# COMPARATIVE ANALYSIS BETWEEN MODERN AND CONVENTIONAL HVAC SYSTEMS FOR USE AT COMMERCIAL BUILDING IN BAGHDAD CITY / IRAQ +

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**Abstract:**

**This research use the life cycle cost analysis and a detailed cooling, heating and electrical load profiles to determine the initial, running and maintenance costs for evaluation the economic feasibilities of using three different types of central air conditioning systems in a commercial building located in Baghdad city / Iraq, so as to select the best air conditioning system. The systems were modern air conditioning system (variable refrigerant flow), all air conditioning system (package roof top unit) and all water air conditioning system (fan coil unit). The present-worth cost method for lifecycle cost period for fifteen years analysis is applied. The transfer function method was used with hourly analysis program (HAP v4.9) for estimation the cooling and heating loads in each space of the building with adopted the indoor air quality in the design as adequate fresh air per person, acceptable noise level and air quality. The comparison between the different methods for the total cost (during fifteen years) for air conditioning systems showed that the variable refrigerant flow system has lowest total cost compare with other methods used for the period operation, so as the variable refrigerant flow air conditioning system worked into variable cooling and heating load between 0% and 100% of total load.**

**Keywords:** ***variable refrigerant flow, fan coil unit, life cycle cost analysis, initial cost, running cost, , total cost.***

# تحميل مقارن لمنظومات التبريد والتكييف الحديثة والتقليدية لبناية تجارية في مدينه بغداد / العراق

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**ألمستخلص:**

يتضمن البحث الحالي اجراء تحميل لكمفة العمر الافتراضي وحسابات احمال التبريد والتدفئه بالاضافه الى الأحمال الكهربائية لتحديد الكلفه الاوليه وكلفه الصيانه وكلفة التشغيل لثلاث أنواع مختلفة من منظومات التكييف المركزيه التي تعمل في نموذج لبنايه تجاريه( مول )تقع في مدينه بغداد/العراق .المنظومات كانت عمى النحو التالي منظومة تبريد وتكييف هواء مركزية نوع هواء كمي ومنظومة تبريد وتكييف هواء مركزية نوع ماء كمي ومنظومة تبريد وتكييف هواء مركزية حديثة .تم اعتماد طريقة دالات التحويل مع برنامج ( HAP نسخة 4.9 ) لأيجاد احمال التبريد والتدفئة الخاصة بكل حيز من المول مع الاخذ بنظر الاعتبار توفير شروط جودة الهواء الداخلي ( IAQ ) التي تخص توفير هواء نقي لكل شخص ويكون الهواء المجهز ذو نقاوة جيدة بالاضافة الى توزيع الهواء بدون ضوضاء تؤثر عمى

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راحة الانسان في داخل الحيز المشغول ، من خلال مقارنة الكلفة الكمية لمنظومات التبريد والتكييف المركزية وخلال مدة تشغيلية قدرها خمسة عشر عام تبين ان الاختيار الامثل والمناسب لهذا المشروع هو منظومة تبريد وتكييف هواء مركزية حديثة (VRF ) لانها تعمل حفظ لمطاقة وبالتالي تكون صرفيات الطاقة أقل من المنظومات الاخرى فضلا عن عمل المنظومة بحمل جزئي للتبريد او التدفئة متغيير يترواح بين 0 % الى. % 100 .

**Nomenclature:**

| | | | |
|---|---|---|---|
| A/C | Air Conditioning | n | Number of Year |
| CLF | Cooling Load Factor | OC | Operation Cost |
| COP | Coefficient of Performance | PRTU | Package Rooftop Unit |
| DBT | Dry Bulb Temperature °C | Q | Mass Flow Rate $m^3/s$ |
| EBP | Even Break Point | Qt | Quantity |
| EQP | Equipment Price | r | Discount rate |
| H&C | Heating and Cooling | T.R. | Ton Refrigerant |
| HAP | Hour Analysis Program | $T\infty$ | Ambient Temperature °C |
| HVAC | Heating, Ventilation and A/C | TFM | Transfer Function Method |
| IAQ | Indoor Air Quality | VAV | Variable Air Volume |
| IC | Initial Cost ($) | VRF | Variable Refrigerant Flow |
| LCC | Life Cycle Cost (year) | MC | Maintenance Cost ($) |

## Introduction:

The commercial building sector is responsible for 64% of electricity consumption in many regions around the world when dedicated to space heating, cooling and ventilation loads [1]. An air conditioning system that saves operating costs usually requires a higher initial investment so engineers should decide whether it is worth paying the extra first cost for a system that has lower operating cost [2]. Park, J. [3] presented an investigation for system performance and economic value of variable refrigerant flow (VRF) systems relative to conventional HVAC systems by comparing life-cycle cost of (VRF) systems to that of conventional HVAC systems. The result of the study showed that the variable refrigerant flow system(VRF) had an average of 39% HVAC energy consumption savings and for the results of the life-cycle cost analysis, the average of simple payback period was (12) years. Zhu, Y. et. al [4] proposed and simulated a new VRF and outdoor air processing unit combined air conditioning system, a VRF model of condenser number independence was developed and validated. The combined system is simulated under conditions of the same and different set-points of the air conditioning zones which show that the combined system could maintain all the zones at their specific set points within small errors. Aynur, T. et. al [5] studied the performance of two air conditioning systems, variable air volume (VAV) and variable refrigerant flow (VRF), it was found that the VRF system promised 27.1–57.9% energy saving potentials depending on the system configuration, indoor and outdoor conditions, when compared to the VAV system. The advantages and disadvantages of the central air conditioning system and the residential multi-unit air conditioning equipment system and the lithium bromide absorption chiller

were studied by Sheng and Xie, [6] based on comparing the first and annual cost according to providing cooling of 90 days, the predicted results showed an economic feasibility of using the refrigerating units in air conditioning systems in Beijing region, and point out the developing directions for the future. Abul Hasan, et. al [7] presented a design for an air conditioning system using (VRF) techniques for a commercial building. The cost analysis between different units showed that there was not big difference in their initial cost but the difference was seem to be high considering the operating cost per the usage of the system. Wicoff, P. [8] showed that the VRF systems have potential to reduce energy consumption and utility costs in the correct applications. It established that air to air VRF having highest energy consumption based on energy use and operating costs.

The purpose of this work is to be compare the initial, maintenance and operation costs between three different types of central air conditioning systems based on the Iraqi's market costs, these system are all air system, all water system and modern air conditioning (variable refrigerant flow). A commercial building (Mall) located in Baghdad city were chosen to be a model. The operating time interval of the air conditioning system from 9:00AM to 12:00PM hours and the life cycle cost for these air conditioning system were considered to be fifteen years [9,10] and used to analysis the details of cooling and heating load estimation, initial, maintenance and operating costs to evaluate the economic feasibility of air conditioning systems.

## Building Description with Load Estimation:

A sample of a commercial building (Mall) consist of two floors ground and first floor with area 1860.9 m² and 1060.6 m² respectively were chosen. Fig.(1-a) showed 3D view for building under study. The building located at Baghdad city, Iraq (33.325 latitude, 44.422 longitude and 34m altitude), and Fig (1-b) showed the architectural plan. Table (1) explained the dimensions, cooling and heating load estimation values, fresh air quantity and number of persons for each space [11,12]. The cooling period for Baghdad city which has a hot and dry climate during summer season, covers 213 days approximate between April and October while the heating period which has a cold and humid climate during winter season, covers 152 days approximate between November and March. The indoor conditions for human comfort in winter season is (20.3– 24.2°C) and (30 to 40%) for dry bulb temperature and relative humidity respectively in winter, while in summer (23.3–26.7°C) and (50% – 60%) respectively. The outdoor design condition considered in this study at winter and summer respectively (0°C & 50°C) dry bulb temperature and (-3°C & 21.6°C) wet bulb temperature [13]. The transfer function method used with hourly analysis program (HAP v4.9) to estimate cooling and heating load in each space and zone for the Mall with additional (10%) as modification safety factor due to result in the heat storage in the building envelope and furniture release of the stored heat which lead to additional cooling or heating load in subsequent hours [14]. The ventilation value was selected depending on the number of person depend on the type of application [15]. All spaces in the building have positive pressure value (5%) except restaurant (10%) and all office is neutral pressure [16]. The noise level within main and branch air duct were acceptable value for each zones [17,18]. The total cooling load for ground and first floor were calculated according to above assumptions are 154 and 80 ton refrigerant respectively.

## Air Conditioning Systems:

Three different types of central air conditioning systems were selected:

### 1-Variable Refrigerant Flow:

In the variable refrigerant flow (VRF) system, consist of one outdoor unit and multiple indoor fan coil units that provide space cooling or heating by recirculating inside air. The term of VRF system refers to the ability of the system to control the amount of refrigerant flowing to the multiple indoor units, enabling the use of many evaporators of differing capacities and configurations connected to single condensing unit [19], Fig.(2) showed the types of indoor unit connected with outdoor unit [20]. The main advantage of a VRF system is ability to respond to fluctuations in space load conditions by allowing each individual thermostat to modulate its corresponding electronic expansion valve to maintain its space temperature set point [20]. The VRF air conditioning system with scroll inverter compressor manufactured by York Brand and by use JCI-VRF selection software [21]. Fig.(3) showed the design and distribution of indoor and outdoor unit of VRF air conditioning system that use in this search .

**2-All Water System:**
In this type of air conditioning systems, water is used for thermal distribution. When cooling is required in the conditioned space then cold water is circulated between the conditioned space and the plant, while hot water is circulated through the distribution system when heating is required. The four pipe system has a fan coil units with separate heating and cooling coils were used. The system is able to instantly switch from the heating to the cooling mode and can provide heating and cooling simultaneously [22,23]. A flow control valve controls the flow rate of hot or cold water to the conditioned space and thereby meets the required building heating or cooling load. The flow control valve is controlled by the zone thermostat. The main advantages of this system is the thermal distribution system requires very less space compared to all air systems, Individual room control is possible. The air cooled scroll chiller, electric boiler, four water pipe system and fan coil unit manufactured by York brand and by using HVAC solution software [24] used to state the bill of quantity. Fig.(4) showed the water pipe design with FCU distribution that use in this study.

**3-All Air System (PRTU):**
This type of air conditioning systems going to use air cooled package rooftop unit. There are multiple choices of rooftop and/or horizontal grade mounted configurations to meet building needs. Heating is usually done by using duct electric heater while cooling is usually by direct expansion. Outdoor air ventilation can be provided by barometric relief, fan-powered relief, or return air exhaust air fan[25]. Equipment is generally mounted on the roof. PRTUs are designed as central station equipment for single zone, multi zone, and VAV applications. The PRTU with fixed scroll compressor manufactured by York brand with equal friction method used to state the bill of quantity [26], Fig.(5) showed the design and distribution the terminal of PRTU air conditioning that use in this search.

**Cost Analysis:**

The overall cost analysis for air conditioning system which selected to be use in the mall building is classified as initial cost, operation cost and maintenance cost, that will be incurred over the lifetime of A/C system should be taken into account.

**1-Initial Cost:**
The total initial cost of air conditioning systems includes purchasing and installation cost was carried out. Tables (2), (3) and (4) includes the estimated initial costs for the three types of air conditioning system, while Fig.(6) showed the initial cost for three types of air conditioning system.

**2-Operation Cost:**
In general the operation the A/C system is depends on the electrical energy. Electric power consumption calculation was carried out depending on the book data for each A/C system under study. The indoor and outdoor units running cost were calculated according to the electrical unit price measured in kilowatts unit hours. The electricity tariff is the sale price

of the unit electrical required to calculate the cost per month for commercial consumption [27]. The operating time of the Mall building is fifteen hours per one day and for all days of year. Equation (1) illustrates the amount of running cost for one day only. Tables (5) and (6) showed the amount of electric cost for indoor unit, blower fan, condenser fan motor, electrical boiler, electric heater, water pump and compressor for each type of A/C systems for both cooling and heating modes, Figs.(7-a) and (7-b) showed the running cost per one year with ambient temperature for cooling are (35°C & 46°C) respectively and ambient temperature for heating is (0°C) . Running Cost per One Month ($) = Amount of Energy (kW) × Operating Time (Hours per Day) × (No of Days per Month) × Electricity Tariff ($/kW. hr) . . . …. **(1)**

**3-Maintenance Cost:**

Maintenance costs include the cost of all planned equipment maintenance, such as cleaning, replace and repair complexity of the air conditioning system and the relative ease of access to plant play an important role on the maintenance cost [28]. Maintenance cost depends on many parameters such as local labor rates, experience, and duration of system operation. The maintenance cost was calculated from the following expression [29] and were listed in Table (7).

$$MC = \frac{0.5 \times EQP}{LIFE} \qquad \text{……. (2)}$$

**4 Life - Cycle Cost Analyses (LCC):**

The life cycle cost analysis was carried out to analyses the total cost for each central of A/C system as initial, operating and maintenance costs. The air conditioning systems span has fifteen years as live cycle work, the present worth cost technique was used for evaluating the air conditioning system and used to examine total costs of the three different central air conditioning systems [29], and the formula (3) shows the life cycle cost for air conditioning system:

$$\text{……. (3)} \quad LCC = IC + \sum_{n=1}^{n=15} \frac{(OC + MC)}{(1+r)^n}$$

The discount rate (r) is always neglected then equation (3) becomes:

$$LCC = IC + \sum_{n=1}^{n=15} (OC + MC) \qquad \text{……. (4)}$$

## <u>Results and Discussion</u>:

This study present comparison total costs for each type of A/C system, which include the initial, operating and maintenance cost, also this comparison submit the life cycle cost analysis between three different types of A/c systems so as to select the lower cost for life cycle as fifteen years. As can be seen from the Tables (2), (3) , (4) and Fig.(6)
that the initial cost for the all air A/C system (PRTU) is lower than VRF and FCU
approximately 4.4% and 55.6% respectively. Tables (5) and (6) showed that the running cost for one month of VRF is lower than FCU and PRTU as cooling mode running at ambient temperature 35°C as 23.1% and 51.8% respectively, while VRF system is lower than FCU and PRTU as cooling mode run at ambient temperature 46°C is 19.5% and 50.7% respectively, while the running cost for VRF system is lower than FCU and PRTU as heating mode at ambient temperature 0°C is 54.3% and 33.4% respectively. Table (7) showed the

maintenance cost for the PRTU is lower than VRF and FCU approximately 45.5% and 72.3% respectively for each year. Fig.(7-a) and (7-b) showed the running cost for one year of the PRTU and FCU air conditioning system have break-even point aft five months and the running cost for FCU is lower electrical consumption compare to the PRTU, while the VRF is maintain lower than two A/C system. Fig.(8-a) and (8-b) showed the total cost for one year at different central air conditioning system, the PRTU and VRF air conditioning system have break-even point approximate after 133 day as heating and cooling mode at ambient temperature 0°C and 36°C respectively while break-even point approximate after 126 day as heating and cooling mode at ambient temperature 0°C and 46°C respectively. Fig.(9-a) showed the life cycle cost for fifteen years , the VRF system saved 45.5% of total cost after 15 years for FCU and 36.6% for PRTU as heating and cooling mode at ambient temperature 0°C and 35°C respectively, while the Fig.(9-b) showed the VRF system saved 43.4% of total cost after 15 years for FCU and 37.5% for PRTU as heating and cooling mode at ambient temperature 0°C and 46°C respectively. Although the PRTU air conditioning system less than FCU system in initial and maintenance costs, the total cost approached from the FCU due to the operation cost weight, while the VRF system remains lowest total cost compare with other air conditioning system since the fourth month of operation the project because technology uses smart integrated controls, variable speed drives, refrigerant piping, renewable refrigerant and heat recovery so as to provide the products with attributes that include high energy efficiency, flexible operation, ease of installation, low noise, zone control, and comfort using all electric technology.

## Conclusions:

The results of this study led to the following conclusions:

1. The best selection of air conditioning system is variable refrigerant flow (VRF).The VRF air conditioning system provides save energy by 43.4% and 37.5% of the total cost after fifteen years for compare with FCU and PRTU respectively.
2. The package rooftop unit has lowest initial cost compare with other air conditioning systems. The package rooftop unit has lowest maintenance cost compare with other air conditioning systems.
3. The PRTU and FCU air conditioning systems have break-even point after five months for operation cost per one year. The FCU air conditioning system has operation cost lower than PRTU for fifteen years.
4. The VRF air conditioning system has operation cost lower than FCU for fifteen years.
5. The VRF and PRTU air conditioning systems have break-even point after 126 day for total cost per one year.

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Fig. (1-a): 3D View of the Commercial Building

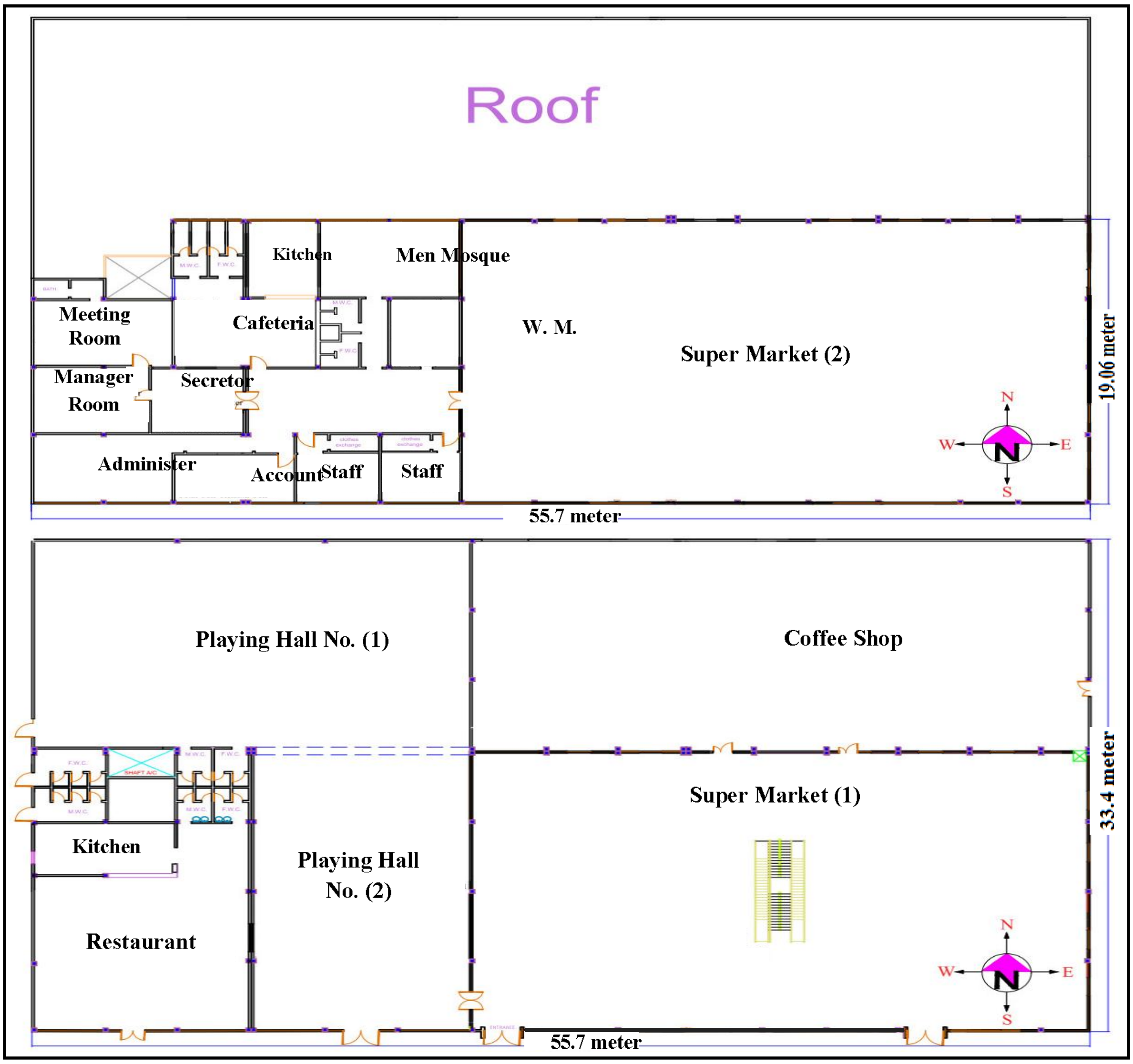


Fig. (1-b): Architectural Plan details

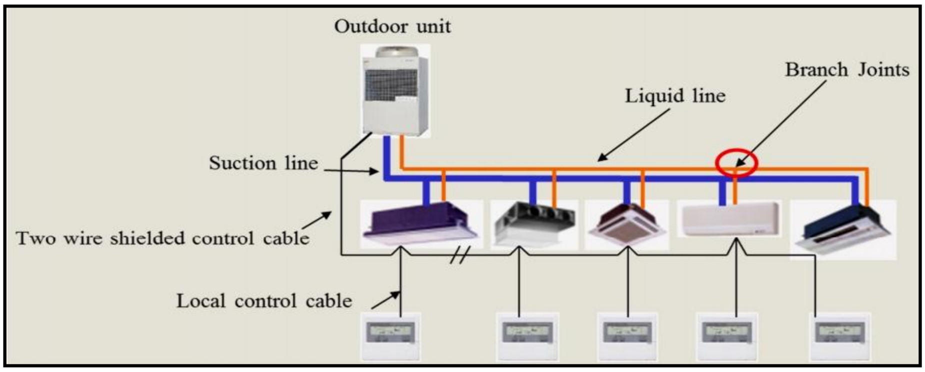


**Fig.(2): Types of Indoor Unit Connected with Outdoor Unit of VRF**

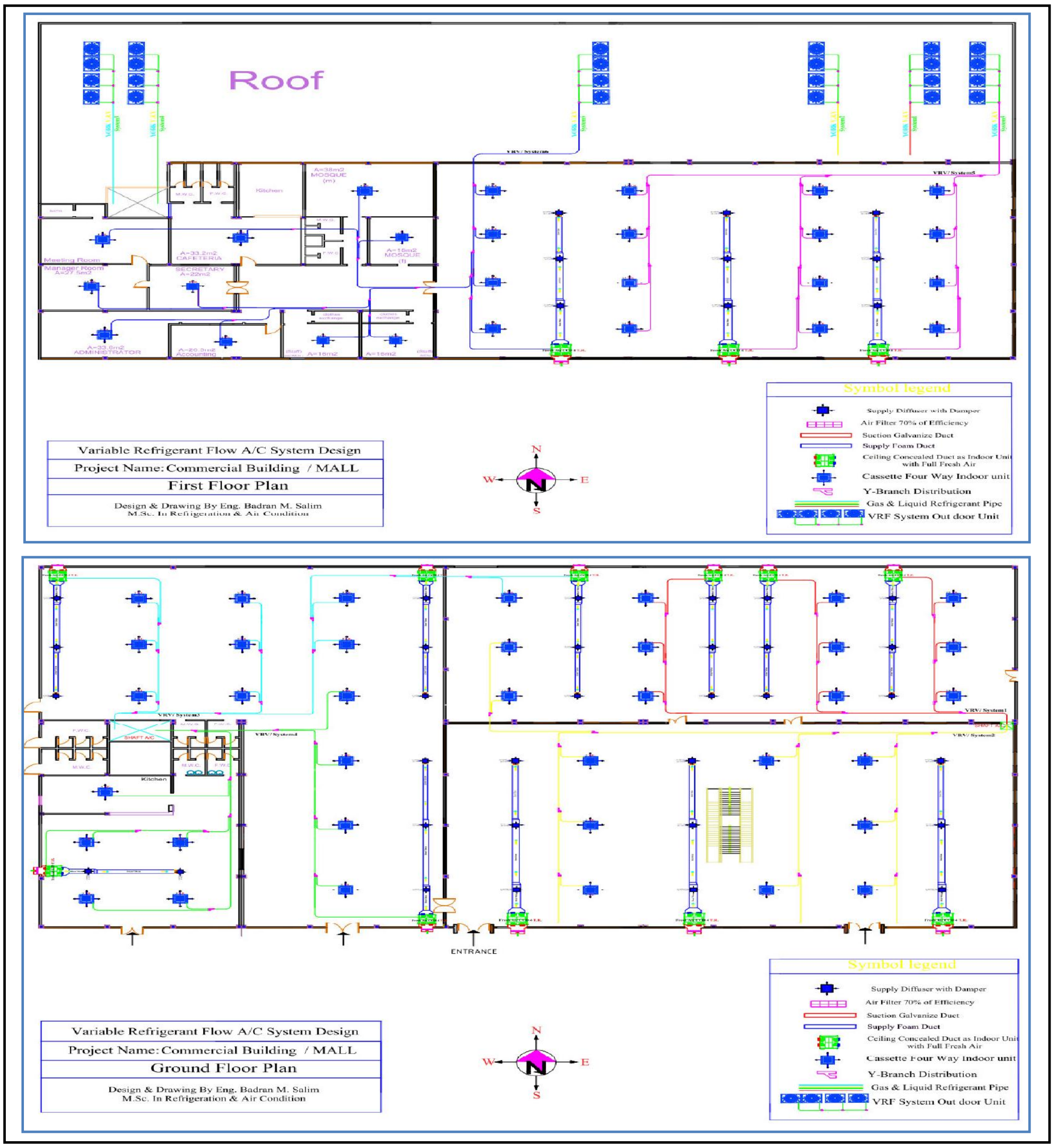


**Fig.(3): VRF Air Conditioning System Design and unit Distribution for Ground and First Floors of Mall Building**

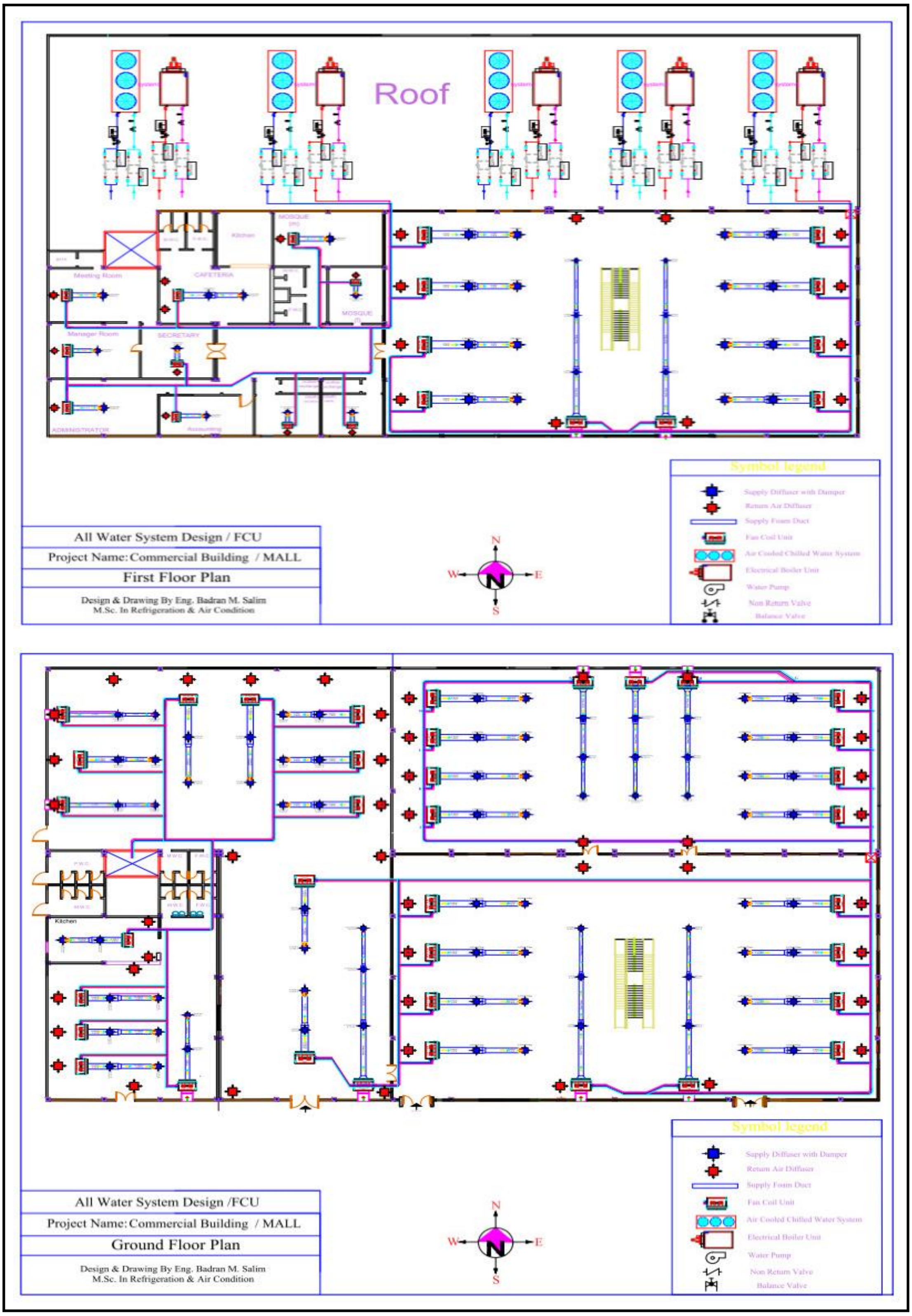


**Fig.(4): All Water A/C System Design and FCU Distribution for Ground and First Floors of Mall Building**

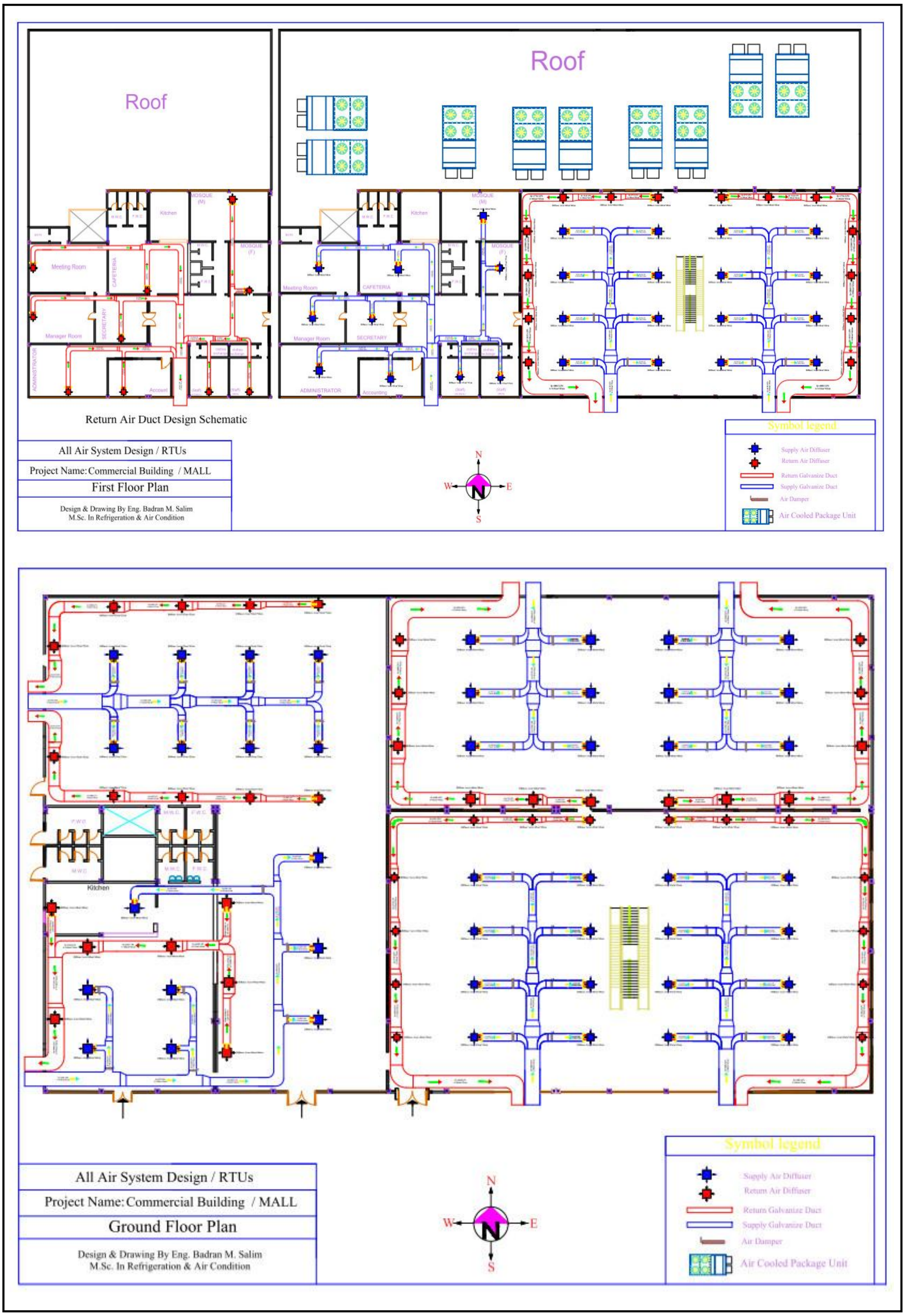


**Fig.(5): RTU Air Conditioning System Design and Terminal Distribution for Ground and First Floors of the Mall Building**

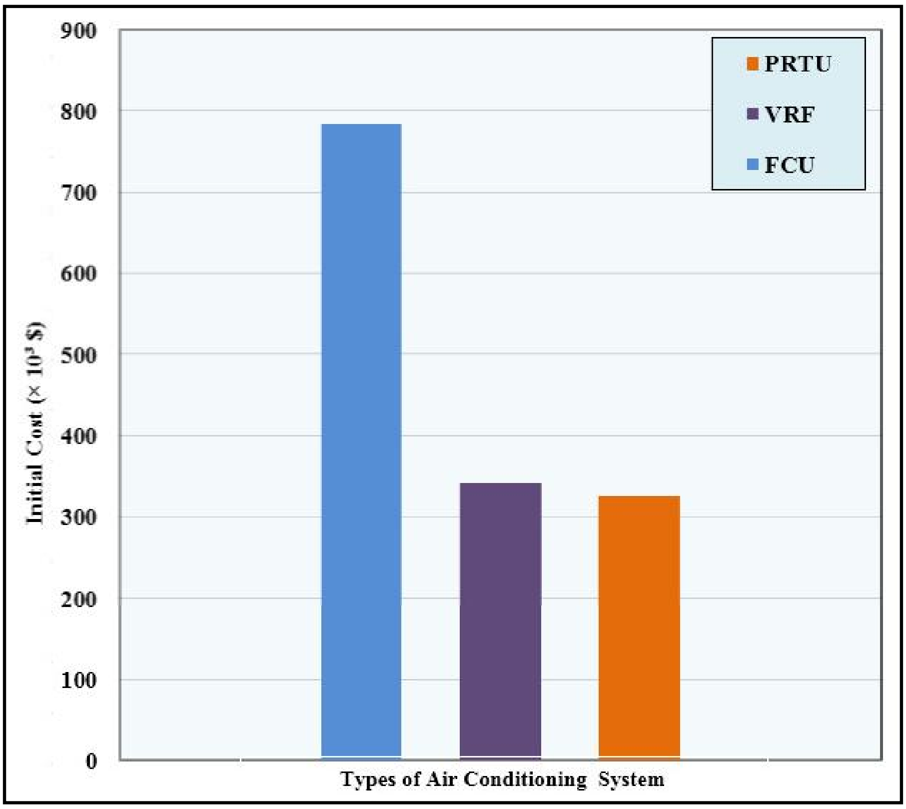


Fig.(6): Initial Cost for the Three Types of A/C System

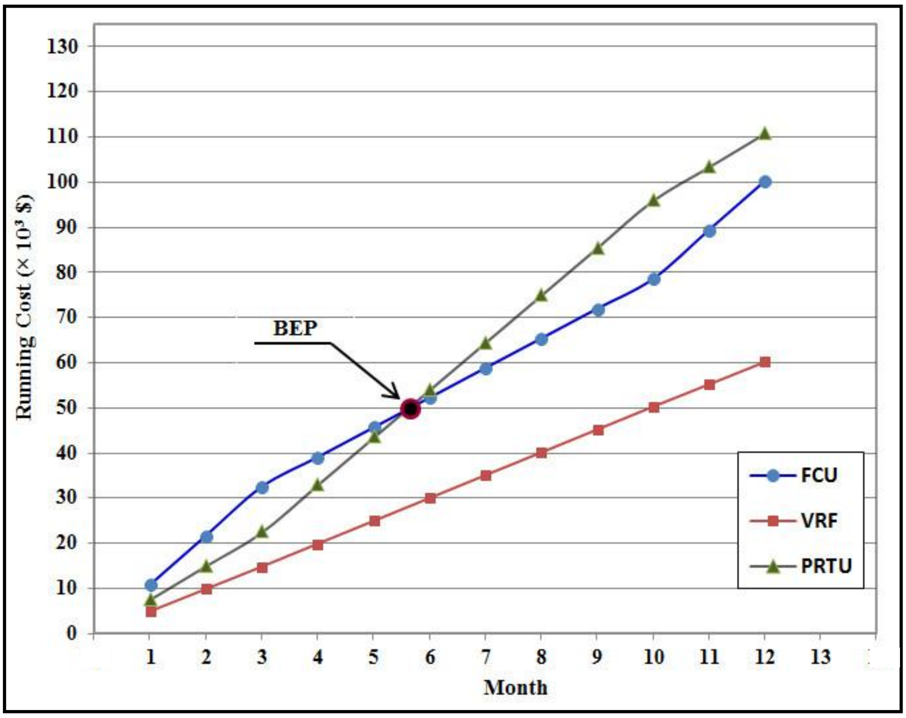


Fig.(7-a): Running Cost for One Year of Heating (T∞=0°C) and Cooling Mode (T∞=35°C)

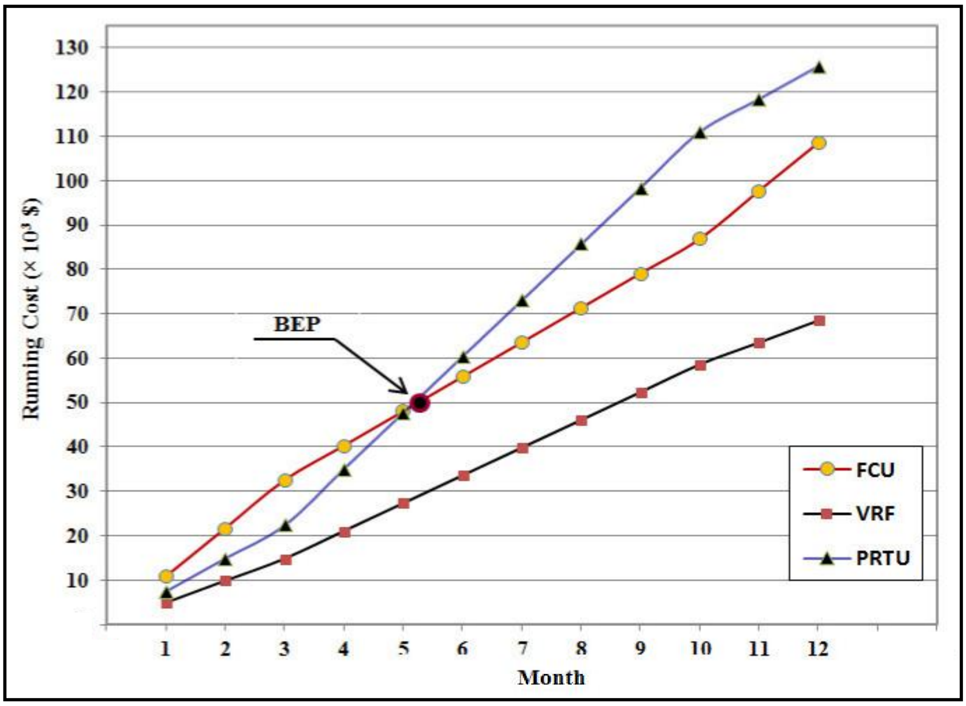


**Fig.(7-b): Running Cost for One Year of Heating (T∞=0°C) and Cooling Mode (T∞=46°C)**

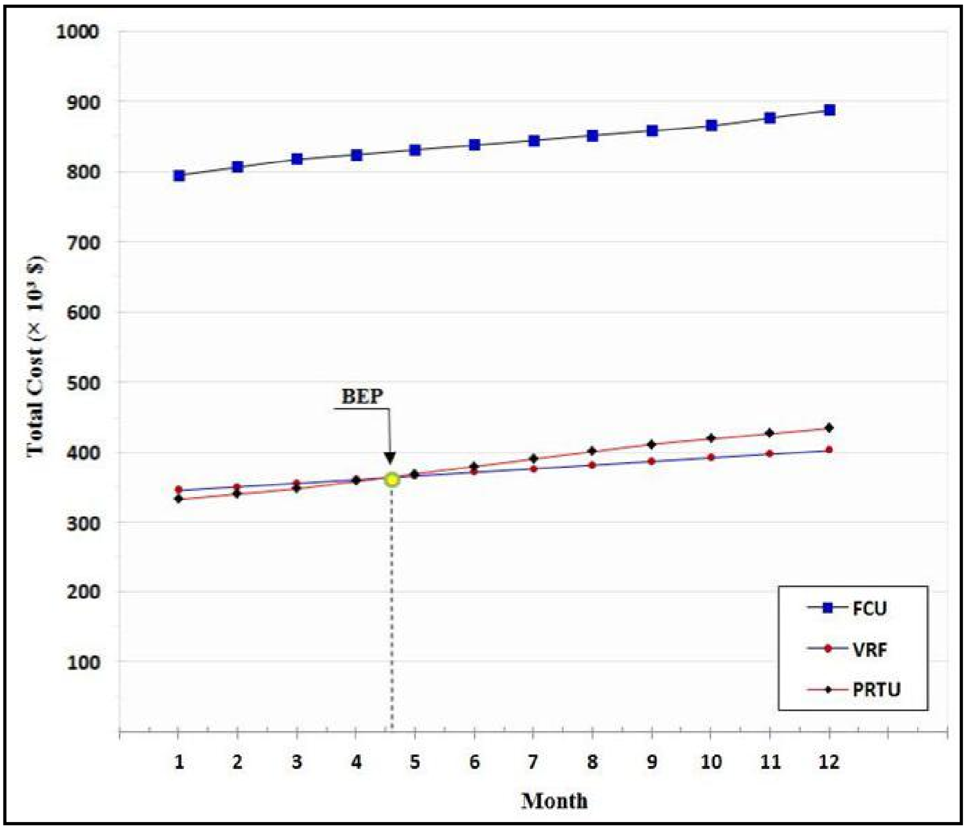


**Fig.(8-a): Total Cost for One Year of Heating Mode at T∞=0°C and Cooling Mode at T∞=35°C**

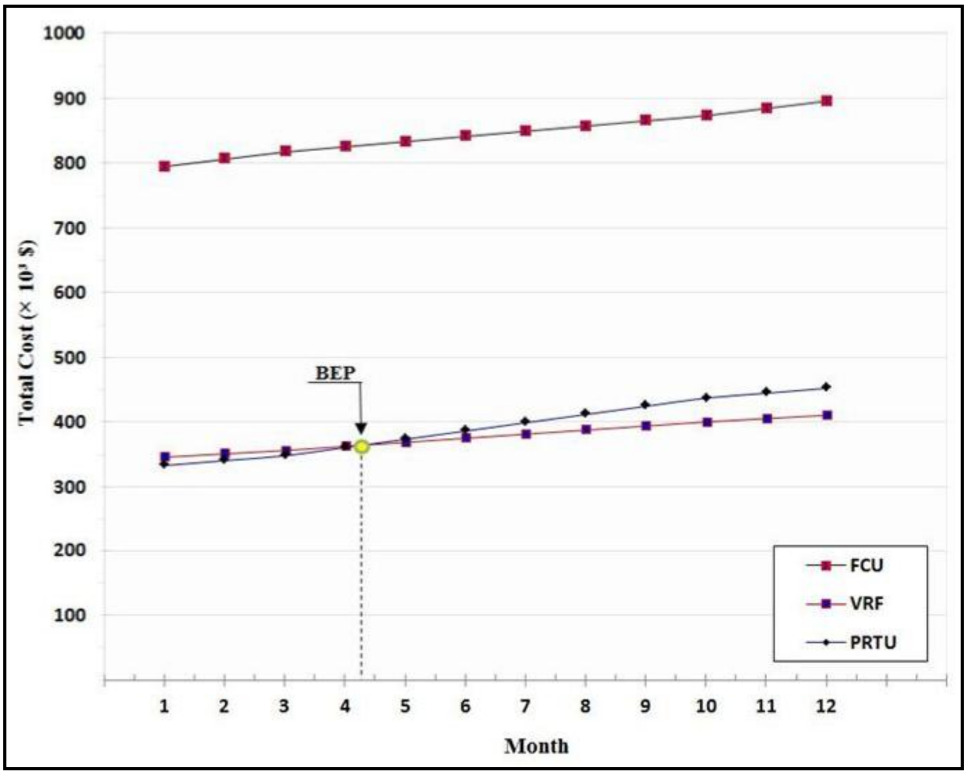


Fig.(8-b): Total Cost for One Year of Heating Mode at T∞=0°C and Cooling Mode at T∞=46°C

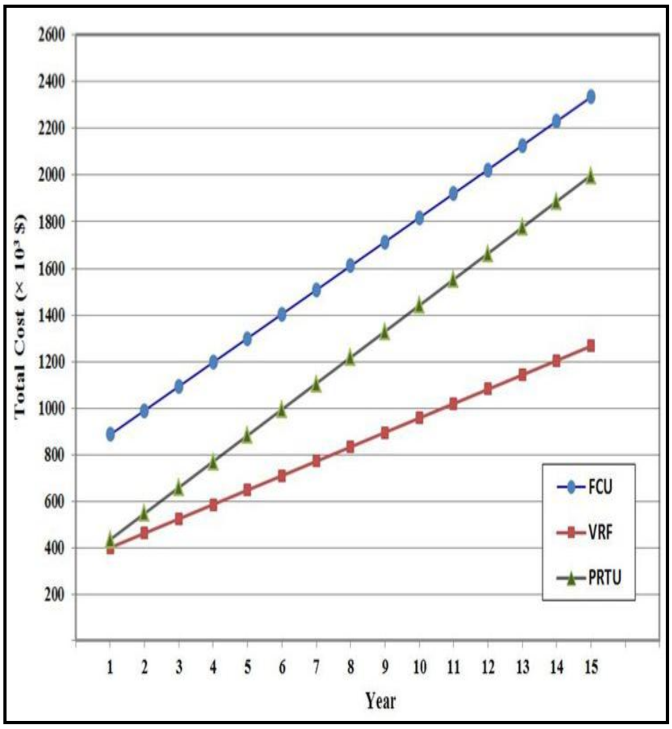


Fig.(9-a): Life Cycle Cost for Fifteen Year of Heating at T∞=0°C and Cooling Mode at T∞=35°C

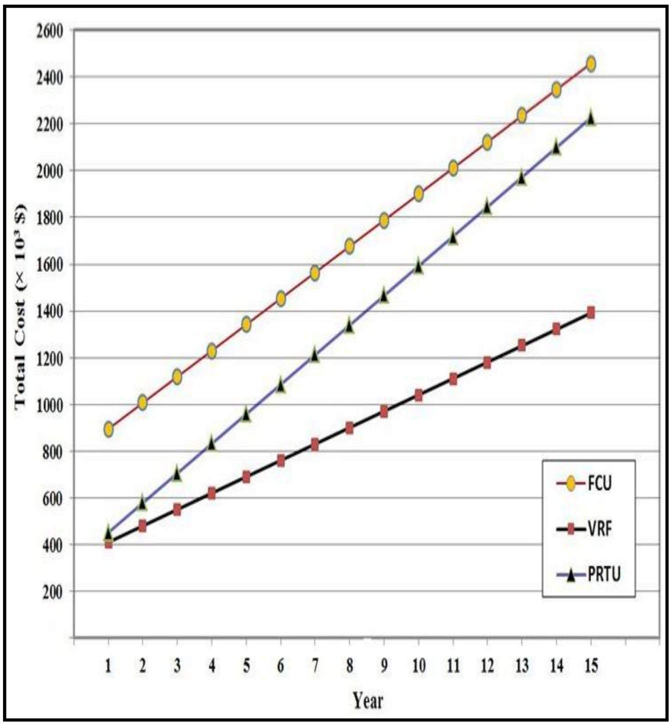


Fig.(9-b): Life Cycle Cost for Fifteen Year of Heating at T∞=0°C and Cooling Mode at T∞=46°C

**Table (1): Dimension of each Space and Load Estimation Values**

| Name of space / Floor | Area (m²) | Volume (m³) | Cooling Load (T. R.) | Heating Load (kW) | Ventilation Quantity (l/s) | No. of Person |
|---|---|---|---|---|---|---|
| Super Market Hall (1) /Ground | 622 | 3110 | 36 | 70 | 987 | 141 |
| Restaurant /Ground | 119.3 | 596.5 | 20 | 42 | 330 | 33 |
| Coffee Shop /Ground | 468.8 | 2344 | 50 | 96 | 1320 | 132 |
| Playing Hall (1) /Ground | 332.2 | 1661 | 35 | 66 | 660 | 66 |
| Playing Hall (2) /Ground | 220 | 1100 | 13 | 24 | 308 | 44 |
| Super Market Hall (2) /First | 622 | 3110 | 56 | 110 | 987 | 141 |
| Mosque for men /First | 38 | 133 | 3 | 10.5 | ----- | 32 |
| Mosque for women First | 18 | 63 | 1.5 | 5.3 | ----- | 14 |
| Cafeteria /First | 33.2 | 116.2 | 4 | 14 | ----- | 15 |
| Meeting Room /First | 33.7 | 117.95 | 3 | 10.5 | ----- | 14 |
| Manager Room /First | 27.5 | 96.25 | 2.5 | 8.7 | ----- | 8 |
| Secretary /First | 22 | 77 | 2 | 7 | ----- | 5 |
| Administrator /First | 33.6 | 117.6 | 3 | 10.5 | ----- | 9 |
| Accounting /First | 20.5 | 71.75 | 2 | 7 | ----- | 3 |
| Staff for Men /First | 16 | 56 | 1.5 | 5.3 | ----- | 5 |
| Staff for Women /First | 16 | 56 | 1.5 | 5.3 | ----- | 5 |

**Table (2): Initial Cost Details of VRF Air Conditioning System**

| Description of Items | Unit | Qt. | Unit Price($) | Total Price($) |
|---|---|---|---|---|
| Indoor Unit / Cassette Type 5.6kW H.&C. Capacity | No. | 3 | 550 | 1,650 |
| Indoor Unit / Cassette Type 7.1kW H.&C. Capacity | No. | 4 | 580 | 2,320 |
| Indoor Unit / Cassette Type 9.0kW H.&C. Capacity | No. | 17 | 630 | 10,710 |
| Indoor Unit / Cassette Type 11.2kW H.&C. Capacity | No. | 31 | 690 | 21,390 |
| Indoor Unit / Cassette Type 12.5kW H.&C. Capacity | No. | 4 | 750 | 3,000 |
| Indoor Unit / Cassette Type 14.0kW H.&C. Capacity | No. | 4 | 850 | 3,400 |
| Indoor Unit / Fresh Air Intake 14.0kW H.&C. Capacity | No. | 14 | 950 | 13,300 |
| Outdoor Unit / 146kW Cooling & Heating Capacity | No. | 1 | 29,000 | 29,000 |
| Outdoor Unit / 152kW Cooling & Heating Capacity | No. | 5 | 32,000 | 160,000 |
| Y & T Joint / Model YBP- YG4B | No. | 54 | 70 | 3,780 |
| Y & T Joint/ Model YBP- YG3B | No. | 68 | 90 | 6,120 |
| Y & T Joint / Model YBP- YG1B | No. | 36 | 110 | 3,960 |
| Y & T Joint / Model YBP- YG2B | No. | 8 | 130 | 1,040 |
| Refrigerant Pipe 6.35mm Diameter | m | 20 | 12 | 240 |
| Refrigerant Pipe 9.52mm Diameter | m | 360 | 16 | 5,760 |
| Refrigerant Pipe 12.7mm Diameter | m | 150 | 18 | 2,700 |
| Refrigerant Pipe 19.05mm Diameter | m | 210 | 22 | 4,620 |
| Refrigerant Pipe 15.88mm Diameter | m | 290 | 20 | 5,800 |
| Refrigerant Pipe 22.23mm Diameter | m | 40 | 26 | 1,040 |
| Refrigerant Pipe 25.40mm Diameter | m | 85 | 29 | 2,465 |
| Refrigerant Pipe 28.58mm Diameter | m | 108 | 32 | 3,456 |
| Refrigerant Pipe 34.90mm Diameter | m | 32 | 36 | 1,152 |
| Refrigerant Pipe 38.10mm Diameter | m | 94 | 40 | 3,760 |
| PVC Pipe for Water Condensation Diameter 1.5&1inch | m | 650 | 13 | 8,450 |
| Refrigerant R410a Quantity | kg | 77 | 22 | 1,694 |
| Foam Air Duct Area | m² | 178 | 45 | 8,010 |
| Square Air Diffuser 4 Way with box / Size 22cm*22cm | No. | 39 | 50 | 1,950 |
| Square Air Diffuser 4 Way with box / Size 30cm*30cm | No. | 2 | 60 | 120 |
| Another Cost to Complete Installation | --- | --- | 30,000 | 30,000 |
| **Total of Purchasing and Installation Cost** | | | | **340,887 $** |

**Table (3): Initial Cost Details of FCU Air Conditioning System**

| Description of Items | Unit | Qt. | Unit Price($) | Total Price($) |
|---|---|---|---|---|
| Air Cooled Scroll Compressor Chiller 40T.R. Capacity | No. | 1 | 40,000 | 40,000 |
| Air Cooled Scroll Compressor Chiller 50T.R. Capacity | No. | 3 | 49,000 | 147,000 |
| Air Cooled Scroll Compressor Chiller 60T.R. Capacity | No. | 1 | 58,000 | 58,000 |
| Air Cooled Chiller 50T.R. Capacity / **Stand By** | No. | 1 | 49,000 | 49,000 |
| Electrical Boiler Heating Capacity 78 kW | No. | 1 | 10,000 | 10,000 |
| Electrical Boiler Heating Capacity 105 kW | No. | 2 | 12,000 | 24,000 |
| Electrical Boiler Heating Capacity 118 kW | No. | 2 | 13,000 | 26,000 |
| Electrical Boiler Heating Capacity 105 kW / **Stand By** | No. | 1 | 14,000 | 14,000 |
| Horizontal Concealed Fan Coil Unit 1.5T.R.Capacity | No. | 3 | 1,000 | 3,000 |
| Horizontal Concealed Fan Coil Unit 2.0T.R.Capacity | No. | 2 | 1,100 | 2,200 |
| Horizontal Concealed Fan Coil Unit 2.5T.R.Capacity | No. | 1 | 1,250 | 1,250 |
| Horizontal Concealed Fan Coil Unit 3.0T.R.Capacity | No. | 11 | 1,350 | 14,850 |
| Horizontal Concealed Fan Coil Unit 3.5T.R.Capacity | No. | 2 | 1,400 | 2,800 |
| Horizontal Concealed Fan Coil Unit 4.0T.R.Capacity | No. | 12 | 1,500 | 18,000 |
| Horizontal Concealed Fan Coil Unit 5.0T.R.Capacity | No. | 7 | 1,650 | 11,550 |
| Horizontal Concealed Fan Coil Unit 5.5T.R.Capacity | No. | 8 | 1,700 | 13,600 |
| Fresh Air Intake Fan Coil Unit 4.0T.R.Capacity | No. | 5 | 1,550 | 7,750 |
| Fresh Air Intake Fan Coil Unit 6.0T.R.Capacity | No. | 6 | 1,700 | 10,200 |
| Expansion Tank Size 1m$^3$ | No. | 1 | 1,000 | 1000 |
| Black Steel Water Pipe 15mm Diameter | m | 128 | 30 | 3,840 |
| Black Steel Water Pipe 20mm Diameter | m | 307 | 40 | 12,280 |
| Black Steel Water Pipe 25mm Diameter | m | 320 | 50 | 16,000 |
| Black Steel Water Pipe 32mm Diameter | m | 500 | 58 | 29,000 |
| Black Steel Water Pipe 40mm Diameter | m | 330 | 65 | 21,450 |
| Black Steel Water Pipe 50mm Diameter | m | 300 | 69 | 20,700 |
| Black Steel Water Pipe 65mm Diameter | m | 350 | 75 | 26,250 |
| Black Steel Water Pipe 80mm Diameter | m | 370 | 80 | 29,600 |
| Black Steel Water Pipe 100mm Diameter | m | 210 | 90 | 18,900 |
| Fitting for all Size with Air Separator | No. | 100 | 28 | 2,800 |
| PVC Pipe for Water Condensation Diameter 1.5&1inch | m | 750 | 13 | 9,750 |
| Water Pump Mount End Suction / Q=1.55L/S , H=66.3m | No. | 4 | 1,450 | 5,800 |
| Water Pump Mount End Suction / Q=7.83L/S , H=86.6m | No. | 2 | 1,650 | 3,300 |
| Water Pump Mount End Suction / Q=7.70L/S , H=96.2m | No. | 2 | 1,700 | 3,400 |
| Water Pump Mount End Suction / Q=1.60L/S , H=59.4m | No. | 2 | 1,400 | 2,800 |
| Water Pump Mount End Suction / Q=8.60L/S , H=142.m | No. | 2 | 1,800 | 3,600 |
| Water Pump Mount End Suction / Q=1.03L/S , H=54.6m | No. | 2 | 1,300 | 2,600 |
| Water Pump Mount End Suction / Q=7.04L/S , H=92.7m | No. | 2 | 1,700 | 3,400 |
| Water Pump Mount End Suction / Q=1.39L/S , H=62.2m | No. | 2 | 1,400 | 2,800 |
| Water Pump Mount End Suction / Q=5.50L/S , H=83.1m | No. | 2 | 1,550 | 3,100 |
| Square Air Diffuser 4 Way with box / Size 22cm*22cm | No. | 6 | 50 | 300 |
| Square Air Diffuser 4 Way with box / Size 30cm*30cm | No. | 24 | 60 | 1,440 |
| Square Air Diffuser 4 Way with box / Size 37cm*37cm | No. | 19 | 70 | 1,330 |
| Square Air Diffuser 4 Way with box / Size 45cm*45cm | No. | 45 | 80 | 3,600 |
| Square Air Diffuser 4 Way with box / Size 50cm*50cm | No. | 19 | 85 | 1,615 |
| Square Air Diffuser 4 Way with box / Size 60cm*60cm | No. | 68 | 100 | 6,800 |
| Foam Air Duct Area | m$^2$ | 523 | 45 | 23,535 |
| Another Cost to Complete Installation | --- | --- | 20,000 | 20,000 |
| **Total of Purchasing and Installation Cost** | | | | **734,190 $** |

**Table (4): Initial Cost Details of PRTU Air Conditioning System**

| Description of Items | Unit | Qt. | Unit Price($) | Total Price($) |
|---|---|---|---|---|
| Air Cooled PRTU 18 ton refrigerant cooling capacity. | No. | 2 | 12,500 | 25,000 |
| Air Cooled PRTU 24 ton refrigerant cooling capacity. | No. | 1 | 18,500 | 18,500 |
| Air Cooled PRTU 25 ton refrigerant cooling capacity. | No. | 2 | 20,500 | 41,000 |
| Air Cooled PRTU 28 ton refrigerant cooling capacity. | No. | 2 | 23,500 | 47,000 |
| Air Cooled PRTU 33 ton refrigerant cooling capacity. | No. | 1 | 26,000 | 26,000 |
| Air Cooled PRTU 35 ton refrigerant cooling capacity. | No. | 1 | 28,000 | 28,000 |
| Electrical duct heater 36kW capacity | No. | 2 | 900 | 1,800 |
| Electrical duct heater 50kW capacity | No. | 3 | 1300 | 3,900 |
| Electrical duct heater 58kW capacity | No. | 2 | 1500 | 3,000 |
| Electrical duct heater 65kW capacity | No. | 1 | 1800 | 1,800 |
| Electrical duct heater 68kW capacity | No. | 1 | 2100 | 2,100 |
| Square Air Diffuser 4 Way with box / Size 60cm*60cm | No. | 77 | 100 | 7,700 |
| Square Air Diffuser 4 Way with box / Size 52cm*52cm | No. | 18 | 85 | 1,530 |
| Square Air Diffuser 4 Way with box / Size 45cm*45cm | No. | 36 | 80 | 2,880 |
| Square Air Diffuser 4 Way with box / Size 37cm*37cm | No. | 6 | 70 | 420 |
| Foam Air Duct Area | m² | 2,115 | 45 | 95,175 |
| Another Cost to Complete Installation | --- | --- | 20,000 | 20,000 |
| **Total of Purchasing and Installation Cost** | | | | **325,805 $** |

**Table (5): Details about Monthly Running Cost per Day at Cooling Mode**

| A/C System | Outdoor Energy Consumption 3Ø / (kW) | Indoor Energy Consumption 1Ø / (kW) | Electricity Tariff ($/kW Hr.) | | Running Cost ($) |
|---|---|---|---|---|---|
| | | | 3Ø | 1Ø | |
| VRF | 335.40 kW at 46°C | 5.2 kW | 0.041 | 0.025 | 6246.630 $ |
| | 271.15 kW at 35°C | | 0.041 | 0.025 | 5061.210 $ |
| FCUs | 416.57 kW at 46°C | 6.4 kW | 0.041 | 0.025 | 7757.700 $ |
| | 352.68 kW at 35°C | | 0.041 | 0.025 | 6578.940 $ |
| PRTU | 686.22kW at 46°C | ---- | 0.041 | 0.025 | 12660.75 $ |
| | 569.10 kW at 35°C | | 0.041 | 0.025 | 10499.89 $ |

**Table (6): Details about Monthly Running Cost per Day at Heating Mode**

| A/C System | Outdoor Energy Consumption 3Ø / (kW) | Indoor Energy Consumption 1Ø / (kW) | Electricity Tariff ($/kW Hr.) | | Running Cost ($) |
|---|---|---|---|---|---|
| | | | 3Ø | 1Ø | |
| VRF | 265.05 kW | 5.2 kW | 0.041 | 0.025 | 4948.680 $ |
| FCUs | 583.63 kW | 6.4 kW | 0.041 | 0.025 | 10839.96 $ |
| PRTU | 403.00kW | ---- | 0.041 | 0.025 | 7435.350 $ |

**Table (7): Details about Maintenance Cost per One Year**

| A/C System | EQP ($) | Maintenance Cost ($) |
|---|---|---|
| VRF | 46,800 | 1,560 |
| FCUs | 92,142 | 3,071 |
| PRTU | 25,500 | 850 |