UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EXPERIMENTAL EVALUATION OF MULTIFUNCTIONAL VARIABLE REFRIGERANT FLOW (VRF) SYSTEM IN AN APPLICATION LABORATORY

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Heating, Ventilation and Air Conditioning) with Honours.

by

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DECLARATION

I hereby, declare that this entitled “Experimental evaluation of multifunctional variable refrigerant flow (VRF) system in an applicational laboratory” is the result of my own research except as cited in reference.

Signature : ....

Name : ……………………………………………........

Date : ……………………………………………

APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as one of the requirement for the award of Bachelor's Degree of Mechanical Engineering Technology (Heating, Ventilation and Air Conditioning) with Honours. The following are the members of supervisory committee:

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(Supervisor)

ABSTRACT

Variable refrigerant flow (VRF) system is a multi-split system contains at least one variable speed compressor. It becomes popular in market because of its high energy efficiency and high flexibility in design. The introduce of VRF system is perfectly to fill the empty space between the large centralised chilled water system and split unit. It is most suitable to use in light and medium commercial building. The equipment used in this project is located at Applicational of HVAC laboratory and it is not fully utilized in term of cooling capacity and application. The objectives of this project are to determine the excessive cooling capacity by performance test, the effect of the excessive cooling capacity to its daily performance and the number of indoor unit that able to connect to the system. The excessive cooling capacity and the number of indoor unit that able to connect to the system are successfully determined. After the experiment, I found that the VRF working in excessive cooling capacity will give negative effect to its daily performance include the energy efficiency. The limitation of this project is the outdoor unit is placed inside the laboratory which will affect the performance of the VRF system and the test room is not fully insulated. Thus, the recommendation of this project is to reinstall the VRF system to fully utilized its function and cooling capacity.

ABSTRAK

Sistem *variable refrigerant flow* (VRF) adalah sistem unit pisahan berbilang mengandungi sekurang-kurangnya satu pemampat kelajuan berubah-ubah. VRF menjadi popular di pasaran kerana kecekapan tenaga yang tinggi dan fleksibiliti tinggi dalam reka bentuk. Perkenalan sistem VRF adalah sempurna untuk mengisi ruang kosong antara *chilled water system* besar dan unit perpisahan. Ia adalah paling sesuai untuk digunakan dalam bangunan komersil ringan dan sederhana. Peralatan yang digunakan dalam projek ini terletak di Makmal Aplikasi HVAC dan ia tidak digunakan sepenuhnya dari segi kapasiti dan aplikasi. Objektif projek ini adalah untuk menentukan kapasiti penyejukan yang berlebihan dengan ujian prestasi, kesan kapasiti penyejukan berlebihan kepada prestasi harian dan bilangan unit dalam yang dapat disambungkan ke sistem. Kapasiti penyejukan berlebihan dan bilangan unit tertutup yang dapat disambungkan ke sistem berjaya ditentukan. Selepas itu, kesan VRF yang bekerja dalam kapasiti penyejukan berlebihan akan memberi kesan negatif terhadap prestasi hariannya termasuk kecekapan tenaga. Batasan projek ini adalah unit luaran diletakkan di dalam makmal yang akan menjejaskan prestasi sistem VRF. Oleh itu, cadangan projek ini adalah untuk memasang semula sistem VRF untuk menggunakan sepenuhnya fungsinya dan kapasiti penyejukan.

DEDICATION

To my beloved mother, Wong Ve Chin for rising me become who am I today. It is also dedicated my supervisor who taught and guided me when I faced the problem of doing this project.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

AHRI	The Air Conditioning, Heating, and Refrigeration Institute
AHU	Air Handler Unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
Btu/h	British Thermal Unit per hour
COP	Coefficient of Performance
COP_{HP}	Coefficient of Performance for Heat Pump
COP_R	Coefficient of Performance for Refrigeration
DC	Direct Current
DX	Direct Expansion
EEV	Electronic expansion valve
HVAC&R	Heating, Ventilating, Air Conditioning and Refrigerating
PCM	Phase Change Materials
PLR	Partial Load ration
SEER	Seasonal Energy Efficiency Ratio
SI units	International System of Units
STA	Separation Tube Assemblies
TES	Thermal Energy Storage
VRF	Variable Refrigerant Flow
VRV	Variable Refrigerant Volume
YDS	York Digital Scroll Compressor
h_{a1}	enthalpy of return air
h_{a2}	enthalpy of outlet air
Q_C	heat removed from the hot reservoir.

Q_{Ci}	cooling capacity of indoor unit
Q_{CO}	cooling capacity of the outdoor unit.
Q_f	air flow rate
Q_H	heat supplied to the cold reservoir.
T_i	Initial Temperature
T_f	Final Temperature
V_a	Air Flow Velocity
V_n	specific volume of moist air
W	Watt
W_n	air humidity ratio

CHAPTER 1

INTRODUCTION

1.1. Problem Statement and Objective

The Variable Refrigerant Flow system installed in the laboratory application always facing a problem which is the system is not fully utilized according to its capacity. Thus, the objective of this project is to investigate the effects of excessive cooling capacity on the daily performance usage and total energy consumption was experimentally investigate in the field performance tests. After determine the excessive cooling capacity, the number of indoor unit that able to be added to the system is estimated base on the excessive cooling capacity. The initial cost of the VRF system is normally 20% higher than other system in the same amount capacity. [1] Thus, utilize the VRF system is importance to make the money spend become valuable.

1.2. Background

Air conditioning is a combined process that performs many functions simultaneously. It conditions the air, transports it, and introduces it to the conditioned space. It can provide heating and cooling from its central plant or rooftop units. It also controls and maintains the indoor air quality, sound level, and pressure of the conditioned space to provide good thermal comfort to the occupant of the conditioned space. Air conditioning also used for product processing too to provide clean condition. For example, the manufacturing plant of automotive which using carbon fibre need to have a no-dust working condition.

VRF is a multi-split system with at least one variable speed compressor at the condenser unit to compress refrigerant and transfer it through a piping network to multiple indoor fan coil units which capable of individual zone temperature control by zone temperature control devices and common communications network. [2]

VRF is first introduced in Japan by Daikin in 1982. VRV, variable refrigerant volume is the trademark for Daikin Industries, Ltd for variable refrigerant flow technology. The reason for Daikin to develop VRF is to provide individual control for each zone. Then, this technology had gradually become more popular and reach Euro in 1987. In Japan, VRF system take approximately 50% market share for medium size commercial building's air conditioning system and one third of the large commercial building. [1]

VRF system is differentiate into two type which are VRF Multi-split system and VRF Heat Recovery Multi-split system. The VRF system used in this project is VRF multi-slit system. A multi-split VRF system is a refrigerant system that has variable refrigerant flow rate with the help of the variable speed compressor and electronic expansion valve located in each indoor unit to match with the cooling load of each indoor unit in order to maintain the temperature and humidity with the set value of each zone. [3] The multi-split VRF system has two types of pipe configuration which are two pipes and three pips and usually two pipe is used for VRF multi-split system and three pipe is for VRF heat recovery system. For two pipe configuration piping system, there is one pipe for high pressure(supply) and other one pipe for low pressure(return). [4]

In other words, VRF system is the larger capacity, more complex version of the ductless multi-split system. Besides that, VRF has can connect to ducted style fan coil units too. VRF technology able to control the amount of refrigerant flow into each indoor unit based on its load. Thus, individual zone control and simultaneous heating and cooling in different zone is easy to achieve in VRF system. [1]

Cooling capacity is the ability of the cooling system to remove the amount of heat per unit time and its SI unit is Watt(W). There is other unit to measure cooling capacity too. Example, Btu/h and ton. The value that shows on plate on each system is the maximum cooling capacity of the system. A system with excessive cooling capacity means the cooling capacity provided by the machine is more than the cooling load of the system.

1.3. Equipment

The VRF system in the laboratory application is manufacture by YORK and its model number is YDS120B5. YDS means York Digital Scroll Compressor and 120 means the 12 horsepower of input power. This VRF system has 2 compressors, one is fix speed and other one is variable speed compressor and 6 horsepower for each. The refrigerant used is R410a. It is manufactured in 2013. The system is using 2 pipes system to connected to indoor units, one for supply and one for return. The system has variable speed condenser fan too to adjust the fan speed base on requirement. The system has been connected to 5 indoor units with different cooling load.

1.4. Scope

In this project, the energy consumed of the system when connected to different number of indoor unit is determined through experiment to compare the COP of the system in different condition. After that, the effect of the excessive capacity to the system performance and the number of indoor unit can be connected to the system based on the excessive capacity are determined. In this study, the VRF system is only for cooling. Thus, the study of heating performance is not in our scope. Then, we only study the air-cooled VRF system and not include water-cooled VRF system.

CHAPTER 2

LITERATURE REVIEW

This chapter is discussed about evaluative report of information found in the literature which related to my selected area of study. Some definition from several sources, operation of VRF, application and the case study from the other authors about the VRF. Besides, the sources from Internet or library will be used to describe, summarize, evaluate and clarify the method to test the VRF system.

2.1. Definition of HVAC

The term *HVAC&R* defined as *heating, ventilating, air conditioning, and refrigerating*. HVAC design system is a sub discipline of mechanical engineering, based on the principle of thermodynamics, fluid mechanic and heat transfer. Air conditioner is a type of HVAC product. The main purpose of air conditioning had invented is to control the indoor air quality to provide good thermal comfort to the occupant in the conditioned space. Air conditioning system is used for the product processing too to provide a clean air that needed for the process.

Based on the working fluid used in the thermal distribution system, HVAC systems can be classified as [5]

a. All air system
b. All water system
c. Air-water system
d. Unitary refrigerant based system

A great amount of world energy demand is used for built environment. It is estimated that HVAC system consume about half of the total energy consumption in the office building. [7,8]. Therefore, reduce the energy used for air conditioning system in building is a key measure for energy saving. When design air conditioning system for a building, there are many types of air conditioning systems can be in your option list.

For example, window unit, fan coil unit, split unit, packaged unit, central air conditioner dual duct system and variable refrigerant flow system. [1] The main factors for consideration are climate, client and building configuration. For climate, the 4 seasons country need to use the HVAC system for cooling in summer and heating in winter but heating is unnecessary for country in equator like Malaysia. Client is also a main factor because they control the budget. Building configuration is important because some existing old building might not have enough space to place the chiller plant and ducting system. With the awakening of people on energy saving, producer and researcher have to make great efforts to study and develop various kind of air conditioning system to fulfil the market, and one of the most interesting developed product is the variable refrigerant flow (VRF) system with the variable speed compressor and the electronic expansion valve because of its high demand of energy saving. [9]

2.2. VRF SYSTEM

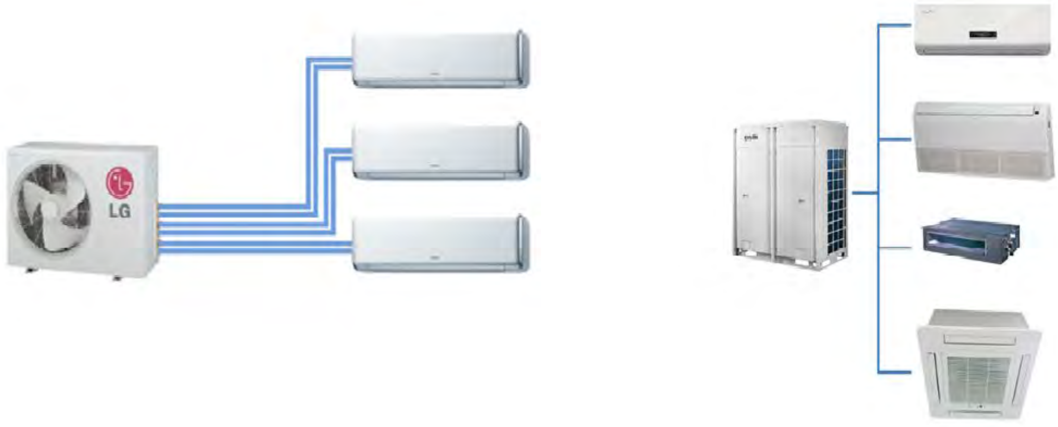
VRF system is classified into unitary refrigerant based system with direct expansion (DX). [5] This system was first introduced in 1982 by Daikin, which is a Japanese company. [3] In Japan, VRF system take approximately 50% market share for medium size commercial building's air conditioning system and one third of the large commercial building. [1] The ASHRAE Standard 62 defined a VRF system as ''to ability of HVAC system to regulate and control the amount of refrigerant flow to each of the indoor units/evaporators, then enable to use multiple evaporators of differing capacities and configurations, individualized comfort control, simultaneous heating and cooling in different zones with heat recovery from one zone to another". [1]

In section 3.27 of AHRI Standard 1230, VRF multi-split system is defined as a split system air-conditioner or heat pump incorporating a single refrigerant circuit, with one or more outdoor units, at least one variable speed compressor or an alternative compressor combination for varying the capacity of the system by three or more steps, multiple indoor fan coil units, with individual metered and individually controlled by a proprietary control device and common communication network. The system shall be capable of operating either as an air conditioner or a heat pump. [2]

The most important moment in development of VRF came in 1990 when Daikin introduced inverter control into its heat pump VRV and its number of supported indoor units increased from four to eight. Inverter capacity control increased system flexibility and efficiency by controlled the compressor speed based on the cooling load and using a more energy efficient direct current(DC) motor. In the next year, a further development was come with the introduction of heat-recovery, extended the following year by fresh-air supply and computerized system management. By 1994, Daikin's VRV can operate up to 16 indoor units from one outdoor unit. Commercial air-conditioning technology move big step forward in 2003 with Daikin introduce the VRVII — the first VRF system using R410a and available in both heat-pump and heat-recovery formats and many new features. The advantage of R410a is more environmental friendly compare to R22. R410a has lower ozone depletion factor and global warming potential than R22. VRVII represented a considerable advance over earlier systems. The use of a purpose-built inverter-controlled scroll compressor for example, raised COPs to a new level, whilst its DC motor promoted high energy efficiency, particularly in the most frequently used low to mid settings, reducing energy consumption and costs. In 2000, the first VRF system with water-cooled condenser was introduced which help to extended its application. Before that, VRF system only has air-cooled condenser. The water-cooled VRF system suited to both new and existing high-rise commercial buildings or projects lacking roof space or external space for outdoor units or where stringent noise regulations apply. The layout of a water-cooled system allows operation independent of ambient conditions. [10]

2.2.1. Operation of VRF system

A VRF system able to cool and heat different zones in a building at the same time but this only happen for the three pipe VRF system. The skeleton of VRF systems are similar to the multi-split systems which include multiple indoor fan coil units connected to a single outdoor unit. [11] The difference between VRF multi-split and conventional multi-split is the piping system. The conventional multi-split connect to every indoor unit by individual refrigerant cycle. That means if it connected to 3 indoor units, it will have 3 refrigerant cycle. In the other hand, VRF multi-split connect to all indoor unit by a single refrigerant cycle.



(a) (b)

Figure 1: Piping system of conventional multi-split (a) and VRF multi-split (b)

The outdoor unit consists of one or more variable speed compressors. Some manufacturer uses inverter technology and some manufacturer use digital scroll compressor. The speed of the compressor is varying by control the current input. In other words, the amount of refrigerant delivered by the compressor will be changed when the compressor speed changes. Multi-split system is only response to one controller but VRF systems will respond to each controller located in each indoor unit and adjust the flow of refrigerant to each indoor evaporator continuously. The amount of refrigerant flow into indoor unit can vary due to the level of opening of electronic expansion valve also. The demands of indoor units will send directly to outdoor unit by liking through a control wire to vary its compressor speed to correspond of a total cooling/heating requirements as shown in Figure 1. [12]

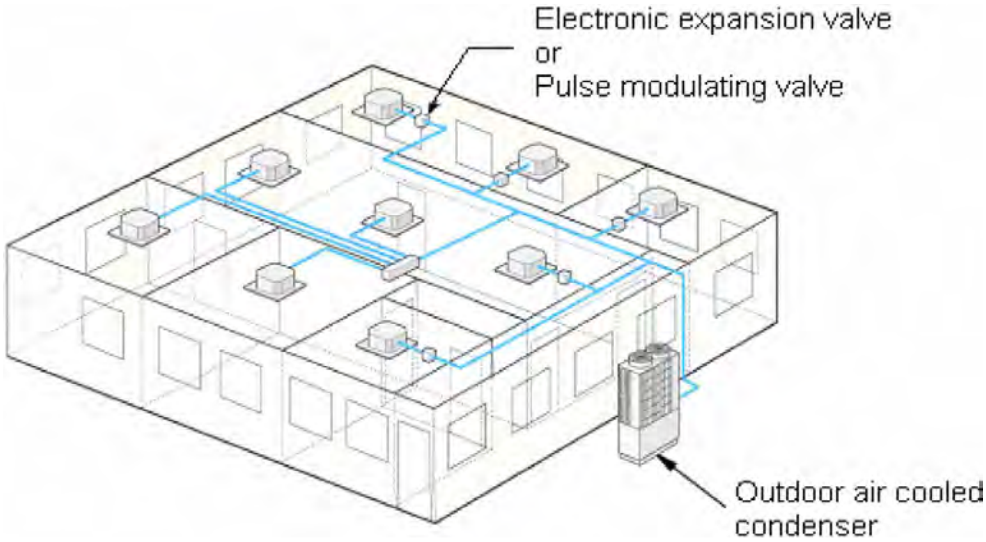


Figure 2: VRF System with multiple indoor evaporator units. (A. Alahmer, S. Alsaqoor)

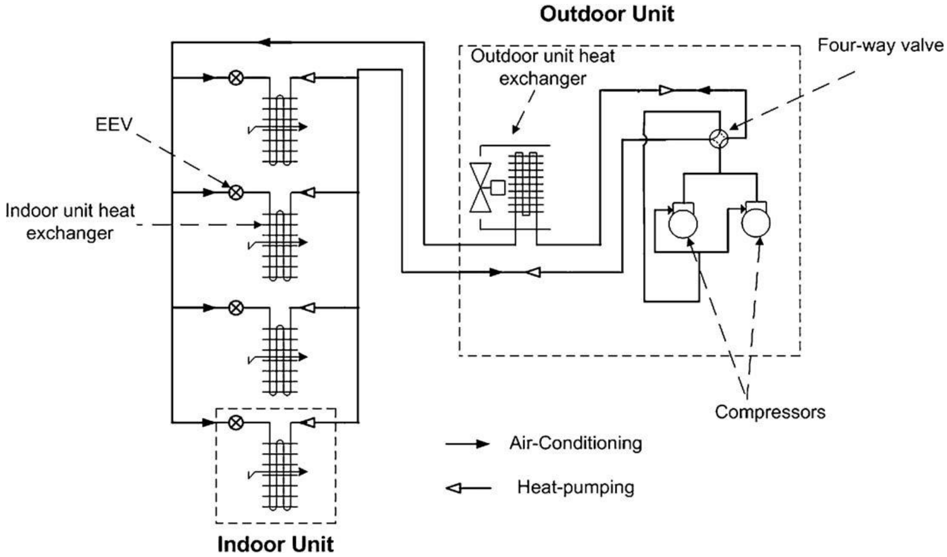


Figure 3: Schematic diagram of a multi-split VRF system having four indoor units. (Tolga N.Aynur)

In the cooling mode, the refrigerant discharged from the compressors enters the outdoor unit heat exchanger which act as condenser to remove heat from refrigerant to the environment for reduce its temperature. Then, the high pressure, low temperature refrigerant is expanded to low pressure by the EEV and enters the indoor unit heat exchanger which act as evaporator to absorb heat from the conditioned air. Then, the low pressure superheated refrigerant returns to the compressors, and finishes the cycle. [13]

In the heating mode, the four-way valve which shown in Figure 2, reverses the flow direction of refrigerant. The high pressure and high temperature refrigerant that discharged from the compressors enters the indoor unit heat exchanger to reject heat to the indoor air to provide warm air to the conditioned space. Then, the high pressure, low temperature refrigerant is expanded to a low pressure by the EEV. The low pressure, low temperature refrigerant enters the outdoor unit heat exchanger (used as an evaporator). The low pressure superheated refrigerant returns to the compressors, and repeat the cycle again and again. [13]

Generally, the multi-split VRF systems have either two-pipe or three-pipe configurations and they are worked with or without ice thermal storage tanks. The two-pipe (a high-pressure gas pipe, a low-pressure liquid pipe) multi-split VRF systems are the general ones that can be used for cooling or heating depending on the season. That means it cannot provide heating and cooling at the same time. In the other hand, the three-pipe (a high- pressure gas pipe, a low-pressure gas pipe, and a low pressure liquid pipe) VRF systems has the best efficiency and can provide heating and cooling at the same time with the same outdoor unit. This generally occurs in the winter season in medium-sized to large sized commercial buildings with a substantial core such as computer rooms [4].

VRF system connect multiple indoor units to a common liquid and suction line by using separation tube assemblies (STA) and EEV. STA diverts the common flow of refrigerant to individual evaporator and the amount of refrigerant flow into the indoor unit is controlled by the EEV on each indoor unit. The advantage of this kind of piping are [5]

a. Pipe length of VRF system can up to 150 meters.
b. Less copper used
c. Eliminates most duct work
d. Quick installation
e. Use less space

2.2.2. Application

Applications suitable to the multi-split VRF systems include anywhere there is an advantage to delivering individual zone control, such as office buildings, schools, hotels and motels. [1,4] Hospitals and nursing homes can also be good candidates for the multi-split VRF systems, since both have to avoid zone to-zone air mixing. Banks have favoured the system for security because the entrance tracks into the bank are minimized due to the minimal smaller diameter ductwork. The multi-split VRF systems can also be used in luxury single-family homes as well as in condos and multi-family residential buildings [4]. In addition, the historical buildings have benefited from the minimum alterations needed for the addition of a multi-split VRF system because the building layout of the old building is not ready for the ducting system. Retrofit situations can also be good applications for the ductless systems since additional ductwork can be minimized with the multi-split VRF systems compared to ducted systems [4].

In 21st century, high rise building become the main character in a city or town because in the limited amount of space need to take lots of people. Thus, when design a HVAC system for a high-rise building, use the minimum of space, low maintenance cost, availability of individual control, high flexibility and reliability is very important. VRF system can satisfy almost all of the requirements. Most of the VRF system is working in ductless eliminate the needs of the water pipe to transfer the chilled water through the building. It only need refrigerant pipe which is very small in size compare to the water pipe to supply chilled water. After that, VRF multi-split system also can provide individual zone control which is difficult to do in chilled water system. The using of VRF system in high rise building can help reduce the use of space for HVAC system means save cost because the price of land is very expensive. VRF system predicted to save nearly 50% of energy compare to average HVAC system in the same amount of life time. [14]

The other application of the VRF system is combined VRF system with thermal energy storage system (TES) to reduce the power consumption. [15] Basically, the TES system can be operated during the on peak thermal load conditions for conserving the average energy consumed by the cooling unit on a per day basis. Of the different types of TES systems available, the latent thermal energy storage system using phase change materials (PCMs) has proven its performance over two decades. [16]

2.3. Cost

The initial cost of the multi-split VRF systems is one of its main weaknesses. The installation costs of VRF system are highly dependent on its application, construction, and layout of the building and whether the installation is new or retrofit. In USA, lack of knowledge with the technology will add extra cost to the VRF multi-split system. [1,4] The total costs of the multi-split VRF system were likely to be about 5% to 20% higher than the chilled water systems with comparable capacity and about 30% to 50% more than equivalent capacity single package ducted system with seasonal energy efficiency ratio (SEER) of 13 to 14. The total cost of VRF system is two times more than the packaged unit too. [4] Cassidy and Sweet compared the whole-life costs of four common air conditioning systems (variable air volume with perimeter heating, four-pipe fan-coil units, multi-split VRF, chilled ceilings and passive beams with radiant panel perimeter heating) used in a new modern three-storey commercial office building with a gross internal floor area of 6500 m^2 for a 25-year operating period. The whole-life cost analysis showed that, the cheapest to operate is the chilled ceiling, follow by four-pipe fan-coil units and variable air volume system. The most expensive is the VRF system which is 111% more expensive than the chilled ceiling unit. [17] Besides, the multi-split VRF systems do not have any ventilation capability, that's why additional ventilation systems are necessary, which also increases the cost. [1]

2.4. Design VRF system

In a study by Ramez Affify in 2008 [18], the most importance factor in designing a VRF system is the building configuration although the maximum permissible pipe length of VRF is much longer than the conventional multi-split system. The reason for this statement is the longer the pipe length, the more copper will use and cause higher installation cost. Long pipe length may also increase the friction lose when refrigerant flow and affect the efficiency. Any design of the VRF system should not has pipe length which longer than the pipe length that stated in recommend data in the catalogue provided by manufacturer. The other most challenged problem when design VRF system in a building stated by Ramez Affify is to provide the amount of fresh air to comply with ASHRAE Standard 62.1 for maintain good indoor air quality because VRF system did not provide ventilation. Most manufacturers offer an outside air kit, for transport outdoor fresh air into the conditioned space. A separate outside air fan and control system is generally required for larger buildings. In humid climates, providing preconditioned outside air to each indoor unit ensures good indoor air quality. For example, dehumidified the fresh air before enter the system.