Energy and Life Cycle - Comparative Analysis of HVAC Systems for a Commercial Building

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Abstract: *An air conditioning system mainly designed to satisfy to provide comfort for the occupants in a specific area or whole building. Efficient design of heating, ventilating and air-conditioning (HVAC) systems is a principal concern in building projects as it affect main investment as well as running cost. For the characteristic commercial building projects, it is not difficult to acquire the reference settings for efficient operation. But for some special projects, due to the specific design and control of the HVAC system, conventional settings may not be necessarily energy-efficient in daily operation. The study focusing on the comparative analysis of VRF v/s chiller systems for a commercial building. For the analysis energy and life cycle has taken primary considerations. The HVAC system design based on both VRF and Chiller and equipment selection for a commercial building (360 TR) is included as a case study in this paper. The outcomes of this paper are efficient design of HVAC system with minimum energy consumption and equipment selection based on energy and life cycle cost analysis.*

***Keywords*:HVAC system, VRF system, Chiller system, Life cycle cost analysis**

1. Introduction

A heating, ventilating, and air conditioning (HVAC) system is designed to provide thermal comfort and acceptable indoor air quality in building. HVAC systems can be classified into central and local systems according to multiple zones, location, and distribution. Designers have to understand well the geographic characteristics, building design and the outdoor climate for the effective design of HVAC system. They must also understand the process or the comfort requirements.

The detailed study regarding the construction of building, space orientation, materials, occupancy, activity level, humidity, outside temperature, ventilation requirements will help designer in effective design of HVAC system.

The effective design of HVAC system is very important as it critically affect the operational cost of a building. For every effective design of HVAC system at first designers have to calculate heat load for the particular space either manually or using AP software. After the design based on the heat load of the building designer have to select the available possible options for HVAC systems such as split air conditioning units, air cooled chillers, water cooled chillers or variable refrigerant flow systems(VRF).

In this study HVAC system is designed for a commercial building 360 TR is taken in consideration. As the name indicate split air conditioning systems consist of and indoor and outdoor unit. For each area based on the cooling load separate system must be installed. The outdoor unit is installed on or near the exterior wall of the room that you wish to cool. This unit houses the compressor, condenser coil and the expansion coil or capillary tubing.

A chiller is a machine that removes heat from a liquid via a vapour compression or absorption refrigeration cycle.[1] This liquid can then be circulated through a heat exchanger to cool equipment, or another process stream (such as air or process water). As a necessary by-product, refrigeration creates waste heat that must be exhausted to ambience, or for greater efficiency, recovered for heating purposes.

Variable Refrigerant Flow (VRF), also known as Variable Refrigerant Volume (VRV), is an HVAC technology invented by Daikin Industries, Ltd. in 1982. VRFs use refrigerant as the cooling and heating medium [3]. This refrigerant is conditioned by a single outdoor condensing unit, and is circulated within the building to multiple indoor units. Even though VRF systems are comparatively newer and costlier than chiller systems, it has many benefits over it. Some benefits are the small space requirement, less noise production, individual room setting control, less energy requirement, longer life span etc. But depending on the budget of the customer and the space to be conditioned, the system to be employed can vary.

After heat load calculation designer have to focus on designing out based on their cost requirements, efficiency, energy requirements and life cycle. Depending on this, an economical and efficient system is suggested to the customer.

2. Literature Review

Buildings account for around 40% and 24% of the total energy consumption in the United States and the world, respectively [6] In United States, chillers represented about 35% of the total commercial building HVAC cooling equipment energy use [7]). Therefore, improving the operational efficiency of the chiller plants can be essential to reducing the building energy consumption.

The main objective of any air conditioning (AC) systems is toachieve the optimum thermal human comfort for building occupants with acceptable indoor air quality, more energy efficientand cost reduction [1]. To achieve human thermal comfort, thereare many patterns of air conditioning systems as window unit, splitunit, packaged unit, central air conditioner dual duct system andvariable refrigerant flow system [2]. The main advantages of VRFsystem compared to conventional air conditionings are its highrespond to fluctuations in space load conditions [3]. Moreover, pro-vide the heating and cooling flexibility for multiple zones thatrequire individual thermal comfort controls. On the other sidethe main disadvantages of VRF system is its high initial cost andthe ventilation issue which they cannot provide any fresh air tothe indoors during the conditioning processes [4]. To overcomethis drawback, an additional ventilation system is required; some-time it is called heat recovery ventilation (HRV) system to providefresh air from the exhaust air stream in order to reduce the ventilation loads [5].

A variable refrigerant flow system has the ability to cool andheat different zones in a domestic building at the same time. Theskeleton of VRF systems are identical to the multi-split systemswhich include multiple indoor fan coil units connected to a single outdoor unit.

3. Project Methodology

In order to execute this project, a thorough study of the refrigeration cycles, refrigerants (mainly R32), various air conditioners and their applications was carried out. Since cooling load calculation plays a major role in this project, a thorough study of manual cooling load calculation was also carried out.

Under the guidance of Daikin industries limited, through the HVAC course they provided, further data was collected. Additional information was further obtained through journals and other literary articles. Through the training provided on the software HAP, by the HVAC course, we were also able to study the cooling load calculation through software and to design an effective air conditioning system for a given space. Since HAP software is used alongside AutoCAD software, our knowledge on AutoCAD had to be revised. Duct Sizer software was also studied, as it helped in the sizing of ducts used.

A floor plan of a commercial building, to be air conditioned, was given in AutoCAD. Using HAP, cooling load and air flow required for each zone/room in every floor was designed. Once this was obtained, the VRF and chiller machine corresponding to the cooling load and air flow was selected for each zone/room in each floor. These machines were placed at optimum positions and then ducts were designed for air distribution in each zone/room with help of Duct Sizer software. Once the ducts were designed, the outdoor units corresponding to the indoor units was selected and placed at optimum positions (In case of chiller machine, the cooling towers were also selected appropriately). Then the necessary pipe connections between the outdoor and indoor units were designed.

Once the design part of VRV and chiller machine was carried out on the commercial building, the cost of installation was carried out (separate for VRV and chiller). Installation cost consisted of calculating the cost of the indoor and outdoor machines, sheet metal costs, various piping costs, refrigerant cost, testing cost, labour cost etc. Also costs of running both machines for 20 years were calculated.

4. Heat Load Calculation.

The values of tonnage and airflow (in CFM) for each room/zone of the floors to be conditioned were designed with the help of HAP software. These values are shown below.[the HAP reports have been included after reference

- **Basement**

NAME	AREA(ft^2)	CFM	TONNAGE
BASEMENT			
ZONE 1	1353.44	1927	5.2
ZONE 2	559.292	2116	3.8

- **Ground Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
GROUND FLOOR			
MAIN ENTRY	2714.36	4578	22.5
ZONE 1	3334.83	3176	8.5
ZONE 2	2000.1	4433	9.2
ZONE 3	4289.16	5572	17.9

- **Third Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
THIRD FLOOR			
VC 1	1117.14	2074	6.7
VC 2	167.91	417	1.1
VC 3	249.46	654	1.4
VC 4	158.75	716	1.4
VC 5	422.6	2028	3.7
CCTV CMS	2209.91	8538	19.8
JGM 1	200.46	1167	2.1
ZONE 1	40009.79	5166	14.5

- **Fourth Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
FOURTH FLOOR			
GYM	627.71	1272	5.6
RECREATION SPACE	776.69	888	4.7

- **Sixth Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
SIXTH FLOOR			
DGM 1	147.88	195	0.6
DGM 2	158.99	555	1.1
DGM 3	150.77	1072	1.9
DGM 4	133.46	976	1.7
DGM 5	134.2	592	1.1
CR 1	212.78	476	1.6
VC 1	98.77	380	0.9
GM 1	188.15	832	1.6
CH 1	208.62	1197	2.2
ZONE 1	3902.22	7164	20.3
ZONE 2	3878.12	5628	17.8

- **Seventh Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
SEVENTH FLOOR			
DGM 1	133.35	547	1.1
DGM 2	133.35	547	1.1
DGM 3	133.35	547	1.1
DGM 4	160.98	1060	1.9
VC 1	221.33	1284	2.1
VC 1	221.33	1284	2.1
GM 1	215.92	1172	2.1
CR 1	205.57	1272	2.4
ZONE 1	3718.9	5182	14.4

- **Eighth Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
EIGHTH FLOOR			
DGM 1	150.69	1066	1.9
DGM 2	133.99	192	0.5
DR 1	404.58	1796	3.7
VC 1	144.58	469	1.3
ZONE 1	3927.13	7131	20.3
ZONE 2	3354.64	4820	13.8

- **Ninth Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
NINTH FLOOR			
DGM 1	189.03	1112	2
MR 1	566.55	2421	5.9
CR 1	436.46	1491	5.1
GM 1	180.8	1103	2
VC 1	217.99	1284	2.4
ZONE 1	3399.69	4729	13.7
ZONE 2	4107.5	5877	15.7

- **Tenth Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
TENTH FLOOR			
CR 1	556.11	1602	5.9
DGM 1	151	1098	2
ZONE 1	3977.42	7282	17.9
ZONE 2	4097	6534	16.7

- **Eleventh Floor**

NAME	AREA(ft^2)	CFM	TONNAGE
ELEVENTH FLOOR			
ZONE 1	2192.61	6779	14.8
ZONE 2	1632.36	2971	10.7
ZONE 3	762.27	3565	7.8
ZONE 4	1640.54	2636	5.9
LADIES ROOM	91.7	367	0.8
GENTS ROOM	94.5	329	0.7
KITCHEN WEEKLY STORAGE	495.8	785	1.6

5. Energy and Life Cycle Calculations

Notes and assumptions for comparison of alternatives

- Electrical unit rate @ RS. 6 per KWHR
- Chiller operating power consumption is calculated based on the input McQuay

- Power consumption is assumed with 90% compressor loading

Calculation for water cooled screw chiller

- Total TR: 376 TR
- Non diversified cooling load: 376 TR
- Assume 80% diversity due to commercial building, therefore

Diversified TR = 376 X 0.8 = 301 TR

System connected load chiller = 301 X 0.75 = 226 KW (0.75 KW/TR: Power consumption in KW)

System connected load chiller (Plant room equipment excluding chiller) = 48 KW

System connected low side AHU = 376 X 0.2= 75 KW

Total connected load = 226 + 48 + 75 = 349 KW

Operating load = 349 X 0.9 = 326 KWH

Power consumption (Per hour) = 326 KWH

Power consumption (Full load 12 hrs) = 326 X 12 = 3915 KWH/Day

Power consumption (Per year @ 75% usage time) = 365 X 3915 X 0.75 = 1071698 KWH / yr

Power consumption Rs. /year (@ 6 RS. /unit) = (6 X 1071698) / 100000 = 63 Rs. L /yr

Operating and maintenance cost RS. / Year = (12750 X 64) / 100000 = 8.5 Rs. L /yr

Make-up water cost Rs./yrs (@ 5 Paisa/ltr) = (301 X 12 X 10 X 365 X 0.75 X 0.05) / 100000 = 4.9 Rs. L /yr

Total operating cost Rs. / yr = 64 + 8.5 + 4.9 =77.7 Rs. L /yr

Capital cost of HVAC system installation = 376 X 0.67 = 252 Rs. L

Table 1. Comparison of Alternatives

	Unit	Option I	Option II	Option III	Option IV
System Brief		Water Cooled Screw Chiller	Air Cooled Screw Chiller	All DX Conventional Split Ac Units	Air Cooled VRF System
Non Diversified Cooling Load	TR	360	360	360	360
Total Installed Non Diversified Capacity (Low Side)	TR	360	360	410	410
Diversified Installed Capacity High Side @ 80% Diversity	TR	290	340	410	328

(Chiller/VRF ODU/DX ODU)					
System Connected Load Chiller	KW	218	358	520	410
System Connected Load - Plant Room Equipment Excluding Chiller	KW	48	48	0	0
System Connected Low Side AHU	KW	72	72	0	0
Total Connected Load	KW	338	478	520	410
Operating Load (At 90% Loading)	KWH	305	430	468	369
Power Consumption (Per Hr)	KWH	305	430	468	369
Power Consumption (Full Load 12 Hrs)	KWH / Day	3660	5160	5616	4428
Power Consumption (Per Year @ 75% Usage Time)	KWH / Year	1001925	1412550	1537380	1212165
Power Consumption Rs. / Year (@ 6rs./Unit)	Rs. L / Yr	60	85	92	73
Operating And Maintenance Cost Rs./ Year	Rs. L / Yr	7.7	10.8	11.7	9.3
Make Up Water Cost Rs./ Years (@ 5 Paisa / ltr)	Rs. L / Yr	4.7	0.0	0.0	0.0
Total Operating Cost Rs./ Years	Rs. L / Yr	72.4	95.8	103.7	82.3
Capital Cost Of HVAC System Installation	Rs. L	241.2	234	123	246
System Life	Years	18 -20 years	15 Years	10 Years	18 Years

Space Requirement		Chilled Water Plant Room At Utility Room In Basement , Cooling Tower At Roof Level Or In Open Yard	Chiller At Roof With CHW Pump Room	Required To Locate Some 150 Condensing Unit Of Conventional Split Ac UnitsWithin 7.5 mtr Distance Of The IDU	All VRF ODU Can Be Placed On The Roof / Ground / Chhajja
Redundancy		Very Good	Very Good	Partial	Partial

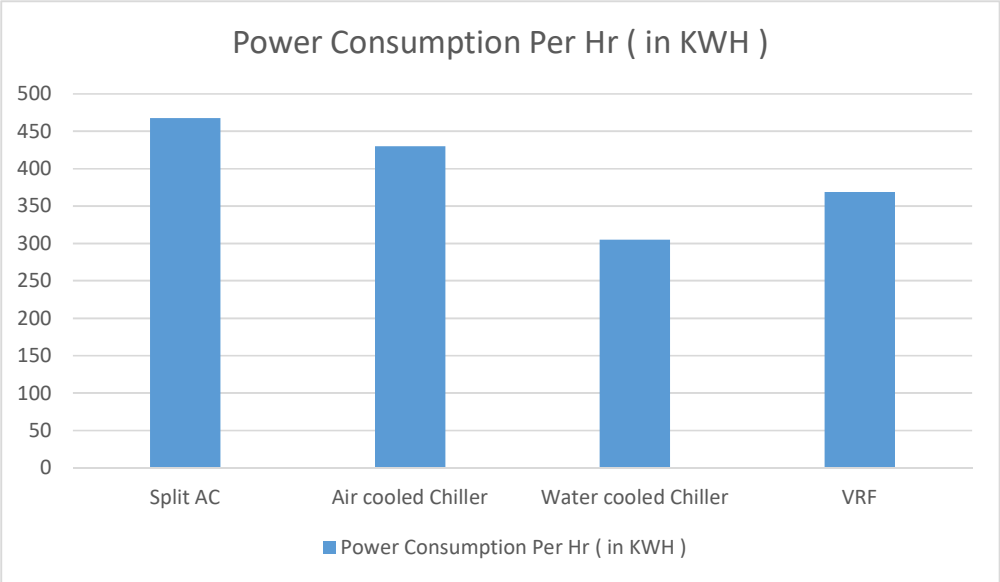

Figure 1. Power Consumption per Hour

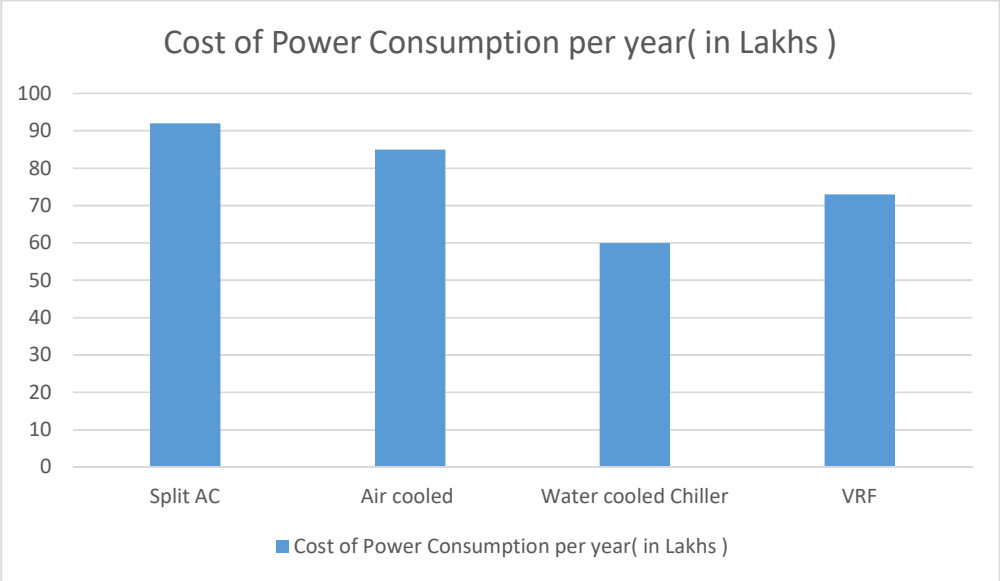

Figure 2. Cost of Power Consumption per year

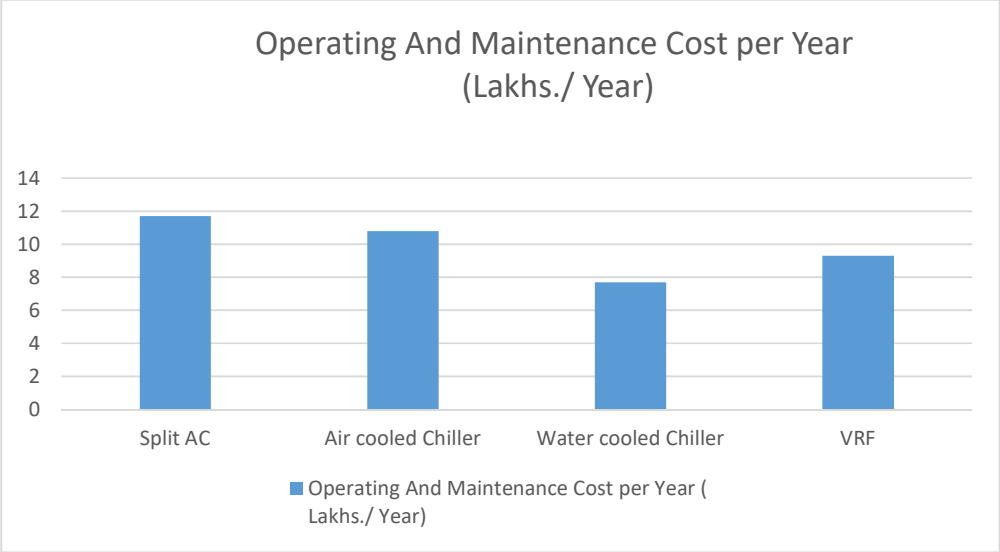

Figure 3. Operating and Maintenance Cost

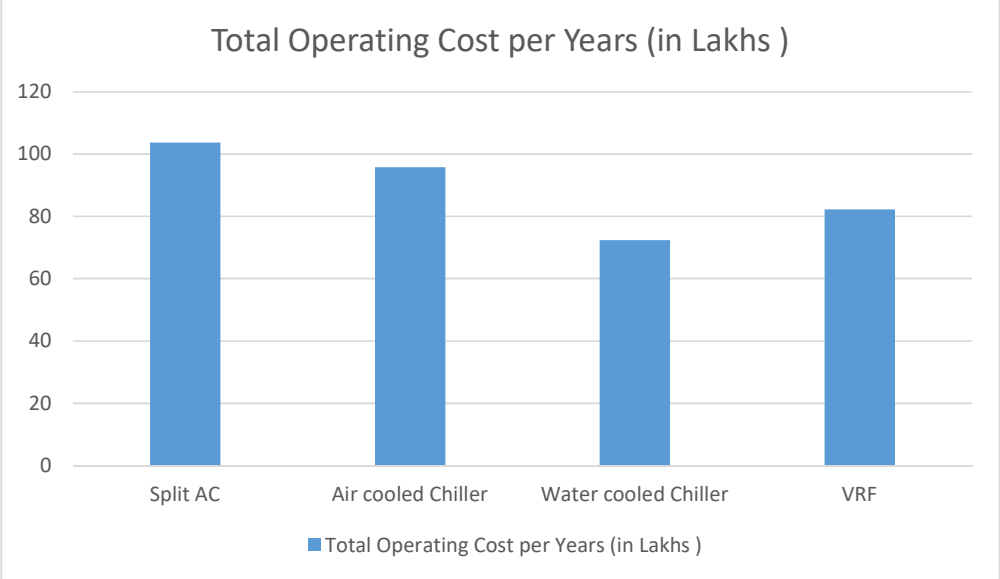

Figure 4. Total Operating Cost per year

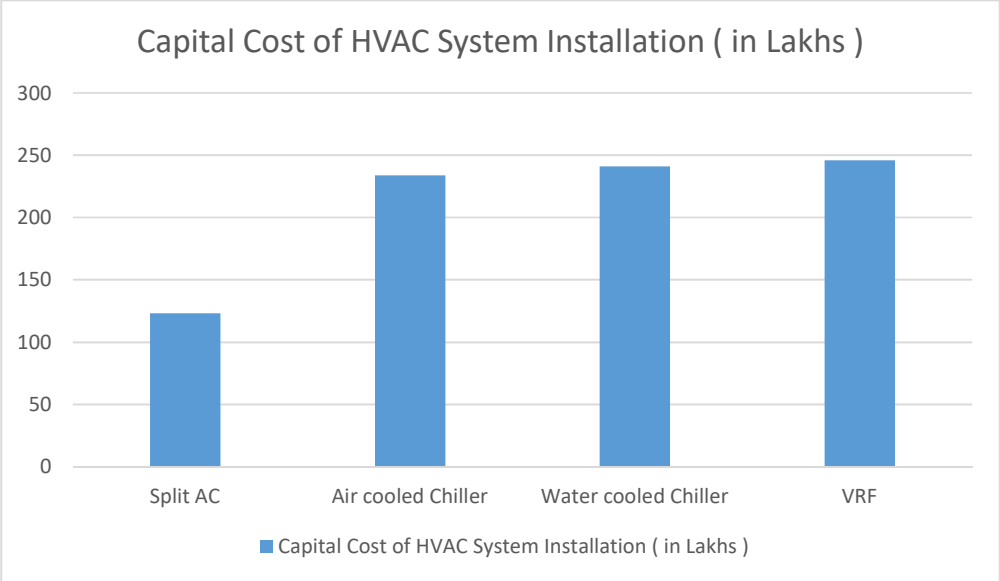

Figure 5. Capital Cost of HVAC system Installation

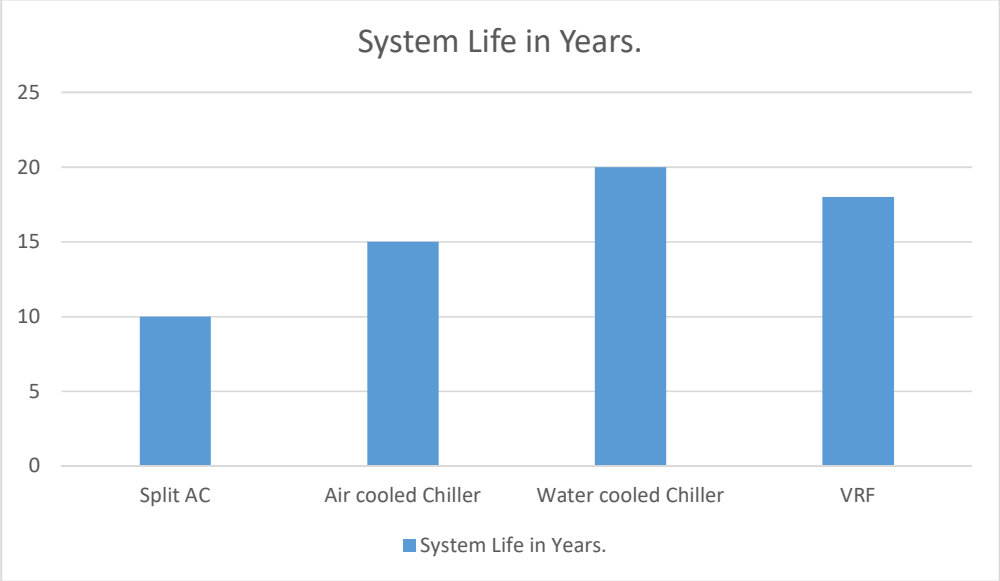

Figure 6. HVAC System Life in years

6. Result and Discussions

Table 1 gives the comparative analysis of possible HVAC systems for the commercial building. It shows that the power consumption is minimum for the water cooled chiller and maximum for split AC units. Also the VRF has more power consumption than water cooled chillers. It will result in the cost of power consumption also in the same nature as shown in Figure 2. From Table 1, the operating and maintenance cost for the water cooled chiller is minimum and split AC find as most expensive. Figure 4 shows that the total operating cost will be minimum for water cooled chillers and maximum for split AC.

The capital cost of installation is minimum for the split AC and water cooled chiller units have higher installation cost but slightly less than the VRF system. Figure 6 shows that the life cycle of water cooled chillers is higher than any other HVAC system.

7. Conclusion

In this study heat load calculations of a commercial building of (360 TR) taken in consideration. Possible alternatives of HVAC system design such as Water Cooled Screw Chiller, Air Cooled Screw Chiller, All DX Conventional Split Ac Units and Air Cooled VRF System are preferred for the total cooling load. Based on comparative analysis of energy, life cycle cost and operating cost of possible substitutions, a chilled water system (water cooled screw chiller) with counter flow induced draught cooling tower is selected for a particular project of 360 TR.

The comparison of chiller vs VRF system shown that the life cycle cost, operation and energy cost of chiller is lower than that of VRF system. But VRF system has various advantages over chiller system like-

- Better efficiency
- Low maintenance (hence low maintenance cost)
- Low noise production
- Controlling the temperature of each zone (in chiller system only one temperature can be set for every zone)
- Air conditioning for a zone can be fully switched off (in chiller system all zones must be air conditioned at all times)

But even though the VRF system has all these major advantages over chiller system, the one place where it lacks is energy consumption. This proves to be a major disadvantage for the VRF system as organizations nowadays, whether large or small, gives great importance to energy conservation. The high initial cost of chiller system is thus negated by the high running (ie, energy consumption) cost of the VRF system, over the course of 20 years. Also the cost of replacing the lost refrigerant in VRF system is higher than replacing lost water in chiller system.

Thus it comes down to the fact whether the organization requires a very efficient yet energy consuming system or a somewhat efficient and low energy consuming system. And hence, taking all these factors into consideration, it's come to the conclusion that the chiller system is better suited for the commercial building.

This doesn't mean that the VRF system is bad, but being a somewhat new system compared to chiller system, that has been there for a long time, the VRF system has many issues still remaining to be solved. Once solved, it will prove to be a way better system than chiller system.

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