Information Paper – VRF / VRV Systems

Alternative names for these systems are

Variable **R**efrigerant **F**low air conditioning systems – **VRF**.

Variable **R**efrigerant **V**olume air conditioning systems – **VRV**.

General

In this paper we will use the reference **VRF** as it is the more-technically correct version. This information paper is primarily aimed at Building Owners and Managers as a guide to getting the best out of your VRF systems.

Many of you will by now be familiar with the terms VRF or VRV and are likely to have had some experience with these systems in the buildings you manage.

The intent of this paper is to provide general background information and raise awareness of the need for meticulous care with the installation, maintenance and/or alterations made to these systems, to avoid potentially expensive remedial work.

The information and observations made are presented as an independent view, with necessary generalisations to ensure the document is neutral toward all brands. While the basic system operating principles are similar for all VRF systems, technical differences between brands, such as 2-pipe vs. 3-pipe configurations, mean that any specific issues must be taken back to the system manufacturer to seek the most current and accurate advice.

As a system, VRF has a lot to offer in terms of efficiency, running costs, flexibility in use and control. As with any system, it suits some buildings, applications and climates better than others. Competent designers should be able to provide you with guidance on where these systems are most suited with respect to a particular application.

We apologise in advance for the length of this paper. For those who simply want a set of instructions, go to the last two pages outlining how to minimise the risk of system problems and how to go about system recovery if problems have already occurred.

We might add at this point that we opted to have a VRF system installed in our own offices earlier this year, believing it to be the most appropriate choice of equipment. To date it has performed very well.

History

It is approximately 10 years since VRF entered the NZ market with any regularity. Since then its popularity has escalated to a point where it is now one of the most common solutions offered by designers and contractors for small to medium sized buildings, typically between 1 to 4 floors.

Like any new (and relatively complex) product, there have been highs and lows, lessons learnt and product improvements. Each generation of equipment is hailed as being better than the last, with time proving the ultimate judge as to whether such claims met the expectations of the purchaser.

Our experience with these systems ranges from new system design, reviewing new and existing installations, assisting with trouble shooting and diagnostics where problems arise and retrofitting of systems that have reached the end of their economic lives.

It is the very fact that less than 10 years into the product life cycle in NZ we are finding the need to retrofit a number of VRF systems that provided the main motivation to publish this information paper.

We trust you will find the following accounts of our experiences interesting and of some value towards managing the maintenance and possible alterations to your existing systems as well as specifying new systems.

What is a Variable Refrigerant Flow system?

A VRF air conditioning system is a particular type of heat-pump air conditioning system in which one outdoor unit can be connected to multiple indoor units. Each indoor unit is individually controllable by its user and a variety of unit styles can be mixed & matched to suit individual tenancy requirements e.g. high-walls, cassettes and ducted units.

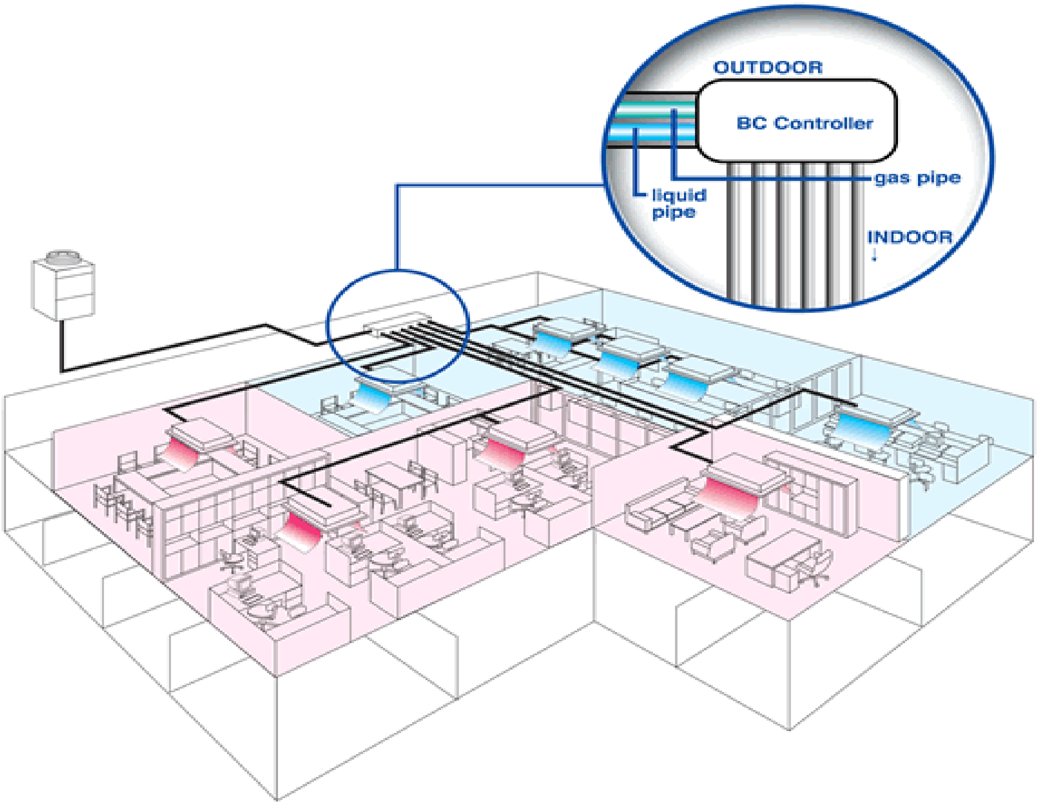
The outdoor unit can be made up of a number of modules to create the required capacity. The compressors can be operated at varying speeds, so the VRF units work at only the rate needed to meet the prevailing heating or cooling requirements, considerably enhancing their efficiency.

Each 'outdoor unit' can be made up of up to 3 modules, each having up to 3 compressors. Often there will be a separate 'outdoor unit' for each floor or pair of floors sized to match the load. Large buildings can have up to 30 or 40 compressors in total.

A large building can have in the order of 50-60 indoor units, and up to 1,000 metres of refrigerant piping to connect them to their outdoor units. The refrigerant pipework will also be fitted with several control boxes to create the correct flow of refrigerant to the indoor units.

The efficiency of many VRF systems can be further enhanced by their ability to provide simultaneous heating and cooling. An example of this would be cooling an east facing office subject to direct sunlight on a cool sunny morning, and using the heat extracted to warm up a cooler west facing office which does not have the benefit of direct sunlight.

A basic (simplified) schematic of a typical 2-pipe VRF system is provided below, indicating simultaneous heating (red) and cooling (Blue).



System uptake

While VRF systems have been around for almost three decades, they're relatively new to New Zealand – having arrived in the 1990's. As design engineers have become increasingly familiar with the technology and the drive for energy efficiency has increased, more people in the industry have been willing to implement these systems.

Statistics suggest that approximately half of new medium sized commercial buildings in Japan (up to 6,500m^2) are now serviced by VRF systems, as well as approximately one third of larger buildings. Uptake in NZ has been slower, but has been gaining momentum steadily over the last 5-8 years.

System features (Pros)

VRF systems offer a number of benefits to designers, installers and end users. While it is best to peruse the manufacturer's literature for a full list of benefits, a few of the common features include:

- One outdoor unit for multiple indoor units, saving space and installation costs and improving the building's external appearance.
- The ability to use long pipe runs, so the outdoor units can be located in 'out of the way' places.
- Sophisticated control, offering modulated heating and cooling for better comfort (subject to some set-up criteria, especially heating / cooling changeover criteria)
- High efficiency heating
- Simultaneous heating and cooling (some models), offering even higher efficiencies
- Essentially all systems now sold in NZ use ozone friendly refrigerants

Of the above, it is the energy efficiency argument that is most often promoted as the compelling reason to use VRF. A closer look at this discussion in relation to the NZ climate is provided below.

Energy efficiency

If you search the web or talk to suppliers, some pretty impressive (and sometimes optimistic) energy savings figures are being quoted. Our advice here is to have an energy analysis completed for your particular project to get a better understanding of what savings you are likely to realise from a VRF system compared with a second choice system suitable for your site.

Our experience, coupled with computer aided building thermal analysis is that 'modest' energy savings can be made, depending on geographical location, the use of double glazing as well as many other factors. A few pertinent points are:

Refrigerated cooling and 'free' cooling

In cooling operation, VRF systems offer broadly similar efficiencies to any other modern refrigeration based system.

However, central plant systems such as VAV (Variable Air Volume) offer a natural ability to provide 'free cooling' by supplying cool outside air whenever it is cooler than the building exhaust air temperature, and a cooling load exists in the building.

In New Zealand's temperate climate (particularly in the northern regions) this can provide significant energy savings. VRF systems do not generally provide free cooling. Instead, they recirculate room air, with a separate outside air system providing the minimum ventilation requirements.

Some designers are now incorporating over-sized outdoor air systems for use in conjunction with VRF systems. These are designed to deliver higher quantities of outside air under favourable conditions, effectively providing more free cooling, and reducing to compliance airflow rates in very warm or very cool weather.

Heating

As with other heat pumps, VRF systems provide efficient heating, with typical efficiencies of around 400%, compared to 100% for electric resistive heating. However, in the temperate North Island climate, heating is probably only going to make up about 10% of your energy usage, with the rest of the energy going into cooling operation. The heating requirement rises significantly (possibly up to 50%) in colder climates, especially in retrofit applications where double glazing is not in use.

Realistic savings in heating operation are likely to range from about 7% in temperate climates with well insulated buildings to 35% in cool climates with poorly insulated buildings. Building size, use and orientation also play a role in actual energy consumption.

Most modern commercial buildings only require heating in quite cold weather, even for zones without solar gain. As the outdoor air temperature rises the flowrate of heat out through the walls and windows decreases and the incoming fresh air needs less heating. A point is soon reached when the rate of heat generation in the room from lighting, equipment and people matches the heat loss, so the need for heating drops to zero.

Simultaneous heating and cooling

VRF systems have a unique ability to extract heat out of areas requiring cooling and put it into zones requiring heating. However, while this is a great feature, it is only of value when at least one zone needs heating.

Recent modelling of a typical medium sized commercial office building in Newmarket, Auckland, indicated the requirement for simultaneous heating and cooling to be about 1-2% of the system's operation. The need for this feature increases in colder climates & may form up to 10-15% of the system's operation.

To some extent, differing preferences of occupants for warmer or cooler workspaces can also result in a demand for simultaneous heating and cooling, which is normally frowned upon, but can be economically catered for with the VRF system.

In general, energy savings from VRF systems will be higher in the South Island and better again in Europe or North America, where much of the published data emanates from.

System issues (Cons)

Many VRF systems provide relatively trouble free operation with normal maintenance costs. Full life expectancies in NZ are yet to be determined, as there are relatively few systems that are over 10 years old to date.

However, over recent years we have been involved in the replacement of several VRF systems which have by all accounts failed prematurely.

Many of the issues encountered have root causes stemming from poor installation or poor maintenance practices. We would stress the importance of following 'best practice' refrigeration industry standards for the design, installation and maintenance of these systems.

A review of some of the issues encountered is provided below.

1. Obsolescence

VRF technology continues to develop rapidly with respect to control systems and the adoption of new ozone friendly refrigerants.

To varying degrees, some of the earlier VRF systems installed throughout NZ are now becoming obsolete, due to parts being difficult and/or expensive to source and support for aging product fading away. These earlier systems were invariably based on R22 refrigerant which is on its own path to obsolescence, with new imports banned from 2015. It is important to seek advice from the equipment supplier to get an understanding of where your system sits in its product life cycle and what options are available to maximise the system's useful life. Some manufacturers are actively building in replacement technologies.

The combination of reliance on R22 refrigerant and unavailable or expensive parts is leaving some building owners with little option but to replace entire systems.

2. Quality of installation

The spidery nature of VRF pipework, and specific installation requirements (which vary between different manufacturers), makes the standard of the initial installation a crucial factor in the life expectancy of a VRF system.

These are complex refrigeration systems that may have up to 1,000 metres of pipework, dozens of brazed joints, and up to a hundred flare-type screwed joints, creating many opportunities for leakage. Some manufacturers are moving away from flared joints to increase the robustness of installed systems.

VRF systems require the same level of care and attention to detail as afforded to large chillers or industrial refrigeration systems.

Pipework must be supplied to the site cleaned and capped, and must remain capped as long as possible. As soon as the installation of a section of pipe has been completed it should be sealed again, to minimise the entry of moisture.

The air inside the pipe must be totally replaced by nitrogen during brazing, or a layer of carbon will form on the inner surface of the pipe. Then, once the system is operating, carbon flakes will progressively be released and carried to filters, restricting the refrigerant flow.

Special tools and techniques are needed to tighten flare joints correctly and minimize the risk of leakage.

Isolation valves with service-ports should be fitted to the branch lines to each indoor unit, so that the unit may be repaired or moved without having to de-commission and re-evacuate the whole system.

3. Quality of commissioning

Completed systems must be thoroughly pressure tested, preferably before joints are insulated, to identify leaks. Of course the leaks must then be fixed, which may involve re-purging the lines with nitrogen, and/or re-assembling flared joints.

The systems must then be thoroughly evacuated, to remove all air and moisture. Evacuation can also identify leaks that do not show up during pressure testing. Evacuation may take several days, especially if the system is large or contains a significant amount of moisture.

The vacuum pumps must be connected to the system via copper tubing rather than a refrigerant hose, with a non-return valve to prevent back-flow into the system. The oil in the vacuum pump must be changed when hot just prior to evacuation, to minimize its moisture content.

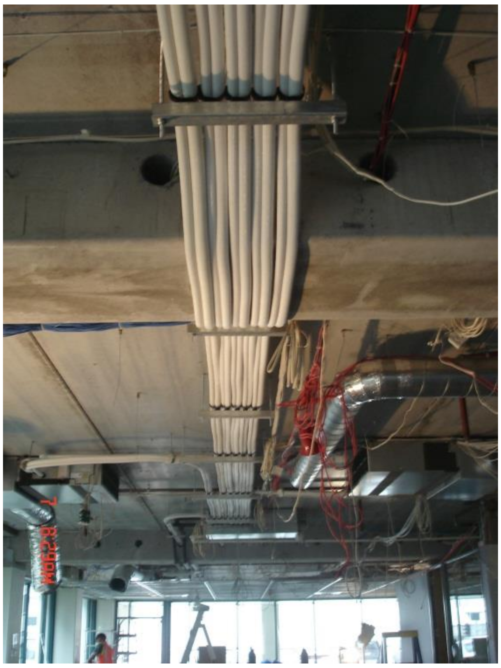
VRF systems are equipped with very good diagnostic tools, but the manufacturer's full commissioning procedure must be carried out to obtain their full benefit and verify that the complete system is operating correctly in all modes. Detailed commissioning sheets should be completed to demonstrate that the procedure has been followed, and to record the data for future reference.

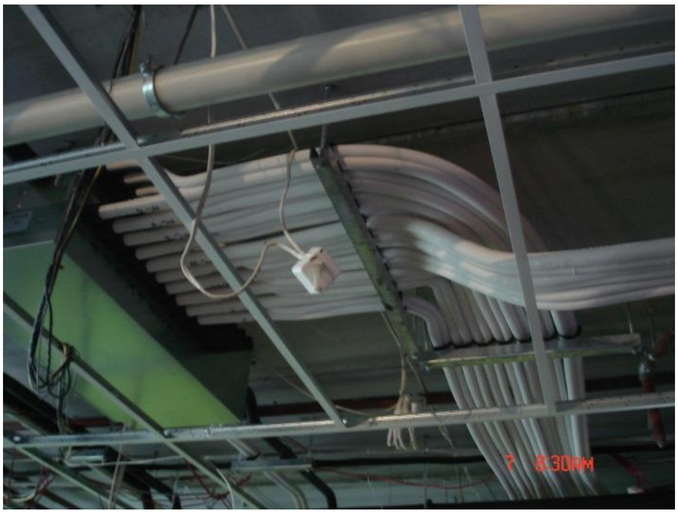
The contractor must be allowed sufficient time and money to install and commission a VRF system properly. Sadly, many contracts do not achieve this essential outcome.

The issues stemming from poor workmanship may take months or even years to surface, so often occur outside of standard warranty periods.

These photographs show a very poor standard of installation.

If your installation looks like this, it is hard to imagine much care has been taken or the required attention to detail has been provided to avoid future problems.





These photographs show a good quality installation completed under proper supervision.

4. Maintenance

Location and detection of refrigerant leaks can be very difficult with VRF systems. Some factors contributing to this are:

- The systems tend to be quite large, so it can take weeks or months for a slow refrigerant leak to become apparent.
- Physical leak detection is difficult as the refrigerant pipes are insulated, and is even harder where they are run in inaccessible or difficult to access spaces. Also leaks on internal parts of equipment, such as indoor units, can be difficult to locate without disassembly.
- If a leak has occurred, it is almost impossible to determine how much refrigerant has been lost.

Where a loss of refrigerant has been diagnosed, the only sure way to re-charge the system is to decant all remaining refrigerant out of the system and replace it with a known (weighed) quantity.

Time and cost pressures often mitigate against this practice, so the service company may just ‘top-up’ the system, using traditional refrigeration instincts to judge when the charge is about right. Such judgements are generally inadequate for VRF systems.

5. Poorly executed system alterations

Alterations to systems are a major cause of problems with VRF systems. Typically resulting from a fit-out requirement part way through the equipment’s normal life cycle, system alterations must be completed under the same strict standards required by a new installation.

Often isolating valves have not been installed to individual indoor units as part of the original installation, so the whole system must be shut down to move a single indoor unit. This adds time and cost pressures to the contractors who have to get the job done quickly to minimise disruption to other tenants, so proper pressure testing and evacuation procedures may not be followed.

6. Original choice of refrigerant

Older systems will be based on R22, which as most people are now aware, is being phased out, with a complete ban on new imports from 1 January 2015. Service stocks are decreasing and the price is rising.

It is technically possible to convert R22 systems to a newer refrigerant but many commonly-available refrigerants are not compatible with the mineral oil used in R22 systems. Multiple oil changes are needed, and since the oil travels right through the system with the refrigerant it is very difficult to achieve the required purity.

Most manufacturers we have spoken to would not support a change in refrigerant for their existing VRF systems.

If a conversion was attempted, it would have to be decided who would carry the risk of consequent compressor failures. In our view, the system owner might decide the cost of possible failures would be an acceptable risk compared with the alternative i.e. the cost and disruption of complete system replacement.

If a contractor was required to carry the risk they would have to add a very substantial amount to the cost of the job, because of the sheer uncertainty of the risk.

If an R22 system is to be replaced, the new system will almost invariably use R410A. This means that many components including larger diameter pipework will have to be replaced because the operating pressure of R410A is much higher than that of R22.

Systems based on the use of R407C were introduced from about 2004 for a few years until R410a became the standard refrigerant for these systems.

R407C is a blended refrigerant, using three main components with different temperature / pressure characteristics. The significance of this is twofold:

- The standard industry practice of determining system operation by observing refrigerant pressure / temperature relationships gives misleading results. A very high level of technical expertise is needed to correctly interpret such data with this refrigerant.
- Should a leak occur, one of the components will leak more than the others, which alters the operating performance of the remaining refrigerant. In such cases the entire remaining charge has to be removed and new refrigerant introduced. However, R407C should remain readily available for some years, so if an R407C system is operating satisfactorily and is being well maintained it should be able to remain in service so long as replacement components are available.

7. Types of failure

The complex nature of VRF can result in many different problem types. So how do serious problems manifest from the issues outlined above?

1. Controls / electrical

Electrical, electronic and control component failures can and do occur. These can be exacerbated by vibration from fans & compressors, excessive temperatures and poor quality power supplies. Obsolescence of control boards has been an issue with some brands with early generation equipment.

2. Compressor failures

This is the most common 'serious' problem. Compressor failures are generally classified as electrical (compressor motor) or mechanical (compressor) failure. Assessment of the system's oil condition and physical inspection of the failed compressor provide the clues as to what may have contributed to the failure.

The most common cause of an electrical (or compressor motor) failure is due to the system's oil becoming acidic. This can happen due to undiagnosed refrigerant leaks, poor system evacuation or previous compressor failures. The acidic oil damages the electrical insulation on the motor windings and causes an electrical 'short'. The service report is likely to say that the compressor motor is 'down to earth' or has an 'earth fault'.

The most common cause of a mechanical (compressor) failure is lack of oil at the compressor, usually caused by sludge and blocked strainers and oil-ways within the outdoor unit. Mechanical damage to the compressor bearings and /or suction & discharge valves usually results. The service report is likely to say 'compressor failure'. Mechanical or valve damage can only be confirmed if a compressor is cut-open for diagnosis.

A compressor replacement is required under either mode of failure.

System failures

Compressor failures occur for various reasons in many refrigeration systems, ranging from large chillers to simple split system air conditioning units. Repairs are generally undertaken if economically viable. Provided the diagnosis is thorough, root causes can be identified and proper remedial work can be undertaken to minimise the chances of further failures. In most instances repair work is successful and the systems are put back into normal operation.

The above statement applies equally to VRF system failures. However, the inherently complex nature of these systems makes it all the more important to follow best practice refrigeration industry service and repair standards.

In practice, we have observed several VRF systems which experience on-going problems, seeming to go from bad to worse. So what's different about VRF?

- Most faults experienced on a VRF system will result in the complete system being out of action. With systems typically serving 4-16 indoor units, a fault on one unit could affect many people. As noted above, this adds severe pressure to the service provider to get the problem fixed and the system operational as soon as possible, increasing the chances of 'shortcuts' being taken.
- If the oil has become acidic it must be virtually completely removed from the system. To achieve this, the suction accumulators should be replaced along with failed compressors. The piping and indoor units should also be cleaned out, but this is very difficult and time-consuming, so is rarely done. Consequently the new compressor starts out life in an acidic environment, which is likely to lead to another premature failure. If this process is allowed to repeat, a runaway trail of compressor failures is likely to result.
- Mechanical damage due to chronic lack of oil (or foaming oil due to low refrigerant levels) will result in metal 'fines' being released as metallic components wear excessively. These 'fines' will block strainers within the refrigeration system, (which are generally non serviceable and inaccessible), causing a further lack of oil return to the compressor. As above if this process is allowed to repeat, further compressor failures are likely to result.

Summary - How to minimise the risks

Installation

The way to minimise risks is to:

- Have your system designed by a competent, experienced professional air conditioning engineer.
- Use a supplier-approved qualified installer.
- Use corrosion-treated outdoor units, to maximise their life.
- Ensure isolating valves with service-ports are fitted for every indoor unit.
- Make sure all brazing is done using nitrogen purging and at least some joints are witnessed.
- Make sure pipework pressure tests are undertaken in accordance with the manufacturer's recommendations and are witnessed.
- Make sure proper system evacuations are undertaken to remove all moisture and are witnessed.
- Have the system commissioned by a supplier-approved agent.

It is critical that the standard of installation is as high as possible.

Pressure testing is often omitted or carried out to lower than recommended levels due to time pressures. Pressure testing pipework and joints stresses the metals in different directions than achieved by system evacuation procedures. Leaks that show up under a pressure test may not show up under an evacuation test and vice versa.

Proper triple evacuation procedures must be followed and will ideally be left until a specific level of vacuum is attained rather than by time alone. Sufficient time must be allowed, particularly in cold weather for all of the moisture to be drawn out of a system. There is no short-cut to this process. It will take as long as it takes and on a large system, it could sit under vacuum for 3-5 days before acceptable results are achieved. If leaks are detected they must be found and fixed, and the evacuation process repeated.

Sufficient time must be available at the end of the construction period to allow these tasks to be carried out to the levels required.

By contrast, chillers arrive to site having been properly evacuated and charged during manufacture before leaving the factory. Simpler split system installations have much smaller refrigeration systems, so do not require the same time for evacuation procedures as large VRF systems.

System maintenance and remedial work

If a system requires repairs such as a compressor replacement, or alteration work such as relocation of an indoor unit, all of the measures relating to a new installation must be followed.

There is likely to be significant pressure from the building occupants to get the system back up and running, so:

- Advise the occupants of the realistic time the work will take (usually several days).
- Issue firm instructions to the contractor so all the necessary tasks are carried out.
- Arrange for observation of at least some of the key tasks such as pressure testing and evacuation, to 'set the scene' regarding the quality of work required.
- Be prepared to pay a realistic price for the work, including out-of hours work if appropriate.

The consequences of shortcuts are likely to be seen in further compressor failures at decreasing intervals. We have seen new compressors fail within 9 months.

System recovery

If you have experienced one or more compressor failures, what can you do to avoid a series of repeat failures?

To an extent, the answer depends on how much damage has occurred to date. Generally speaking, one or two compressor failures should be recoverable, but for every successive failure, the recovery process is likely to become more difficult and expensive.

The road to recovery requires considerable effort and planning by a competent service provider in conjunction with the equipment supplier. Leading manufacturers are taking a proactive approach in assisting customers who experience difficulties with their systems.

Depending on the mode of failure and the history, it might be necessary to remove the refrigerant, change the suction accumulators, pressure test and evacuate the system – requiring the system to be off-line for about 4 days. While the system is down, appropriate valves need to be installed for future isolation and to allow regular oil samples to be taken without interfering with the system.

Burn-out driers with isolation valves will be required and plan on changing them with monotonous regularity for the first few months.

On-going monitoring of the oil will be required and if it shows any signs of increased acidity the refrigerant & oil will need to be removed and replaced.

This will be a relatively costly exercise, but a lesser approach is likely to end in premature failure of the entire system.

Refrigerant volume & safety considerations

A final point to note is one of safety for the occupants of areas served by a VRF system.

VRF systems contain a large volume of refrigerant, so if a substantial leak should occur on an indoor unit serving a relatively small sealed space, there is a risk of the refrigerant displacing the room air, leading to possible asphyxiation of the room occupants. Commercial office installations are rarely at risk due to poor room sealing, but designers must check concentration levels to all spaces served to ensure compliance with AS/NZS 1677.2 1998.

Of particular concern are sleeping quarters such as apartments or hotel rooms, where doors are closed and no other ventilation is provided.

This is a manageable risk and can be designed out by competent designers, or additional protection such as refrigerant detection systems can be installed.

We trust the above provides some useful guidance and tips to ensure you get the best from your VRF system.

For further information or advice, please contact Jackson Engineering Advisers Ltd.