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[ijirset@gmail.com](mailto:ijirset@gmail.com)

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# Evaluating Use of Variable Refrigerant Flow (VRF) in Residential and Commercial Buildings

Jeffrey M Molavi<sup>1</sup>, Brandon Donovan<sup>2</sup>

Professor of Construction Engineering and Management, Department of Built Environment, University of Maryland Eastern Shore<sup>1</sup>

Project Manager, Whitening-Turner Contracting Company, 7240 Cedar Creek Rd, Milford, De 19632<sup>2</sup>

**ABSTRACT:** Energy crises has become a global issue since 1980's and it forced the governmental and private agencies to look into alternative energy sources. In micro level, buildings have faced with the energy cost to maintain a comfortable temperature in summer and winter for the living and working spaces. As a result, the energy efficiency in building system have been the primary focus of designers and builders. There aren't two people in the world that are the same or that have the same exact preferences regarding indoor temperature. This holds true with environmental comfort as well. For example, in a public elementary school, there may be a classroom where the students and teacher would prefer the temperature in their room to be warmer but the students in the adjacent room to them may prefer to have it a little cooler than the other rooms. Before, with traditional air handling, this wouldn't be possible due to each classroom running off of the same air handler. Each room would be subject to being the same temperature, not factoring in the outdoor air quality and the location of the classrooms. With innovations such as VRF systems, this is now an option for all commercial buildings. This study focuses on evaluation of VRF system technology, performance, operation, and cost savings in residential and commercial projects.

**KEYWORDS:** Air Conditioning, Variable Refrigerant Flow, Building Systems, Energy, Heat Pump

## I. INTRODUCTION AND BACKGROUND

HVAC technology has advanced immensely over the past 100 years since it was first created by Carrier but air conditioning actually began in Rome. "Attempts to control indoor temperature began in ancient Rome, where wealthy citizens took advantage of the remarkable adequate system to circulate cool water through the walls of their homes" [7]. America began to pick up on this in the late 1800's but what really set it off was obviously the discovering of electricity. Once Nikola Tesla was able to invent alternating currents for motors the oscillating fan was created to help with indoor temperature control. "In 1902, a 25-year-old engineer from New York named Willis Carrier invented the first modern air-conditioning system. The mechanical unit, which sent air through water-cooled coils, was not aimed at human comfort, however; it was designed to control humidity in the printing plant where he worked" [7]. By 1925, most movie theatres had adopted Carrier's air conditioning system and on hot summer days families from all over would pack themselves into theatres to get out of the sweaty, summer heat and cool off causing a spike in the summer blockbuster. "Europeans have been slower to embrace air conditioning, but like cold beer and ice water, it's beginning to catch on there too" [7]. "Air-conditioning's major public debut was at the 1939 World's Fair. Carrier hosted the Carrier Igloo of Tomorrow expo, where 65,000 visitors would experience air-conditioning for the first time, boosting consumer interest. Over the next decade, as the air conditioner shrank in size, advertisements for the machine shifted their appeals from men in the workplace to women at home" [2]. This would clearly develop an increasing demand in home air conditioning from households around the country. "By the 1960s, millions of air conditioners were being sold every year in the United States. Windows across cities and suburbs were being plugged with the machines" [2]. Today, everyone can probably remember growing up with a window air conditioner in their homes and the whole family gathering in the room where it sat. Fast forwarding to the 21st century, the demand for VRF systems are now beginning to really take off.

II. RELATED WORK

VRF stands for variable refrigerant flow and was first created in 1982 by Daiken Industries. They consist of a ductless split system or multiple ductless split systems and use refrigerant to heat and cool certain zones using only one outdoor unit to control each of the VRF systems inside the building. The ductless split systems can come in different varieties and sizes. They are usually wall hung or recessed into a ceiling. Normally the systems are called cassettes and can be a one-way, two-way, or a four-way cassette.

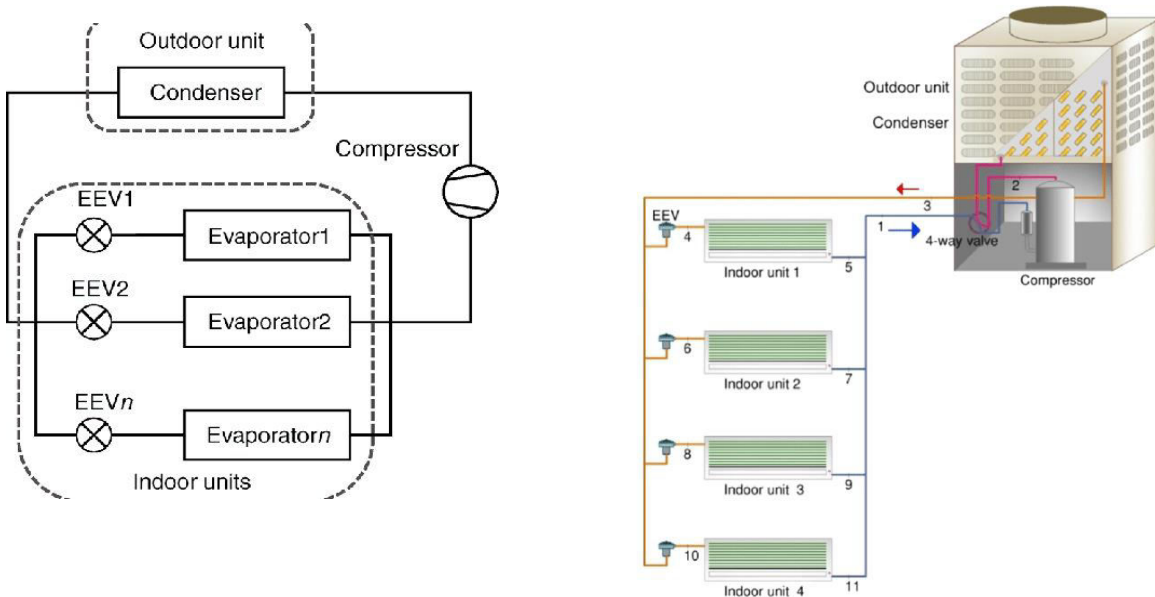


Figure 1- Illustrations of Schematic Diagram of aVRF system [8]

Technology and Application of VRF

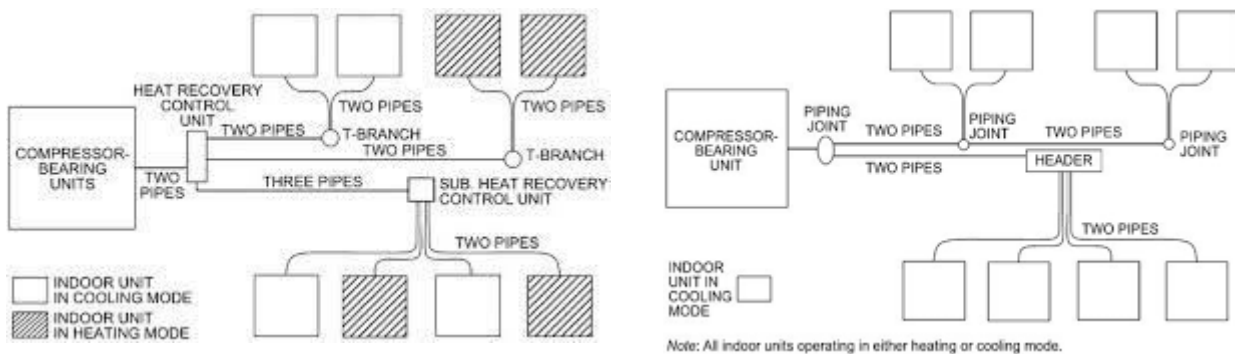
With VRF systems, customers now have the opportunity to set and control their own temperature in their rooms. Each cassette has its own thermostat to control the temperature of the tenant. Even though this innovation was developed in the early 80’s, it has only recently taken off in commercial construction over the last decade and wasn’t available for use in the United States until the 2000’s. Today hotels, hospitals, schools, and office buildings are all moving towards relying more on these types of systems and less on normal duct supplied air flow. These systems not only please the customers who use them but they also run more efficiently than traditional units and can cut down on energy costs for a building, sometimes over 50%. The system gets input from its user, who controls the thermostat, as well as from the surrounding ambient air and according to the data it inquires, it implements its logic in order to get the desired comfort conditions. By working in this manner, the systems can adjust themselves to work against the ambient air that is brought into the area by multiple factors. Factors that add to the ambient heat or cooling load consist of people, materials, lighting, and R-values of the walls separating the rooms from the outdoors. For customers, this is an exciting advancement in HVAC technology. “Thus, at any point in a system there will be a variable volume of refrigerant flowing. Various strategies are used to vary the output of the outdoor units including, modulating fans, heat exchanger valved in sections, variable speed inverter drive compressors, multiple compressors, twin or multiple modular outdoor units. Outdoor unit capacities range from around 14 kW to over 100 kW. Indoor units cover the full range of DX models normally available” [5]. Imagine not having to sit and sweat in a hot room wearing a three-piece suit, just because there wouldn’t be any tenant control of the indoor air quality.

“The specific design of a VRF system varies based on application. In general, VRF technology provides the ability for multiple indoor units or zones to operate on the same system. VRF systems can either be a heat pump system or a heat recovery system, which provides simultaneous heating and cooling” [3]. A mechanical engineer generally has the final decision on whether or not VRF system would be justifiable in a certain location, and if that system would be able to sustain the heating and cooling load of that location. Another beneficial side to having a VRF system is the



space issue above commercial ceilings. Bulky ductwork takes up a lot of space above ceilings in any building. There is already limited space with other factors taking up the space such as electrical conduit, storm drain piping, etc. With the use of refrigerant lines instead of the use of sheet metal duct work saves the space above the ceiling making it simpler for any above ceiling work or maintenance that would be needed after the system was installed. Other trades would have the room to move more freely above ceiling and layout their work much easier. Refrigerant lines are run from the outdoor unit and fed to a branch selector inside of the building. These branch selectors then feed multiple cassettes inside of the building. The systems are so advanced they are able to be monitored by an engineer via a computer to ensure that all units and cassettes are functioning properly and efficiently to the standards of the specifications and the desires of the consumers. “VRF equipment is sleek and compact compared to other HVAC equipment. This makes VRF an excellent solution for installing HVAC equipment in areas with limited space, such as when renovating historical buildings” (Coley 1). Installation of the traditional VRF system is relatively simple as well. “Because VRF equipment weighs much less than ducted equipment, installing a VRF system is easier and requires less physical effort than a traditional HVAC system” [3].

Once they are set into place, they are normally hung from the roof decking and the condensate lines are then tied into them. Depending on the number of workers that are on the site, a ductless split can be hung and tied in all on the same day. “Due to the advanced use of variable speed compressors, drives, and inverter-driven fans, many manufacturers of these systems are capable of providing simultaneous heating and cooling through their indoor units. Most manufacturers refer to these as heat recovery systems, and they have various methods of recovering the heat through either a two-pipe or three-pipe system” [1].



**Figure 2-** Schematic diagram of systems capable of providing simultaneous heating and cooling [9]

When does it make sense to use these types of systems? Again, it’s about the capacity and the possibility of energy efficiency. “On the renovation of a relatively small government housing project (5,000 sq. ft.), we were tasked within the design criteria to provide a central HVAC system that also provided individual temperature control within each dormitory room. In addition, we had to meet the design requirements of a LEED-certified building, which requires energy savings of 30% compared to the baseline system. Those two criteria limited our options and led us in the direction of VRF. In the end, VRF and geothermal systems were the only two systems able to meet the energy savings” [1]. These units are also available gas powered. In the event of having a limited electrical power supply, Panasonic VRF units are available with Gas driven engines, these will operate off a natural gas. They are all single-phase units and can produce up 90 Kw of Cooling and heating from one single phase 30-amp supplies. They also offer other benefits such as, hot water generation, electrical generation and they will continue to provide heating evening during defrost periods.

VRF systems are also becoming a growing trend in residential homes as well. Many consumers have garnered interest in saving on their energy consumption and have begun straying away from the traditional split systems that control the zones of housing and have steered towards these systems. One family in our neighbourhood has even installed these in their own homes and have noticed the efficiency difference on their monthly energy bills. Only controlling the temperatures in the rooms that they want to control rather than heating or cooling the entire house that wouldn’t currently be fully occupied. A traditional two-story home would have two separate outdoor A/C units that control both zones. One for the upstairs and one for the downstairs. Homes can now use one unit for the house controlling each room. Personally, my wife and I only use a few rooms in our home and I have been considering installing these in my own house. The VRF’s can also transfer heat from one room to another. Some VRF systems offer heat recovery technology, an efficiency feature that extracts heat from one room, like a home gym, and transfers it to



another, like a bedroom or even a pool. This allows a consumer to eliminate unwanted heat in their own homes due to an outside source. For instance, maybe a bathroom gets too warm from the shower operating producing a large amount of steam. The heat would be able to be transferred from said bathroom to an area of the house that is cooler and needs heating provided to it.

There are however some cons to VRF systems. One of them is the fact that if something were to go wrong with the unit that is outside, it would potentially affect every system that is running off of that specific unit. For example, my company and I were on a project at the beach which was the construction of a brand new, state of the art hotel. The hotel was an eight-floor beach front hotel and the HVAC technology that was in the building were multiple VRF systems. Each floor had its own unit supplying the cassettes that were in each of the rooms on that particular floor. Not long after the hotel was opened we began to have an issue with one of the units on the rooftop. On most commercial buildings the units are located on rooftops due to sheer size of the units and space. It was the 7th floor unit that we began to have issues with and ultimately the system shutdown. When that happened each VRF cassette on the 7th floor went down with the unit. This failure caused the hotel to move guests that were in these rooms to other rooms throughout the hotel. This is the down side of VRF systems. With multiple rooms being inoperable, this put a dent in the hotels profit because of the loss of the guests they could've served had the 7th floor been able to be occupied. This issue lasted for around one month and became very frustrating for us and the owner of the building. Having the potential to fail and cause an entire zone of a building to go without air control could deter many of potential consumers from purchasing these types of systems. Who would want to put these systems in their homes or commercial offices if something could possibly go wrong with them? The chances of anything going wrong with VRFs are relatively small but can happen. It's important to have the proper personnel installing and maintaining these units to ensure that the percentage of error stays relatively low.

Another term for VRF is VRV which stands for variable refrigerant volume. Both are essentially the same thing but are basically trade names by corporations. For instance, Daiken uses the term VRV and Fujitsu uses the term VRF. Both systems operate the same way and help deliver a home or business an energy consumption of net zero, which means it will produce as much energy as it uses. If the energy used to operate a system is matched by the energy that system puts out than the buildings energy consumption is thus net zero. This can be beneficial for homes and businesses who desire to have their buildings LEED certified. LEED stands for Leadership in Energy and Environmental Design and is a globally recognized symbol of sustainable achievement. Advancements in preserving the environment and lowering energy consumption are key factors in achieving the certification for a building. Certain criteria are required to be met in order for building to earn some form of a LEED certification and VRF systems are able to meet these consumption requirements. The government also offers rebates to those who are able to earn these certifications which can save even more money for households and businesses.

### III. METHODOLOGY

The methodology of this study is a collection of research published journal papers, case studies, and the proven experiences of the industry who produce and test the related system components. The results of the research studies are reviewed and create a comprehensive guide for the energy use and operations of the VRF system. The background history and concept of the VRF system are explored. More over a specific case study for this study and the comments of the occupants of the building about their personal experience of the new air-condition systems are explained. The bottom line this study provides a comprehensive analysis of VRF system of the operation energy use and the cost savings for the owners, property managers and the occupants.

### IV. EXPERIENCE AND CASE STUDIES

Currently, we are studying a construction project that is an occupied renovation specifically focused on replacing the existing HVAC technology and improving the buildings indoor air quality. The building is a local High School that was constructed in the early 1970's and the existing heating and cooling system that is in the building was very outdated and inefficient. Replacing the old systems are a combinations of dedicated outdoor air supply units, (DOAS) VRF systems, and more modernized air handlers, in each of the classrooms the of the school ductless splits have been installed to allow each instructor the ability to control their own comfort. After communicating with many of the teachers after the renovations were completed in their rooms, the feedback on how they each like the VRF systems in their respective classrooms has all been positive. Many teachers and students have complained in the past due to the air quality in their rooms being so poor. Being able to observe closely these types of systems we have been able to see firsthand the efficiency of them. Only having to or heat the desired rooms is beneficial for the school because not all



rooms in a certain zone need to be conditioned. If some rooms are unused, the faculty has the option of turning off the VRF while still having others running even though they are all controlled by the same outdoor unit. This feature puts the money back into the pocket of a consumer because there isn't as much wasted energy inside of the building. Everyone would most likely get on board with cheaper energy costs.

#### IV. DISCUSSION

VRF system instead of moving the air through ductworks delivers conditioned refrigerant directly to the space eliminating reequipment for long-runs of ductwork. It also eliminates those inefficiencies that come with moving conditioned air a long distance through duct and provides a more energy efficient quiet and flexible way to condition a space. In addition, the VRF's ultimate personalized comfort experience for building occupants each space or zone requiring conditioning will have their own network of indoor units. This network units are controlled from within the space providing the occupants with the ability to personalize their comfort. Some systems even can cool some areas of a building while heating others from exact same system. This leads to happier tenants and fewer comfort controls for the building owners and facility managers. Finally, due to the design flexibility of VRF it can be applied to variety of building types and applications from adding capacity to an already taxed HVAC system on a college campus to providing K through 12 schools with a quiet efficient way to cool classrooms to conditioning a new high-rise construction project VRF is the optimal HVAC choice.

Expanding on the VRF and VRV systems, it's good to understand the different types and brands that are available today and to know the most common that go into building. The four most popular brand that are installed into buildings are produced by the brands Lennox, LG, Mitsubishi, and Trane. Lennox VRF combines the adaptability of zoning features and energy advantages of variable refrigerant flow with the knowledge and expertise of Lennox. All systems include smart features throughout, such as motors that use up to 45 percent less electricity than traditional systems, inverter technology for maximum efficiency and individual temperature controls. They also offer easy configuration for a wide range of buildings and workplaces. This allows contractors to be able to easily install the systems without the difficulties of a lack of space. The LG VRFs bring energy efficiency to commercial office buildings, schools and hotels. LG is one of the largest appliance manufacturers in the world and have been able to be highly successful in the production and sales of HVAC technology. In the project that I am currently working on with my company we are installing Mitsubishi units that are able to operate up to 100% of its rated heating capacity down to around 0 degrees Fahrenheit and can operate up to 85% of its rated heating capacity down to near -15 degrees Fahrenheit.

As the technology and research for heating and cooling buildings improves, it's good to focus on areas that can always be improved upon. Efficiency is always something that we should be striving to achieve. Nothing is 100%, not even VRF units. The more that mechanical engineers can pursue getting units to operate more efficiently, the longer the longevity of the units will be. This not only saves on energy costs throughout the life of the unit but saves on homeowners and business owners from having to purchase newer units. The life of a typical outdoor air unit is around 15 years. Being able to get a unit to last anywhere from 20 to 30 years can have a huge impact on our environment in the future.

If not for Carrier thinking about the future of comfort, who knows, maybe we are all still sitting around in a room sweating wishing we didn't have to deal with the heat. When human beings aren't comfortable, it's hard for all of us to focus on things that are needing to be addressed. A classroom full of students would not be able to focus and pay attention to their school work if it were extremely warm or humid in that classroom. Studies have shown that students grades slip when proper air conditioning in the building. "Researchers calculated that for every 0.55C increase in average temperature over the year, there was a 1% fall in learning" (Coughlan 1). Schools often are in session until June and by this time in the year temperatures have reached over 90 degrees in parts of the country. Many of schools could use an upgrade from their outdated systems that they already have and switch to VRF systems to improve their air quality and help improve students testing scores and mental focus.

#### V. CONCLUSION AND FUTURE

VRF technology has been in use around the world through three decades and is a prominent and often times default HVAC technology of choice. Its worldwide popularity is largely driven by factors such as the high cost of energy type, construction requirements and limited space for mechanical equipment within a building system make up 80% of more HVAC system applied in locations such as Europe, China, and Japan. In conclusion, we believe the world can benefit



themselves by investing in HVAC technology. Society has the choice if they want to cut down on their own energy bills and improve the efficiency of their homes. If everyone gave more thought into switching to a new style HVAC system, such as a VRF or VRV, the environment would thank us all. It's better to pay a little now so that we don't have to pay a lot later.

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