant Evaporating Temperature via EEV for Refrigerant Flow Control

Table 7: Superheat and sub-cooling vs. condensing temperature at constant evaporating temperature (R-410A)

Saturated Evaporating Temperature		Condensing Temperature		Superheat	Sub -cooling
°C	°F	°C	°F		
7.2	45	54.4	130	11.1K/20°F	8.3K/15°F
7.2	45	43	109	7K/13°F	8.3K/15°F
7.2	45	30	80	6K/11°F	8.3K/15°F

Compressor superheat changes with condensing temperature; however, sub-cooling is constant and is related to compressor suction pressure.

Conclusion

This article attempts to raise the awareness of designing an air-conditioning system with VRF AHU connectivity. It is important that the end user should become familiar with AHU connected VRF AC systems. Continuous monitoring of heat load ensures that only the necessary kilowatts are invested in heating or cooling, thus conserving energy at the highest possible level of efficiency.