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A Comparative Study of VRF Air Conditioning System over the Conventional Domestic Air-Conditioning System

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Abstract
All over the world there is a call to encourage sustainable energy thinking and implementation. There is an urgent need to consider sustainable solutions that are able to reduce energy consumption cost. In air conditioning field, the rise of the variable refrigerant flow systems has made big progress. This study focuses on cost analysis to evaluate the economic feasibility of conventional, VRF and VRF duct type air conditioning system. The hourly and daily energy consumption of both systems were characterized based on corresponding outdoor air temperatures. Results showed that VRF air conditioning system is 15% less costly than conventional air condition. Though VRF duct system is less costly than conventional VRF, the standard rooftop height of the studied building doesn't support VRF duct type installation. Besides the open ducting line up will not look good and creating cover for these duct will pile up the cost further. The analysis also shows that the VRF system uses 17% and 73% less energy than the rooftop System in cooling and heating seasons, respectively. The implementation of this pilot result on National level will promote the use of sustainable energy technologies such as VRF system.

Keywords: Domestic AC, VRF, HVAC, Manufacturing Cost, Building Design.

1. Introduction

Designing and selecting air conditioning systems comprises several factors to be considered and these factors differ depending on the type of application. The basic aim in designing air conditioning systems is to provide thermal comfort with good indoor air quality and ensuring low energy consumption (Layeni et al., 2019).

In view of the high demand for electricity for cooling, it is important to increase the efficiency of building systems and technologies in order to reduce the overall demand for energy (Department of Energy, 2015). It is important to select the most appropriate air conditioning system because availability of energy especially the non-renewable energy sources have already started to decrease. (Wan et al., 2020). So choosing an efficient air conditioning system is very important. The aim of is this study is to do a comparative study among the domestic, VRF and HVAC duct system focusing the manufacturing design and power consumption cost.

2. Materials and Methods

For the purpose of conducting a comprehensive cost analysis based on traditional air condition, VRF and VRF duct type, an existing university building was selected. The name of the building is City University located at Khagan, Birulia, Savar, Dhaka, Bangladesh The building is 5 storied and the ground floor is considered for this pilot study. Total 39 room consist of class room, laboratory room and office room in the ground floor that comprise 20,334 square feet with 3.5m roof top height. Providing comfort conditions at CU building needs suitable air conditioning system, so Cooling and heating loads should be considered in all floors to set an accurate air conditioning system. All necessary data was collected and tabulated in all building floors. The details are listed in Table 1.

Table 1. Room Measurement for Pilot Study

Floor	Room Code	Used for	Measurement (Square fit)
Ground Floor	101	Photocopy	270
	102	Admission office	180
	103	Registrar's office	360
	104	Pro-VC'S office	360
	105	Additional Re. office	360
	106	VC's office	450
	107	Store	450
	108	Admin office	450
	109	Account's office	450
	110	Doctor's office	220
	111	Class room	600
	112	Class room	695
	113	Prayer room	1536
	114	Office	560
	115	Class room	655
	116	**Garment's Lab (Textile)**	614
	117	**Weaving Lab (Textile)**	614
	118	**Machine Lab**	200
	119	Class room	360
	120	Department	365
	121	Circuit Lab	400
	122	Physics Lab	400
	123	Chemistry Lab	575
	124	**Wet processing Lab**	535
	125	Civil Lab	535
	126	Circuit Lab	535
	127	Circuit Lab	535
	128	Circuit Lab	535
	129	Class room	535
	130	Class room	600
	131	Class room	600
	132	Class room	600
	133	Class room	600
	134	Class room	600
	135	Class room	600
	136	Class room	600
	137	Class room	600
	138	Class room	600
	139	Class room	600
			Total 20,334 Sq/feet

Total study was done by following points

- Collection of Floor measurement list from City University.
- Collection of required components from local market and online shop.
- VRF System Air-conditioning Piping 3D design created by Media selection software
- HVAC Duct System design created by AutoCAD software
- Collect all Accessories price from different website.

The overall methodology is illustrated in Figure First, the original accumulated use/operating hours were pre-processed into the use duration for different operating conditions of the VRF systems. Second, to obtain the real use status and evaluate the performance of the VRF system, three key performance indicators (KPIs) —use duration (representing operating time in a cycle), ideal coefficient of performance (ICOP, representing the theoretical

efficiency), and load ratio pattern (representing part load operating conditions) — were proposed. Statistical and clustering analyses were conducted to determine the distribution of three KPIs in different building types and climate zones. Finally, a recommendation on VRF system design was proposed based on the data analysis.

Experimental Data

The main building types in the dataset are residential buildings (more than 50%) and office buildings along with the operation data are showing in Table 2 & 3.

Table 2. The main building types in the dataset

Pipe length	Total pipe length(actual)		150m
	Maximum piping	Actual Length	100
		Equivalent length	110
	Piping equivalent length		40
Drop height	Outdoor unit-indoor	Outdoor unit up	50
	unit drop height	Outdoor unit down	40
	Indoor unit to indoor unit drop height		15m

Table 3. Main operation data of VRF systems of this research

Direct measured data (Store in local VRF)	**Calculated data (Log to cloud)**
Evaporation temperature (K)	Accumulated hours under different evaporation temperature range (hour)
Condensing temperature (K)	Accumulated hours under different condensing temperature range (hour)
Indoor units on-off state	Accumulated hours under different Load ratio range (hour)

LR is defined as the ratio of the name plate rated capacities of the running indoor units to the name plate capacities of all installed indoor units. LR is calculated by using following equation-

$$LR = \frac{\sum capcity\ of\ running\ indoor}{\sum capasity\ of\ all\ indoor\ units}$$

3. Results

3.1 Domestic Air Conditioning System

A domestic air conditioning system controls the temperature, humidity, air movement, and air quality of a home. Advancements in technology have made the daily life very comfortable. However, the manufacturing and power consumption rate of this system is not very cost effective.

Price list for domestic AC system, copper tube pipe, manufacturing cost and 8 hours'/day consumption of electricity cost are presented in this section.

Table 4. Price list of Domestic AC Counted for This Research

Room	**Measurement (Square fit)**	**AC Type**	**BTU 1 Ton = 12000 BTU**	**Cost per room USD($)**
101	195	Cassette	2 Ton	$ 1,027.87
102	188	Split	2 Ton	$ 754.94
103	368	Celling	4 Ton	$ 1,567.94
104	368	Celling	4 Ton	$ 1,567.94
105	368	Cassette	4 Ton	$ 1,800.23
106	488	Cassette	3.0 Ton	$ 2,555.17
		Split	2.5 Ton	
107	481	Cassette	3.0 Ton	$ 2,090.59
		Split	2.0 Ton	
108	464	Cassette	3.0 Ton	$ 2,090.59

		Split	2.0 Ton	
109	488	Cassette	3.0 Ton	$ 2,090.59
		Split	2.0 Ton	
110	220	Split	2.5 Ton	$ 1,219.51
111	621	Cassette	4.0 Ton	$ 3,135.89
		Cassette	3.0 Ton	
112	665	Cassette	4.0 Ton	$ 3,135.89
		Cassette	3.0 Ton	
113	1326	Cassette	4.0 Ton	$ 6,271.78
		Cassette	3.0 Ton	
		Cassette	4.0 Ton	
		Cassette	3.0 Ton	
114	590	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
115	633	Cassette	4.0 Ton	$ 1,858.30
		Split	2.5 Ton	
116	614	Cassette	4.0 Ton	$ 3,135.89
		Cassette	3.0 Ton	
117	628	Cassette	4.0 Ton	$ 3,019.74
		Split	2.5 Ton	
118	229	Split	2.5 Ton	$ 1,219.51
119	376	Celling	4.0 Ton	$ 1,567.94
120	300	Celling	3.0 Ton	$ 1,277.59
121	394	Celling	4.0 Ton	$ 1,567.94
122	430	Cassette	3.0 Ton	$ 2,032.52
		Split	1.5 Ton	
123	606	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
124	606	Cassette	4.0 Ton	$ 3,019.74
		Split	2.5 Ton	
125	606	Cassette	4.0 Ton	$ 3,019.74
		Split	2.5 Ton	
126	606	Cassette	4.0 Ton	$ 3,019.74
		Split	2.5 Ton	
127	606	Cassette	4.0 Ton	$ 3,019.74
		Split	2.5 Ton	
128	606	Cassette	4.0 Ton	$ 3,019.74
		Split	2.5 Ton	
129	567	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
130	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
131	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
132	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
133	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
134	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
135	600	Cassette	3.0 Ton	
		Celling	3.0 Ton	$ 2,613.24
136	600	Cassette	3.0 Ton	$ 2,613.24

		Celling	3.0 Ton	
137	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
138	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
139	600	Cassette	3.0 Ton	$ 2,613.24
		Celling	3.0 Ton	
				Total=$ 94,089.18

Table 5. Copper Tube Price

Serial	Pipe Length	Gas pipe	Liquid Pipe	USD($)
101	25 feet	1/4	1/2	$ 29.03
102	15 feet	1/4	1/2	$ 17.42
103	15 feet	3/8	3/4	$ 27.87
104	15 feet	3/8	3/4	$ 27.87
105	28 feet	3/8	3/4	$ 52.03
106	15 feet	3/8	3/4	$ 27.87
	28 feet	3/8	3/4	$ 52.03
107	15 feet	1/4	1/2	$ 17.42
	28 feet	3/8	3/4	$ 52.03
108	15 feet	1/4	1/2	$ 17.42
	28 feet	3/8	3/4	$ 52.03
109	15 feet	1/4	1/2	$ 17.42
	28 feet	3/8	3/4	$ 52.03
110	15 feet	3/8	5/8	$ 24.39
111	30 feet	3/8	3/4	$ 52.03
	30 feet	3/8	3/4	$ 52.03
112	28 feet	3/8	3/4	$ 52.03
	28 feet	3/8	3/4	$ 52.03
113	25 feet	3/8	3/4	$ 46.46
	35 feet	3/8	3/4	$ 56.04
	45 feet	3/8	3/4	$ 83.62
	35 feet	3/8	3/4	$ 56.04
114	15 feet	3/8	3/4	$ 27.87
	28 feet	3/8	3/4	$ 52.03
115	15 feet	3/8	5/8	$ 24.39
	27 feet	3/8	3/4	$ 50.17
116	38 feet	3/8	3/4	$ 70.61
	38 feet	3/8	3/4	$ 70.61
117	22 feet	3/8	5/8	$ 35.77
	28 feet	3/8	3/4	$ 52.03
118	15 feet	3/8	5/8	$ 24.39
119	15 feet	3/8	3/4	$ 27.87
120	15 feet	3/8	3/4	$ 27.87
121	15 feet	3/8	3/4	$ 27.87
122	15 feet	1/4	1/2	$ 17.42
	28 feet	3/8	3/4	$ 52.03
123	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
124	15 feet	3/8	5/8	$ 24.39
	35 feet	3/8	3/4	$ 65.04
125	15 feet	3/8	5/8	$ 24.39
	35 feet	3/8	3/4	$ 65.04

126	15 feet	3/8	5/8	$ 24.39
	35 feet	3/8	3/4	$ 65.04
127	15 feet	3/8	5/8	$ 24.39
	35 feet	3/8	3/4	$ 65.04
128	15 feet	3/8	5/8	$ 24.39
	35 feet	3/8	3/4	$ 65.04
129	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
130	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
131	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
132	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
133	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
134	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
135	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
136	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
137	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
138	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
139	15 feet	3/8	3/4	$ 27.87
	35 feet	3/8	3/4	$ 65.04
			Total = $3065.73	

Electric Cable Cost (DB Board + circuit Breaker + Outdoor + Indoor) = ($3254.68+$616.07+$695.47) = $4566.22
Pipe insulation cost = $871.82

Table 6. Manufacturing Cost

Technician	$162.60*12 = $1951.2
Assistant Technician	$92.91*12 = $1114.92
Refrigerant R-410A (3 Cylinder)	$113.82*3 = $341.46
Thermostat	$4.06*5 = $20.32
Capacitor	$3.71*10 = $37.16
cooling and Heating sensor	$2.32*15 = $34.84
Single Phase & Three Phase conductor	$3.60*10 = $36
	$11.38*8 = $91
Compressor single phase	$148.66*8 = $1189.31
Compressor Three phase	$296.16*10 = $2961.67
Total Maintenance Cost = $7777.88	

Domestic AC power consumption per day (8 Hours Running) is showed in Table 7.

Table 7. Domestic AC power consumption per day (8 hours Operation)

Ton of AC	KWH per day	Unit per day	EB cost per unit	Total cost per day
1.5*1 Ton	5.265kwh	$0.48	$0.048	$2.04
2*5 Ton	35.1 kwh	$3.26	$0.069	$93.43
2.5*10 Ton	87.75 kwh	$8.15	$0.132	$93.43
3*37 Ton	389.61 kwh	$36.20	$0.133	$414.85
4*17 Ton	238.68 kwh	$22.18	$0.133	$254.14
				= $784.06

30 Days Air-condition Power consumption = $23521.95
Domestic AC power consumption for 1 year = $282263.4

Total Cost Calculation for Domestic Air Condition System

Indoor & Outdoor cost = $95220.67

Piping cost = $3065.73

Electric Cable Cost (DB Board +circuit Breaker + Outdoor + Indoor) = ($3254.68+$616.07+$695.47) = $4566.22
Pipe insulation cost = $871.82
AC maintenance cost per year = $7777.88
Domestic AC power consumption for 1 year = $282263.4
Angle Cost= 1463.41
Installation cost = $2439.01
Total Domestic AC cost = $397668.1

3.2 VRF Air Condition System

Commonly known as mini split, VRF systems are unique in their ability to vary and control the refrigerant flow through multiple evaporator coils. This allows them to provide individual temperature control in various mechanical comfort zones. Each zone will have its own thermostat that adjusts independently of other zones in the system. The cost of VRF system is discussed in this section.

Table 8. Pipe Length Price

No	**Length**	**Gas Pipe**	**USD**	**Liquid Pipe**	**USD**
(1)	4.5m	Φ31.8	$48.00	Φ19.1	$28.28
(2)	5.7m	Φ31.8	$60.80	Φ19.1	$35.83
(3)	5.7m	Φ28.6	$60.80	Φ15.9	$29.31
(4)	5.7m	Φ28.6	$60.80	Φ12.7	$26.06
(5)	5.7m	Φ22.2	$46.69	Φ9.53	$21.71
(6)	3.0m	Φ15.9	$15.42	Φ9.53	$11.42
(7)	2.2m	Φ19.1	$13.82	Φ9.53	$8.38
(8)	3.0m	Φ15.9	$15.42	Φ9.53	$11.42
(9)	3.0m	Φ15.9	$15.42	Φ9.53	$ 11.42
(10)	3.0m	Φ15.9	$15.42	Φ9.53	$ 11.42
(11)	2.1m	Φ15.9	$10.80	Φ9.53	$ 8.00
(12)	5.3m	Φ15.9	$27.25	Φ9.53	$ 20.18
(13)	3.0m	Φ15.9	$15.42	Φ9.53	$11.42
(14)	6.8m	Φ15.9	$42.74	Φ9.53	$ 25.90
(15)	6.8m	Φ15.9	$42.74	Φ9.53	$ 25.90
(16)	2.2m	Φ15.9	$11.31	Φ9.53	$11.42
(17)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
			Total=$530.11		Total= $318.28

Samsung VRF DC Inverter Air-condition system per Ton =$603.95(Bangladeshi Market Base)

Total Cost of 1st part

Indoor, outdoor cost & Cable connection = $13,601.06

Piping Cost = $848.36

Total Cost = $14,449.42

Table 9. Pipe length price 2nd part

No	Length	Gas Pipe	USD	Liquid Pipe	USD
(1)	3.3m	Φ31.8	$35.20	Φ19.1	$20.74
(2)	5.3m	Φ28.6	$56.47	Φ12.7	$24.22
(3)	5.3m	Φ19.1	$33.31	Φ9.53	$20.18
(4)	5.7m	Φ28.6	$60.80	Φ12.7	$26.06
(5)	3.0m	Φ28.6	$31.99	Φ12.7	$13.71
(6)	5.7m	Φ19.1	$35.83	Φ9.53	$21.71
(7)	1.5m	Φ19.1	$9.43	Φ9.53	$5.71
(8)	1.0m	Φ15.9	$5.14	Φ9.53	$3.80
(9)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(10)	4.5m	Φ15.9	$23.14	Φ9.53	$17.14
(11)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(12)	4.5m	Φ15.9	$23.14	Φ9.53	$17.14
(13)	4.5m	Φ22.2	$36.85	Φ9.53	$17.14
(14)	5.0m	Φ15.9	$25.71	Φ9.53	$19.05
(15)	7.6m	Φ15.9	$39.08	Φ9.53	$28.94
(16)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(17)	5.3m	Φ15.9	$27.25	Φ9.53	$20.18
			Total=$ 470.07		Total= $275.52

Total cost of 2nd part

Indoor, outdoor cost & Cable connection = $13,676.50

Piping Cost = $745.59

Total Cost = $14,422.09

Table 10. Pipe length price of 3rd Part

No	Length	Gas Pipe	USD($)	Liquid Pipe	Taka
(1)	7.6m	Φ31.8	$81.06	Φ19.1	$47.77
(2)	5.7m	Φ28.6	$60.8	Φ15.9	$29.31
(3)	5.7m	Φ28.6	$60.8	Φ12.7	$26.06
(4)	5.7m	Φ19.1	$60.8	Φ9.53	$21.71
(5)	2.2m	Φ19.1	$13.83	Φ9.53	$8.38
(6)	2.2m	Φ19.1	$13.83	Φ9.53	$8.38
(7)	2.2m	Φ19.1	$13.83	Φ9.53	$8.38
(8)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(9)	4.5m	Φ15.9	$23.14	Φ9.53	$17.14
(10)	1.5m	Φ15.9	$7.71	Φ9.53	$5.17
(11)	4.5m	Φ15.9	$23.14	Φ9.53	$17.14
(12)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(13)	4.5m	Φ15.9	$23.14	Φ9.53	$17.14
(14)	1.5m	Φ15.9	$7.71	Φ9.53	$5.17

(15)	4.5m	Φ15.9	$23.14	Φ9.53	$1714
			Total =$428.35		Total= $241.39

Total cost of 3rd part

Indoor, outdoor cost & Cable connection = $11,831.88

Piping Cost = $669.74

Total Cost = $12,501.62

Table 11. Piping Length price of 4th part

No	Length	Gas Pipe	USD	Liquid Pipe	USD
(1)	7.6m	Φ31.8	$81.07	Φ19.1	$47.77
(2)	5.7m	Φ28.6	$60.80	Φ15.9	$29.31
(3)	5.7m	Φ28.6	$60.80	Φ12.7	$26.06
(4)	2.2m	Φ19.1	$13.83	Φ9.53	$8.38
(5)	2.2m	Φ19.1	$13.83	Φ9.53	$8.38
(6)	5.7m	Φ19.1	$70.67	Φ9.53	$21.71
(7)	2.2m	Φ19.1	$13.83	Φ9.53	$8.38
(8)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(9)	4.5m	Φ15.9	$23.15	Φ9.53	$17.14
(10)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(11)	4.5m	Φ15.9	$23.15	Φ9.53	$17.14
(12)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(13)	4.5m	Φ15.9	$23.15	Φ9.53	$17.14
(14)	1.5m	Φ15.9	$771	Φ9.53	$5.71
(15)	4.5m	Φ15.9	$23.15	Φ9.53	$1714
			Total=$438.27		Total =$241.42

Total cost of 4th part

Indoor, outdoor cost & Cable connection =$11,822

Piping Cost =$679.69

Total Cost =$12,501.69

Table 12. Pipe Length size of 5th part

No	Length	Gas Pipe	USD	Liquid Pipe	USD
(1)	3.0m	Φ31.8	$35.20	Φ19.1	$18.86
(2)	3.0m	Φ28.6	$31.90	Φ12.7	$13.71
(3)	3.0m	Φ19.1	$18.86	Φ9.53	$11.43
(4)	3.0m	Φ19.1	$18.86	Φ9.53	$11.43
(5)	3.0m	Φ28.6	$30.84	Φ12.7	$13.71
(6)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(7)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
(8)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(9)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
(10)	3.0m	Φ19.1	$11.31	Φ9.53	$8.38
(11)	3.0m	Φ19.1	$27.26	Φ9.53	$20.18

(12)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(13)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
(14)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(15)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
			Total=$309.65		Total=$211.94

Total cost of 5th part

Indoor, outdoor cost & Cable connection = $13,888.23

Piping Cost = $521.59

Total Cost = $14,409.82

Table 13. Pipe Length size of 6th part

No	Length	Gas Pipe	USD	Liquid Pipe	USD
(1)	3.0m	Φ31.8	$31.10	Φ19.1	$18.86
(2)	3.0m	Φ19.1	$18.86	Φ9.53	$11.43
(3)	5.7m	Φ28.6	$60.80	Φ15.9	$29.31
(4)	3.0m	Φ22.2	$24.58	Φ9.53	$11.43
(5)	1.5m	Φ15.9	$7.71	Φ9.53	$5.71
(6)	5.1m	Φ15.9	$26.22	Φ9.53	$19.43
(7)	3.0m	Φ19.1	$18.86	Φ9.53	$11.43
(8)	3.9m	Φ15.9	$ 20.06	Φ9.53	$14.85
(9)	3.9m	Φ15.9	$ 20.06	Φ9.53	$14.85
(10)	3.9m	Φ15.9	$ 20.06	Φ9.53	$14.85
(11)	3.9m	Φ15.9	$ 20.06	Φ9.53	$14.85
			Total= $268.37		Total= $167

Total cost of 6th part

Indoor, outdoor cost & Cable connection = $10,132.81
Piping Cost = $435.37
Total Cost = $10,568.18

Table 14. Pipe Length Price 7th part

No	Length	Gas Pipe	USD($)	Liquid Pipe	USD($)
(1)	5.3m	Φ31.8	$56.54	Φ19.1	$33.31
(2)	3.0m	Φ19.1	$20.02	Φ9.53	$11.42
(3)	5.7m	Φ28.6	$60.81	Φ15.9	$29.31
(4)	3.0m	Φ22.2	$24.57	Φ9.53	$11.42
(5)	3.0m	Φ22.2	$24.57	Φ9.53	$11.42
(6)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(7)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(8)	3.0m	Φ15.9	$15.42	Φ9.53	$11.42
(9)	3.0m	Φ15.9	$15.42	Φ9.53	$11.42
(10)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(11)	3.0m	Φ15.9	$15.42	Φ9.53	$11.42
			Total= $266.7		Total= $156.28

Total cost of 7th part

Indoor, outdoor cost & Cable connection = $11,133.81
Piping Cost = $422.98
Total Cost = $11,556.79

Table 15. Piping Length Price of 8th part

No	Length	Gas Pipe	USD	Liquid Pipe	USD
(1)	3.0m	Φ31.8	$23.10	Φ19.1	$18.86
(2)	5.7m	Φ28.6	$60.80	Φ12.7	$26.06
(3)	3.0m	Φ28.6	$31.99	Φ12.7	$13.72
(4)	5.7m	Φ19.1	$35.83	Φ9.53	$21.71
(5)	3.0m	Φ19.1	$18.86	Φ9.53	$11.42
(6)	1.9m	Φ19.1	$11.94	Φ9.53	$7.23
(7)	3.0m	Φ15.9	$15.42	Φ9.53	$11.42
(8)	5.7m	Φ15.9	$29.31	Φ9.53	$21.71
(9)	5.7m	Φ15.9	$29.31	Φ9.53	$21.71
(10)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(11)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
(12)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(13)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
(14)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(15)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
			Total= $372.27		Total= $239.52

Total cost of 8th part

Indoor, outdoor cost & Cable connection = $11,880.97
Piping Cost = $611.79
Total Cost = $12,492.76

Table 16. Pipe length Price of 9th part

No	Length	Gas Pipe	USD	Liquid Pipe	USD
(1)	3.0m	Φ31.8	$31.99	Φ19.1	$18.86
(2)	3.0m	Φ28.6	$31.99	Φ12.7	$13.71
(3)	3.0m	Φ15.9	$15.42	Φ9.53	$11.43
(4)	1.9m	Φ19.1	$11.94	Φ9.53	$7.23
(5)	5.7m	Φ28.6	$60.80	Φ12.7	$26.06
(6)	3.0m	Φ19.1	$18.86	Φ9.53	$11.43
(7)	5.7m	Φ19.1	$35.83	Φ9.53	$21.71
(8)	5.7m	Φ15.9	$29.31	Φ9.53	$21.71
(9)	5.7m	Φ15.9	$29.31	Φ9.53	$21.71
(10)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(11)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
(12)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(13)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
(14)	2.2m	Φ15.9	$11.31	Φ9.53	$8.38
(15)	5.3m	Φ15.9	$27.26	Φ9.53	$20.18
			Total=$381.16		Total=$ 239.53

Total cost of 8th part

Indoor, outdoor cost & Cable connection = $11,880.94
Piping Cost = $220.69
Total Cost = $12,101.63

Total Outdoor & Indoor Manufacturing Cost:
($14,449.42+$14,422.09+$12,501.62+$12,501.69+$14,409.82+$10,568.18+$11,556.79+$ 12,492.76+$12,101.63) = $115004

So, City University's Ground Floor VRF system Air-condition Indoor & Outdoor setup cost is $ 115004.

Table 17. Maintenance Cost for 1 Year

Technician	$ 162.60*12 = $1951.2
Refrigerant R-410A (1 Cylinder)	=$113.82
Thermostat	$8.83*3 = $ 26.49
Capacitor	$5.23*5 = $26.15
cooling and Heating sensor	$2.90*10 = $29
3 Phase conductor	$ 13.94*3 = $41.82
Total Maintenance Cost	= $ 2188.48

Table 18. VRF power consumption per day (8 hours Operation)

Outdoor/ Indoor	Ton of AC	KWH per day	Unit per day	EB cost per unit/USD($)	Total cost per day/ USD($)
1	23.88	670.55 KWH	670.55	$ 0.13	$ 89.25
2	23.88	670.55 KWH	670.55	$ 0.13	$ 89.25
3	20.70	581.26 KWH	581.26	$ 0.11	$ 67.10
4	20.70	581.26 KWH	581.26	$ 0.11	$ 67.10
5	23.88	670.55 KWH	670.55	$ 0.13	$ 89.25
6	17.50	491.4 KWH	491.4	$ 0.11	$ 56.73
7	19.11	536.61 KWH	536.61	$ 0.11	$ 61.95
8	20.70	581.26 KWH	581.26	$ 0.11	$ 67.10
9	20.70	581.26 KWH	581.26	$ 0.11	$ 67.10
				Total = $654.83	

So, VRF AC power consumption for 1 month = $19,644.9
VRF AC power consumption for 1 year = $235738.8

Total Cost Calculation for VRF Air Condition System

Total Indoor & Outdoor setup $115,004+ Maintenance cost for 1 year = $2188.48+ VRF AC power consumption for 1 Years = $235738.8 = $352931.28

3.3 HVAC Duct System

Most air conditioning and heating systems require some form of duct work to channel or direct the air to places where the conditioned air is needed.

HVAC Duct Type AC Measurement List

Table 19. HVAC Duct Type AC measurement List

Room No	Size	**Length**	**S/FT**
101-102	Supply Duct 18*12 Supply duct to reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply duct end cover 20*12 Return Duck 18*12 Return Duct end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16	25 Feet 1.1 feet 2 piece 9 inch 2 piece 50 Feet 2 piece 4 feet 3 piece	82 S/FT 8 S/FT 4 S/FT 4 S/FT 250 S/FT 4 S/FT 16 S/FT 9 S/FT
103-104-105	Supply duct 18*12 Supply duct to reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply Duct end cover 20*12 Return Duct 18*12 Return Duct neck 38*10-4 Return end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16	55 feet 3.7 feet 9 Inch 6 piece 1 piece 90 Feet 1.1 feet 1 piece 3 piece 4 feet	275 S/FT 23 S/FT 42 S/FT 2 S/FT 450 S/FT 36 S/FT 2 S/FT 9 S/FT 24 S/FT
106-107	Supply Duct 18*12 Supply duct reducer 38*8+18*12 Supply duct to diffuser neck 38*12 Supply duct end cover 20*12 Return duct 18*12 Return duct Neck 38*40 Return duct end cover 20*14 Return Box 24*14 Return box end cover 24*16	42 Feet 3.7 feet 9 Inch 6 piece 1 piece 84 feet 1.1feet 8 piece 2 piece 4 feet 3 piece	210 S/FT 23 S/FT 42 S/FT 43 S/FT 420 S/FT 72 S/FT 4 S/FT 24 S/FT 9 S/FT
108-109	Supply Duct 18*12 Supply duct reducer 38*8+18*12 Supply duct to diffuser neck 38*12 Supply duct end cover 20*12 Return duct 18*12 Return duct Neck 38*40 Return duct end cover	42 Feet 3.7 feet 9 Inch 6 piece 1 piece 84 feet 1.1feet 8 piece 2 piece 4 feet 3 piece	210 S/FT 23 S/FT 42 S/FT 2 S/FT 420 S/FT 72 S/FT 4 S/FT 24 S/FT 9 S/FT

	20*14 Return Box 24*14 Return box end cover 24*16		
110-111 112	Supply Duct 18*12 Supply duct reducer 38*8+18*12 Supply duct to diffuser neck 38*12 Supply duct end cover 20*14 Return duct 18*12 Return duct Neck 38*10 Return duct end cover 20*14 Return Box 24*14 Return box end cover 24*16	25 feet 3.7 feet 9 Inch 6 piece 2 piece 50 feet 1.1feet 9 piece 2 piece 4 feet 6 piece	82 S/FT 33 S/FT 36 S/FT 4 S/FT 250 S/FT 84 S/FT 4 S/FT 32 S/FT 18 S/FT
113	Supply Duct 18*12 Sappy duct reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply duct end cover 20*12 Return Duct 18*12 Return Duck Neck 38*10 Return Duct end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16	33 Feet 3.7 feet 9 inch 4 piece 4 piece 37 feet 1.1 feet 3 piece 1 piece 4 feet 3 piece	165 S/FT 23 S/FT 28 S/FT 8 S/FT 185 S/FT 27 S/FT 2 S/FT 24 S/FT 9 S/FT
114-115 116-117	Supply Duct 18*12 Sappy duct reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply duct end cover 20*12 Return Duct 18*12 Return Duck Neck 38*10 Return Duct end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16	80 feet 7.4 feet 9 inch 12 piece 2 piece 220 feet 1.1 feet 16 piece 2 piece 8 feet 6 piece	400 S/FT 46 S/FT 84 S/FT 4 S/FT 1100 S/FT 144 S/FT 4 S/FT 48 S/FT 18 S/FT
118-119 120-121	Supply Duct 18*12 Supply duct reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply duct end cover 20*14 Return Duct 18*12 Return Duck Neck 38*10	70 feet 7.4 feet 9 Inch 9 piece 2 piece 140 feet 11 feet 2 piece 8 feet 6 piece	350 S/FT 46 S/FT 63 S/FT 4 S/FT 700 S/FT 99 S/FT 4 S/FT 48

	Return Duct end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16		18 S/FT
122-123 124-125 126-127 128-129	Supply Duct 18*12 Supply duct reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply duct end cover 20*12 Return Duct 18*12 Return Duck Neck 38*10 Return Duct end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16	290 feet 14.8 feet 9 inch 32 piece 4 piece 320 feet 4.4 feet 16 piece 4 piece 16 feet 12 piece	1450 S/FT 92 S/FT 224 S/FT 8 S/FT 1600 S/FT 144 S/FT 8 S/FT 96 S/FT 36 S/FT
130-131 132-133 134-135 136-137 138-139	Supply Duct 18*12 Sappy duct reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply duct end cover 20*14 Return Duct 18*12 Return Duck Neck 38*10 Return Duct end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16	350 feet 18.5 feet 9 inch 38 piece 5 piece 430 feet 5.5 feet 24 piece 5 piece 20 feet 15 feet	1750 S/FT 115 S/FT 266 S/FT 10 S/FT 2150 S/FT 216 S/FT 10 S/FT 120 S/FT 45 S/FT
130-131 132-133 134-135 136-137 138-139	Supply Duct 18*12 Sappy duct reducer 38*8+18*12 Supply duct to diffuser Neck 38*12 Supply duct end cover 20*14 Return Duct 18*12 Return Duck Neck 38*10 Return Duct end cover 20*14 Chamber box 24*14 Chamber box end cover 24*16	350 feet 18.5 feet 9 inch 38 piece 5 piece 430 feet 5.5 feet 24 piece 5 piece 20 feet 15 feet	1750 S/FT 115 S/FT 266 S/FT 10 S/FT 2150 S/FT 216 S/FT 10 S/FT 120 S/FT 45 S/FT

Table 20. Duct Indoor & Outdoor Manufacturing cost

Room No	**Ton**	**Price (USD)**
101-102	4 Ton(12.63)kw	1974.75
103-104, 105	11 Ton(34.72)kw	4622.53
106-107	10 Ton(31.569)kw	4343.79

108-109	10 Ton(31.569)kw	4343.79
110-111	8.5 Ton(26.83)kw	2752.61
112	7 Ton(22.10)kw	2369.34
113	7 Ton (2)(22.10)kw(22.10)kw	4738.68
114-115	12.5 Ton(39.46)kw	5145.18
116-117	12.5 Ton(39.46)kw	5145.18
118-119	7 Ton(22.10)kw	2369.34
120-121	7 Ton(22.10)kw	2369.34
122-123 124-125	11 Ton (2)(34.72)kw(34.72)kw	9245.06
126-127 128-129	11 Ton (2)(34.72)kw(34.72)kw	9245.06
130-139	12 Ton(37.88)kw	4982.57
131-132 133-134	12 Ton (2)(37.88)kw(37.88)kw	9965.14
135-136 137-138	12 Ton (2)(37.88)kw(37.88)kw	9965.14
	207 Ton(653.48)kw	**Total = $**83577.5

Table 21. Duct accessories price list

Size	Square feet	Price (USD)
Supply Duct & Return duct 18*12	10749*$0.98	10534.02
Supply duct Reducer 38*8+18*12	432*$.98	423.36
Supply duct to diffuser Neck 38*12	840 (121 piece)*$3.5	423.5
Supply duct end cover 20*12	30 *$1	46
Supply duct end cover 20*14	16 *$1	
Return duct Neck 38*10	894 (111 piece)*$1.50	333
Return duct Neck 38*40	144 (111 piece)*$1.50	
Return duct end cover 20*14	46 (23 piece)*$1	23
Chamber box/Return box 24*14	441 (75 piece)*$36.14	2710.5
Chamber box end cover	195 (61 piece)*$4	288
Return box end cover	36 (11 piece)*$4	
Piping insulation cost	634.18* 0.23	$147.31
	Total=$14928.69	

Table 22. Pipe Length price for HVAC Duct

No	Length	Gas Pipe	USD	Liquid Pipe	USD
Outdoor 1	6.7m	15.9mm	34.46	9.53m	25.52
Outdoor 2	6.0m	22.2mm	49.14	9.53mm	22.85
Outdoor 3	6.4m	22.2mm	52.41	9.53mm	24.37
Outdoor 4	5.7m	22.2mm	46.69	9.53mm	21.71
Outdoor 5	8.5m	19.1mm	53.42	9.53mm	32.38

Outdoor 6	4.8m	19.1mm	30.17	9.53mm	18.28
Outdoor 7	5.4m	19.1mm	33.93	9.53mm	20.56
Outdoor 8	5.7m	19.1mm	35.83	9.53mm	21.71
Outdoor 9	6.2m	28.6mm	66.14	12.7mm	8.6
Outdoor 10	6.2m	28.6mm	66.14	12.7mm	8.6
Outdoor 11	6.7m	19.1mm	42.12	9.53mm	25.52
Outdoor 12	7.0m	19.1mm	44	9.53mm	26.66
Outdoor 13	7.3m	22.2mm	59.80	9.53mm	27.81
Outdoor 14	7.3m	22.2mm	59.80	9.53mm	27.81
Outdoor 15	7.0m	22.2mm	57.33	9.53mm	26.66
Outdoor 16	7.0m	22.2mm	57.33	9.53mm	26.66
Outdoor 17	5.4m	28.6mm	57.53	12.7mm	24.68
Outdoor 18	5.7m	28.6mm	60.81	12.7mm	26.06
Outdoor 19	6.0m	28.6mm	64	12.7mm	27.42
Outdoor 20	5.6m	28.6mm	59.73	12.7mm	25.60
Outdoor 21	6.4m	28.6mm	68.26	12.7mm	29.25
			Total= $1099.04		Total= $498.71

Table 23. Power consumption for Duct AC

Outdoor/ Indoor	Ton of AC	KWH per day	Unit per day	EB cost per unit/USD($)	Total cost per day/ USD($)
1	4	101.04 KWH	101.04	$0.067	6.77
2	11	277.76 KWH	277.76	$0.069	19.17
3	10	252.55 KWH	252.55	$ 0.069	17.43
4	10	252.55 KWH	252.55	$0.069	17.43
5	8.5	214.64 KWH	214.64	$ 0.069	14.38
6	7	176.8 KWH	176.8	$ 0.067	11.84
7	7	176.8 KWH	176.8	$0.067	11.84
8	7	176.8 KWH	176.8	$0.067	11.84
9	12.5	315.68 KWH	581.26	$ 0.115	66.84
10	12.5	315.68 KWH	581.26	$ 0.115	66.84
11	7	176.8 KWH	176.8	$ 0.067	11.84
12	7	176.8 KWH	176.8	$ 0.067	11.84
13	11	277.76 KWH	277.76	$0.069	19.17
14	11	277.76 KWH	277.76	$0.069	19.17
15	11	277.76 KWH	277.76	$0.069	19.17
16	11	277.76 KWH	277.76	$0.069	19.17
17	12	303.04 KWH	303.04	$0.074	22.42
18	12	303.04 KWH	303.04	$0.074	22.42
19	12	303.04 KWH	303.04	$0.074	22.42
20	12	303.04 KWH	303.04	$0.074	22.42
21	12	303.04 KWH	303.04	$0.074	22.42
	Total = 207				Total = $456.84

Power consumption for Duct AC for 30 days = $13705.2
Power consumption for Duct AC for 1 year = $164462.4

Table 24. HVAC maintenance cost

Technician + Assistant	$162.60+104.53*12 = $3205.56
Refrigerant R-410A (1 Cylinder)	=$113.82
Thermostat	$8.83*3 = $ 26.49

Capacitor	$5.23*5 = $26.15
cooling and Heating sensor	$2.90*10 = $29
3 Phase conductor	$ 13.94*3 = $41.82
Total Maintenance Cost = $3442.84	

Total cost for HVAC Duct System

Duct Indoor & Outdoor Manufacturing cost ($83577.5) + Duct accessories price ($14928.69) + Total piping cost ($1597.75) + Maintenance Cost ($3442.84) + Power consumption for Duct AC for 1 year ($164462.4) = $268009.2

4. Discussion

After analyzing and calculation we got $397668.1 for domestic Air-condition, $352931.28 VRF system Air-condition and $268009.2 for HVAC Duct Type Air-condition. In this thesis report we worked about Domestic Air-condition total vs VRF system Air-condition and we also added HVAC Duct Type Air-condition. We calculate total cost all of about it. But we notice HVAC Duct Air-condition system installation cost is lower than Domestic and VRF system. But we design City University academic building in this case it is not appropriate for this building design. Because for installation HVAC Duct Air-condition system minimum celling height required 12-13 feet. In our academic building celling height 10 feet. So we can't install it. On the other hand, we install here VRF system Air-condition. Because its installation design according celling height it's much more perfect and its structurer looking good.

5. Conclusion

A comparative cost analysis has done between conventional air conditioning system, VRF air-conditioning system and VRF duct type air conditioning system. When evaluating the conventional system, the total cost especially in the consumption cost was found to be higher than other two systems. Though VRF duct system seems less costly than VRF system, this system also shows some economical limitations. For examples the piping cost and the duct installation cost create additional burden to total operational cost. Besides these, since this study was done on the basis of ceiling height of city university which is standard height for residential

Building, the VRF duct system does not seem to be fit for this height. Only the VRF system has been found to be fit for this height along with considerable energy consumption cost. VRF technology provides energy savings because the system consists of (1) a variable speed air cooling compressor, (2) reduced fan energy due to reduced duct work and (3) dedicated outside air systems with energy recovery. Such effective technologies like VRF should be investigated further to identify potential barriers to the market. As such, the next step forward is to investigate the usage of VRF in residential buildings and to develop strategies for implementing cost effective VRF systems.

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