Combination Ratio of a Variable Refrigerant Flow System

Introduction

At first examination, Variable Refrigerant Flow (VRF) technology may seem similar to a traditional split-system. The VRF outdoor unit (ODU) is compared to a commercial split-system heat pump unit. Indoor units (IDU) are compared with traditional fan coils and other forms of commercial or residential air moving products.

A traditional heat pump system has a single air handler with a single heat pump unit in a one-to-one relationship. The significant difference with VRF is a typical system has an outdoor unit (single frame or a multi-frame outdoor unit operating as a single unit) piped to numerous indoor units in a one-to-many relationship. This one-to-many relationship of VRF system ODU and IDUs introduces an important new concept known as combination ratio (CR).

Note:	All material provided herein is for informational or educational purposes only. It is not intended to be a substitute for professional advice. Please consult with your engineer or design professionals for application to your system

Purpose

This white paper defines CR and why it is good engineering practice to limit CR to between 50% and 130%. It also addresses the concerns of designing a VRF system with a CR outside of that appropriate range. To ensure the most accurate CR calculation, this paper also explains corrected capacity and its effect on equipment selection. Contributing factors of airflow requirements, mixed air limitations, and building diversity are also considered.

How to Determine Combination Ratio for a VRF System

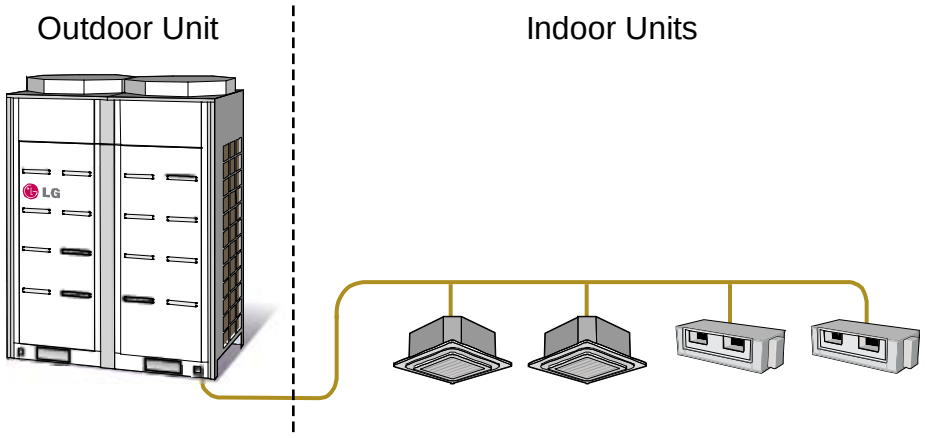
A VRF system's CR is a ratio of the sum of the system's IDUs nominal cooling capacities to the ODU nominal cooling capacity. CR can be calculated

manually or with LG Air Conditioner Technical Solution (LATS) Multi V™ piping and design software. Figure 1 shows the CR calculation.

$$CR = \frac{\Sigma\ [\text{IDU capacity}]\text{nominal}}{[\text{ODU capacity}]\text{nominal}} \times 100\%$$

Figure 1. VRF Combination Ratio Calculation

Nominal capacity information for LG IDUs and ODUs is located in the general data tables of their respective Engineering Manuals. Figure 2 shows example CR calculations using nominal values.



ODU Capacity (tons)	IDU1 Cap	IDU2 Cap	IDU3 Cap	IDU4 Cap	Total IDU Cap	CR (%)
24	4	4	8	8	**24**	**100**
12	2	2	6	4	**14**	**117**
24	2	4	8	6	**20**	**83**
24	6	8	8	8	**30**	**125**
32	4	2	4	6	**16**	**50**

Figure 2. VRF Combination Ratio Examples

VRF equipment product literature is a good source of indoor and outdoor unit nominal capacity information. LG recommends that its Multi V™ VRF systems have a nominal CR of 50% to 130% for a reasonable balance between the effective surface areas of the IDU coils relative to the ODU coil. Acceptable CR ranges vary from manufacturer to manufacturer. It is important to understand the reasons for the differences and if there are any advantages, disadvantages or risks to designing a system with a larger or smaller CR.

Understanding Combination Ratio Theory

Properly Matching Traditional Split System Components

To properly match a traditional split-system condensing unit (or split-system heat pump) to an air handler with a direct expansion coil, the designer refers to the air handler manufacturer's literature or selection software to properly match components. Performed manually, the designer cross-plots the condenser coil performance against the evaporator coil performance to establish the system's saturated suction temperature.

If the evaporator coil is too large or the condensing coil is too small, the system's operating saturated suction temperature will be too high to adequately cool the compressor. If the evaporator coil is too small or the condensing coil is too large, the system's saturated suction temperature will be too low, creating the possibility of slugging the compressor with liquid refrigerant. Therefore, if a system has mismatched components with an excessive difference in the heat transfer surface area of the evaporator coil relative to the condenser coil, the longevity of the system's compressor may be compromised.

Properly Matching VRF System Components

The same refrigeration theory and component matching verification applies to VRF systems. However, instead of using manufacturer's coil performance data to properly match air handler to heat pump condensing unit, VRF system designers calculate the system's CR.

When a system has more combined IDU nominal capacity than ODU nominal capacity, the result is a CR greater than 100%. If the system's CR is greater than 100%, the combined heat transfer requirement of all connected IDUs is greater than the heat transfer capability of the ODU(s). If the block load of the building exceeds the capacity of the ODU(s), the saturated suction temperature may rise to an unacceptable level, resulting in VRF system malfunction.

When a system has less combined IDU nominal capacity than ODU nominal capacity, the result is a CR less than 100%. If the system's CR is less than 50%, the combined heat transfer requirement of all connected IDUs is much less than the heat transfer capability of the ODU(s). When the ODU is excessively oversized, the saturated suction temperature may drop to an unacceptable level, resulting in VRF system malfunction.

Note:	LG's Multi V™ systems will not start, operate, nor can they be commissioned if the CR is outside the allowable 50% to 130% nominal range.

While LG systems must be designed with a CR of 50% to 130%, some manufacturers allow ODU under sizing to the point the CR can reach 200%. As the building load increases, the call for additional refrigerant flow from the ODU(s) increases. If the IDUs are properly sized but the ODU is undersized (for example, with a 200% CR) zones will not be satisfied if the building load exceeds the capacity of the ODU. If the available refrigerant is insufficient, refrigerant flow is distributed according to IDU size.

Keep in mind that VRF system operational limitations are similar for all VRF manufacturers. Typically, the equipment has built-in logic to limit compressor loading to maintain appropriate suction temperature at the compressor. For high CR applications, manufacturers publish warnings and strategies such as:

- IDUs will not achieve full capacity when all IDUs run at full load simultaneously
- Limit fan speed for the IDUs
- Do not allow all IDUs to run at the same time

To ensure safe equipment operation, LATS Multi V™ software displays an error message if the CR of a design is outside the acceptable range.

Corrected Capacity

Corrected capacity considers the environmental and design parameters of the system to give a more accurate measure of each unit's capacity. The corrected capacity of an ODU is the actual capacity of the ODU considering ambient design temperatures and system piping.

The corrected capacity of an IDU is the actual capacity of the IDU considering mixed air conditions. LATS Multi V™ does not consider outside air parameters; this factor must be manually calculated for each IDU receiving outside air.

Note:	It is important for LATS software users to consider all pertinent parameters and enter accurate design data, check the results, and refine the system component sizes as necessary.

High Combination Ratio Applications

If the CR is over 100%, the designer is under sizing the ODU relative to the combined nominal capacity of the connected IDUs. In some applications, under sizing the ODU is prudent as it reduces initial equipment investment. The system will perform properly as long as the designer has considered:

- IDUs are oversized relative to the actual load(s) in the spaces served
- Space loads will peak at different times of the day (i.e., the building has load diversity)
- Minimum IDU size availability

Load diversity can be a design consideration when personnel shifts and movement within a building are expected. If a normally vacant or minimally used space will occasionally become more densely occupied such that a higher zone load is required, it is necessary to size the IDU(s) in that zone to accommodate the peak occupancy scenario. If the ODU is sized based on the sum of the peak zone loads, the ODU may be oversized for a majority of the operating hours. In response, the ODU size may be reduced if the shift of personnel in the building doesn't result in a combined block load that exceeds the capacity available from the ODU. Whenever the CR is more than 100%, the designer must ensure the ODU is sized to meet the block load.

When outdoor air is ducted to an IDU, it is important to calculate mixed air conditions and remain within the manufacturer's mixed air limits. LG IDUs require a minimum heating mixed air temperature of 59 °F dry bulb (DB) and a maximum cooling mixed air temperature of 76 °F wet bulb (WB). When outdoor air is ducted to an IDU, the size of the IDU may have to be increased to meet the additional ventilation load.

In some designs, over-sized IDUs may be unavoidable if the smallest size LG IDU is larger than necessary to satisfy the space load. This scenario may occur when an IDU selection one size down from the selected unit is slightly short of fulfilling the design load requirements and the designer chooses the next larger size unit.

In all cases of IDU over sizing, the risk of a high CR should not be the only consideration:

- If the ODU is selected based on total block load rather than total IDU load (with oversized IDUs), the system could exceed the CR limit
- In cooling mode, oversized IDUs can cause the system's operating saturated suction temperature to exceed operational limitations, as explained in the *Properly Matching VRF System Components* section of this

paper. This scenario may require limiting IDU fan speed to avoid high suction temperature.

- In heating mode, oversized IDUs can prevent the system's head pressure from developing, resulting in low leaving air temperatures (if the fan starts at all)

Note: In applications where all IDUs are right-sized and there is no building diversity, the system's CR will likely be ≤100%. If the ODU is properly sized to offset the building's total cooling block load and the system's combination ratio is above 130%, the IDUs are likely oversized.

Low Combination Ratio Applications

A system with less combined IDU nominal capacity than ODU nominal capacity must have a CR greater than 50%. When a system is engineered with a CR less than 100%, the ODU is oversized. If the system is designed with less than 50% CR, the ODU compressor(s) could cycle more frequently, potentially compromising user comfort. An oversized ODU can result from compensating for operation in extreme ambient conditions or installing equipment in phases rather than all at once.

In cold climates, heating capacity can be a critical parameter for IDU selection. When air-cooled Multi V™ equipment operates in low ambient conditions, the system's heating capacity is reduced and could cause the designer to oversize the ODU. Because it's important for all occupied zones to be satisfied during morning warm up on the design day, the sum of the IDU capacities is the determining factor with ODU size selection.

A low CR can also occur if only part of the building is finished with the remainder to be completed at a later date. In these applications, it is critical that the final system design include all future IDUs. To avoid pipe system rework, future units must be accounted for in the LATS design. The designer must ensure appropriate pipe sizes are used and confirm that piping limitations are not exceeded when the final build is complete. In multi phase project design, it is important to install enough IDUs in the first phase to account for at least 50% of the ODU nominal capacity.

Oversized ODUs with multiple compressors can more effectively accommodate low load conditions by staging compressors off. Single compressor ODUs may result in entire system short cycling due to on and off operation.

Consider the IDU capabilities. If a designer chooses to place a nominal 7,500 Btu/h unit in an area that requires substantially less capacity, the IDU may

rapidly reach the desired set point. Fan speed will vary more often and may even cycle on and off. Depending on the call for cooling/heating from other zones, as well as the system's CR, a VRF system equipped with a single compressor ODU may also cycle excessively. Keep in mind that the IDU fan speed setpoint(s) can be adjusted approximately ±10% by the user.

Troubleshooting Combination Ratio

Consider these suggestions when the system's corrected CR in both cooling/heating modes is acceptable, but the system's CR remains outside the acceptable range (50%–130%).

If the CR is above 130%:

- Research and determine the true space load(s). Is there a large safety factor? Are the scheduled loads calculated loads or nominal loads?
- Evaluate the zone loads and indoor unit sizes. Are entered loads accurate? Are they exact or rounded?
- Attempt to decrease IDU sizes or reduce the number of IDUs. Where possible, combine neighboring rooms with small loads and the same load profile.
- Determine if airflow requirements governed IDU size selection. Are IDU cooling and heating capacities excessive?
    - For LG high static ducted and some 4-way cassette IDUs, a larger frame with the same capacity can be selected to accommodate a higher airflow or high sensible load. For example, if the selected IDU is the largest unit in a frame family but more airflow is required, and the selection of a larger capacity IDU negatively affects system CR, select an IDU with the same nominal capacity from the next larger frame family. Adjust the low/medium/high air speed (±10 of rated CFM) to modify the airflow.
- In a multi-system building, move a few IDUs to other ODUs. Be sure the other ODUs have a lower CR and enough spare capacity to accommodate additional IDUs while maintaining an acceptable corrected CR.
- Select a larger ODU if the CR still exceeds the acceptable range.
- Replace a couple of the VRF indoor units with a single-zone or multi-zone duct-free split system. Potential spaces include zones that have consistent loads, or zones that are often unoccupied during normal business hours or occupied after business hours.

If the CR falls below 50%

- Decrease the ODU size if the CR still falls below the acceptable range. Verify the block load is satisfied.

- Ensure adequate airflow will be provided to meet required circulation. Select a larger IDU if necessary or possible to help increase the system CR. Adjust the low/medium/high air speed (±10% of rated CFM) to meet airflow requirement.
- Install more IDUs on the first phase of a multi-phase project.
- Split a large system into smaller systems on multi-phase projects. Connect first phase IDUs to one of the ODUs and delay the installation of the additional ODU(s) until a later date.

Conclusions and Recommendations

CR calculation for VRF systems serves the same purpose as matching components of a traditional split system.

To avoid designing a system that may operate with an excessively high (or low) saturated suction temperature leading to premature compressor failure, ensure the CR of the design is between 50% and 130%.

Manufacturers of VRF equipment set acceptable system design CR parameters for their equipment. LG limits the CR of a Multi V™ system to between 50% and 130%.

For further information, refer to the LG engineering manuals, or consult with your regional sales engineer or an LG applications engineer.