# Value Engineering in HVAC Systems

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## Abstract

Value Engineering (VE) is the systematic approach to improving the value of a product or service. In this study, the authors applied the principles of VE during the design stage of Heating, Ventilating, and Air-Conditioning (HVAC) systems using the VE job plan. The objective was to select the appropriate HVAC equipment for a project to satisfy the basic and needed secondary functions at a minimum cost. Different combinations of various HVAC equipment were generated and evaluated in terms of initial and operating costs. The type of HVAC system used is the Direct-Expansion (DX) Variable Refrigerant Flow (VRF) system. These are one (1) AHU, 5 Ceiling Concealed with 2 Pre-Coolers, 6 Floor Standing with 7 Energy Recovery Ventilators (ERV), 5 Ceiling Concealed with 7 ERVs, and 8 Ceiling Cassette with 7 ERVs, to meet the required thermodynamic properties of the room. From the formulated options, it showed that the 6 Floor standing ACs with 7 ERVs at ₱69,665,391 would meet the said functions and deliver it at a minimum cost for an equipment life span of 10 years. However, even though the operating cost were considered during the selection of the equipment. The options presented should include maintenance, duct initial costs, and varying energy consumption.

## Keywords
Value Engineering, HVAC Systems, Cost Analysis, Value Engineering Job Plan

## 1. Introduction
The Heating, Ventilating and Airconditioning (HVAC) system of a typical building office accounts for approximately more than 40% of the building's total energy consumption (Alptekin, 2019). Hence, highly efficient and low operating cost HVAC equipment are highly sought in residential and commercial infrastructures. Different HVAC manufacturers were relentlessly seeking a new technology that would offer the best comfort cooling and highly efficient low operating cost equipment. This is usually done through in-depth research and development in the field of HVAC. However, another way of achieving this is through conducting value engineering (VE) during the design stage of the HVAC system. A VE should be conducted before committing funds approval of systems, services, or design (Atabay & Galipogullari, 2013).

In this study, the authors aimed to meet the HVAC requirements of the project by improving the function and reducing the operating and initial cost of the air-conditioning (AC) system using VE. VE is a systematic method of improving the value of a product or service that the project produces (Roseke, 2020). Numerous articles and researches about value engineering and analysis were published. Fermilab, (2008) presented studies regarding the value engineering techniques in the HVAC systems. Brahmane et al., (2020) showed how the implementation of value engineering in construction could be utilized to reduce the time of the project. In his study, he presented the steps on how value engineering can be done to achieve a lesser duration of the completion of projects. This study explained how the principles of the VE could be applied in construction projects. Therefore, the utilization of VE in an engineering project could potentially reduce the overall cost without sacrificing the functions.

To ensure that the needed cost and importance of the clients on an AC system would be provided. The different value engineering techniques would be applied during the design stage and up to the equipment selection for the AC system of the project. The design and materials used to create the AC equipment such as the evaporator, condenser, compressor, and expansion valve and the application of the VE regarding the construction and installation of the AC system are not within the scope of this paper. Thus, this paper proposed steps and only discussed the VE in the equipment selection by evaluating the initial and operating cost of the AC equipment such as the air handling units

(AHU), ceiling cassette, ceiling concealed, floor standing, pre-coolers, and energy recovery ventilators (ERVs). Furthermore, this study evaluated what must be the appropriate HVAC equipment for the selected project. However, even though the initial and annual operating costs were analyzed, the cost to maintain the selected equipment, its salvage value, duct installation costs and its deteriorating efficiency as time proceeds are not within the scope of the study.

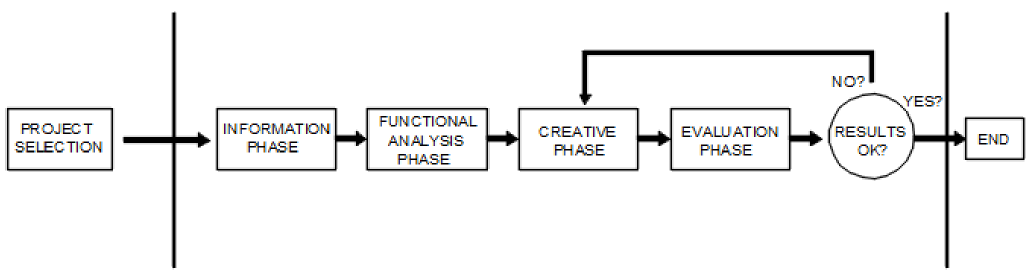
The rest of the sections are presented as follows. A further presentation of the methods and techniques is found in section 2. Section 3 provided the detailed initial observation, characterization, and application. Section 4 presented the conclusions, contributions, and relevance of the study in VE. It also provided directions and recommendations for future work.

## 2. Methodology

This section provided the steps and procedures on how the VE would be conducted on designing an HVAC system. Under this are the sub-sections of the VE Job Plan from the information phase up to the development phase.

### 2.1 VE Job Plan

To identify the functions and the essence of the project, the authors would use the VE job plan. The Job Plan is a systematic approach on how the VE would proceed up to its implementation. According to Roseke, (2020) there are six (6) phases of the VE methodology. These are the (1) Information, (2) Function Analysis, (3) Creative, (4) Evaluation, (5) Development, and (6) Presentation.




Nevertheless, the authors would only cover items 1 to 5 of the VE methodology in this paper, as illustrated from Figure 1: Flow Chart Methodology. However, before moving on to the information phase, the project selection would proceed first. The application of the VE on the design of the HVAC system is the reception area located at the ground floor level of a high-rise condo tower. The space that required an HVAC design is the lobbies shown in Figure 2: Selected Project of Application.

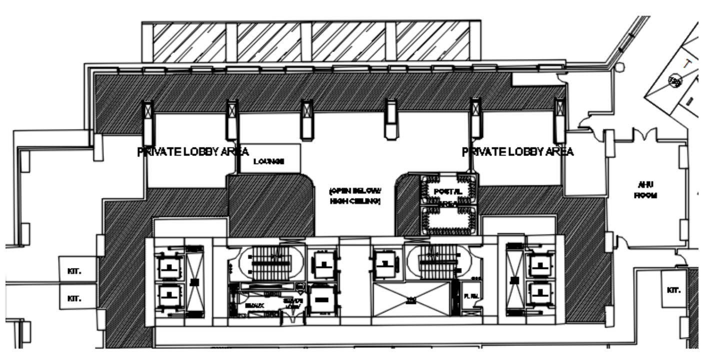



Figure 2: Selected Project of Application (Sample Reception Area of The Project)

After identifying the application of the VE for the HVAC design of the project, the next step would be the information phase; this phase gathers all the required data in conducting the VE.

### 2.1.1 Information Phase

For this study, the client would like to cool the space of the said project that would maximize the cooling and minimize the overall cost. To give a further understanding of how it would comply with the client's requirements. The following information was presented from Table-1 up to Table-3A in the appendix. These are the project information with the required thermodynamic properties, type of HVAC system used, equipment used in the HVAC system, and its associated properties and costs. For the summary of the project information, see Table-1: Project Data.

Table-1: Project Data

| List | Description | List | Description |
|---|---|---|---|
| **Space Profile** | | **Calculated Condition (With Outdoor Air)** | |
| Floor Area | 428 square meters | Supply Air Temperature | 12.8° C |
| Ceiling Height | 3 meters | Total Coil Load | 143 kW |
| Number of Occupants | 50 | Sensible Coil Load | 85.5 kW |
| Total Wall Area | 489 square meters | Supply Air Flow Rate | 4992 LPS |
| Total Window Area | 75 square meters | Outdoor Air Flow Rate | 1751 LPS |
| Building Weight | 341.8 kg/m$^2$ | Bypass Factor | 0.10 |
| Occupant Activity | Seated at Rest | Resulting Relative Humidity | 49 % |
| Soil Conductivity | 1.385 W/(m-k) | Room Thermostat setpoints (occupied) | 23° C |
| **Outdoor Air Properties** | | Room Thermostat setpoints (unoccupied) | 25° C |
| Dry Bulb Temperature | 35° C | Resulting Humidity Ratio | 9.72 g/kg |
| Wet Bulb Temperature | 27.2° C | Resulting Enthalpy | 45 kJ/Kg |
| Relative Humidity | 55.14% | **Calculated Condition (Without Outdoor Air)** | |
| Humidity Ratio | 19.74 g/kg | Supply Air Temperature | 12.8° C |
| Enthalpy | 85.86 KJ/Kg | Total Coil Load | 63.6 kW |
| Dew Point Temperature | 26.65° C | Sensible Coil Load | 61.7 kW |
| | | Supply Air Flow Rate | 4992 LPS |
| | | Bypass Factor | .10 |
| | | Resulting Relative Humidity | 48 % |
| | | Room Thermostat setpoints (occupied) | 23° C |
| | | Room Thermostat setpoints (unoccupied) | 25° C |
| | | Resulting Humidity Ratio | 16.97 g/kg |
| | | Resulting Enthalpy | 68.36 kJ/kG |

The left side of Table-1 presented lists of information about the project. At the same time, the right side of Table-1 presented the specific description of the lists. The Project profiles were gathered by quantifying and measuring lists found in the space profile section of Table-1; the outdoor air properties were based on the ASHRAE handbook 2001, and the HVAC consultants provided the calculated condition of the space. Where kJ is kilojoule, LPS is liters per second, °C is degrees Celsius, kW is kilowatts and W is watts, m-k is meter-kelvin, and Kg is kilogram.

The next step that would be gathered is the type of HVAC system that would be used. For this study, the type of system that would be used is the Direct-expansion (DX) Variable Refrigerant Flow (VRF) system. The direct expansion air-conditioning (AC) system uses refrigerant to absorb and reject the heat through evaporator and condenser through vapor expansion (Dunkin, 2016). The different types of DX AC used in the HVAC systems are presented in Table-1A: HVAC Equipment Data in the Appendix.

Table-1A presents the typical range of capacities for VRF indoor units. This data applies to the different HVAC DX VRF equipment types such as the AHU, ceiling cassette, ceiling concealed, floor standing, pre-coolers, and ERVs. The total cooling capacity and sensible column are the required loads of the project. The supply air column presents the air-flow rate; the external static pressure is the duct pressure; the air entering temperature is the resulting temperature for a cooling capacity; the fan motor presents the electrical energy required and the electrical characteristics are the required volts, phase, and hertz of the equipment. It could also be observed from the table that there are units that were abbreviated. TR stands for Tons of Ref. Since the only AC indoor unit that requires duct installation is the ceiling concealed AC indoor units, then the external static pressure column only applies to ceiling concealed ACs.

The corresponding specifications for the AC outdoor units are shown in Table-2A: Data for AC Outdoor Unit in the appendix. Table-2A in the appendix presents the capacities of the AC outdoor units. Those are the typical range of capacities for AC outdoor units available in the market. To have an actual representation of the AC indoor and outdoor units. Their following configurations are shown in Table-3A: Configurations for AC Indoor and Outdoor Units in the appendix.

The different types of configurations are presented in Table-3A in the appendix. It also showed how the equipment is installed and the different parts associated with each AC indoor and outdoor unit. Table-3A provided the needed information to differentiate the differences on each type of AC used because each of it has a different application based on the compatibility of the space that would be served and customer requirements.

After gathering the configurations for both the indoor and outdoor units, the following data gathered are the equivalent initial and operating cost for the AC units. The initial cost was based on the typical range of costs that the market currently has while the operating cost for the AC units was calculated based on 24hrs-7days per week operating period, which is kW-hr and then multiplied by the equivalent energy consumption rating which is in Peso per kW-hr. The rate of electrical consumption was gathered from the official site of Meralco, Philippines. Since the rate varies depending on the amount of power consumed, the operation cost would be calculated in the evaluation phase to produce more accurate data. The product of the power consumption and the power rating was converted into a monthly operating cost.

Since the required data have been gathered, it would now be much easier to proceed to the succeeding phases of the VE Job Plan. After the information phase, the second phase of the VE Job Plan is the Functional Analysis Phase.

### 2.1.2 Functional Analysis Phase
The Functional Analysis Phase covered the needed function of the project. In this phase, an HVAC system's different types of functions would be determined, elaborated, and classified.

The purpose of the project must be determined. The basic function of an HVAC system is to provide room conditions or indoor air quality (IAQ) conducive to human comfort through humidification or dehumidification, heating, cooling, filtration, air circulation and fresh air supply (Hyndman, 2020). Since the HVAC system are the major energy consumers in residential and commercial structures (Alptekin, 2019). Therefore, the project's objectives are to deliver an IAQ to the room with a minimum overall cost. After the basic function, the next that would be determined is the secondary function. These are the required, aesthetic, unwanted, and sell functions. Required secondary functions are functions that are necessary to support the basic functions. The aesthetic functions are functions that describe the esteem value of the product, service, or project. Functions that adversely affect the system are unwanted functions or functions that the customers do not need. Esteem value and basic function link with the sell function. The better it performed its basic functions, the higher its sell function. After this, formulation of the alternative options would follow.

### 2.1.3 Creative Phase
After the Functional Analysis Phase, the Creative Phase would proceed. This phase would cover the generation of alternative ways of meeting the requirements and other options that would perform the desired function. Currently, there are different types of equipment used in the HVAC system. Each type of equipment presented in Table-1A in the appendix has its advantages and disadvantages. Specifically in terms of installation, capacity, and appearance. The type of equipment that would be selected should adhere to the calculated thermodynamic properties and air requirements of the room presented in Table-1. For example, the total capacity of the selected equipment should have a total cooling capacity of 63.6 kW with a sensible load capacity of 61.7 kW, delivering an amount of 4992 LPS of recirculated air at 11 to 12 degrees Celsius. If the equipment would supply fresh air within the room, then the required flowrate for the amount of fresh air using the Table-1 would be 1751 LPS with a total cooling capacity of 79.4 kW and a sensible cooling capacity of 23.8 kW capable of supplying the fresh air within 23 to 25 degrees Celsius, of meeting the desired room conditions. This could be the combination of any equipment presented in Table-1A. In the

appendix, as long it adheres to the requirements specified in Table-1. For example, it could be 1 AHU or a combination of multiple AC indoor units with either Pre-cooler or ERV for fresh air supply. When the options have been elaborated, the next step would be the evaluation phase.

### 2.1.4 Evaluation Phase

The Evaluation phase would present the weights of the alternatives and choose which ideas have the potential to improve the project generated on the Creative Phase. The alternatives were assessed on how well they meet the required functions and the parameters specified in the Table-1. The alternatives are measured in terms of the initial and annual operating cost analysis of the chosen alternatives. The idea that would be chosen would be the most practical idea that was generated in the creative phase. Since the authors were only looking for an alternative that would produce the minimum operating cost, Choosing by Advantages is the criteria used to assess the appropriate alternative. The assessment included the price and the operation cost of the chosen equipment. This phase evaluated which equipment must be chosen when the life span extends to 10 years. It is given that the rate of electricity increases as time proceeds. So, for the equipment's operating cost, the formula that would be used is the formula presented by Goodwin (2018). Whereas the Future Price equals the current price multiplied by the sum of one and the inflation rate at a specific year. See equation 1 for mathematical expression.

(1) Future Price at Year n= Current Price (1 + Inflation Rate at Year 1) (1 + Inflation Rate at Year 2) (1 + Inflation Rate at Year n)

(2) Overall Cost at Year n= Initial Cost + $\sum$Operating Cost at Year n

Where the rate of inflation that would be used is the average amount of inflation rate in the last five years presented by O'Neill, (2021), which is 2.75%, would be used up to year 10. Lastly, when the different alternatives have been evaluated. It would proceed to the Development Phase.

### 2.1.5 Development Phase

This phase develops the selected options from the evaluation phase. This phase proposed the layouts of the different options. Such as the actual locations of the AC indoor and outdoor equipment, sizes of ducts, if any, and the location of fresh air intake and room air exhaust.

## 3. Results

This section presented the results of the VE Job Plan phases presented in section 2. The classification of functions are found in section 3.1, the results of the creative phase could be seen in section 3.2, the selected options that were generated in the creative phase are found in section 3.3, and the results of the development phase are found in section 3.4.

### 3.1 Functional Analysis Phase

The generation and classification of the secondary function for an HVAC system are presented in Table-2: Classification of Secondary Functions. These functions are classified into required functions, aesthetic functions, unwanted functions, and sell functions discussed in the previous section.

Table-2: Classification of Secondary Functions

| REQUIRED | AESTHETIC | UNWANTED | SELL |
|---|---|---|---|
| Cool Air<br>Circulate Air<br>Supply Fresh-Air | Reduce System Noise<br>Remove Dusts<br>Prevent Spread of Diseases<br>Deodorize Room<br>Remove Air Pollutants | High Operating Cost<br>Low Life Span<br>Complex Installation<br>High Operating Cost | Supply Fresh Air<br>Low Operating Cost<br>Simplified Installation<br>Low Cost of Parts |

Referring to Table-2, it is now clear that the priority when choosing the appropriate equipment for the said project should be capable of cooling the air, circulating the air, and supplying the fresh air. If all the available equipment in the HVAC do have these required functions, then the question would be how well they could perform these functions. Which enters the sell function, it is unusual for ac equipment to acquire both cooling the space and at the same time supplying fresh air. That is why there is a variation of equipment in the HVAC system. If the equipment would acquire cooling and provide fresh air, then its selling function would be sought. Other factors that affect the sell function of HVAC equipment are reduced operation cost, low cost of the parts, and simplified installation. Otherwise, if the said sell functions have the opposite functions, it is classified as an unwanted function. Although the required functions are the top priorities when choosing the appropriate equipment, other benefits associated with the required functions should also be considered. The ability of the HVAC equipment to have a reduced system noise, remove dust, prevent the spread of contagious diseases, deodorize the room and remove air pollutants must also be observed.

### 3.2 Creative Phase

Since all types of HVAC equipment could perform the basic and secondary functions, the question is how efficient the equipment is in performing the needed room condition of the project presented in Table-1. To summarize, the different formulated options were presented in Table-3: Proposed Options for The Project.

**Table-3: Proposed Options for The Project**

| Option | Fresh Air | Quantity | Specifications | For Cooling | Quantity | Specifications |
|---|---|---|---|---|---|---|
| 1 | AHU | 1 | See Table-1A Row 6 | Same equipment | - | Same equipment |
| 2 | Pre-Cooler | 3 | See Table-1A Row 4 | Ceiling Concealed | 5 | See Table-1A Row 3 |
| 3 | ERV | 7 | See Table-1A Row 5 | Floor Standing | 6 | See Table-1A Row 2 |
| 4 | ERV | 7 | | Ceiling Concealed | 5 | See Table-1A Row 3 |
| 5 | ERV | 7 | | Ceiling Cassette | 8 | See Table-1A Row 1 |

**Corresponding Capacities of Outdoor Units of The Formulated Options**

| Option | Fresh Air | Cooling |
|---|---|---|
| 1 | See Table-2A Row 5 | See Same equipment |
| 2 | See Table-2A Row 2 | See Table-2A Row 3 |
| 3 | See Table-2A Row 1 | See Table-2A Row 4 |
| 4 | | See Table-2A Row 3 |
| 5 | | See Table-2A Row 3 |

The first option would be one (1) AHU for performing all the needed secondary functions; the second option would be a combination of five (5) ceiling concealed AC indoor units for cool air recirculation and three (3) Pre-coolers for the fresh air supply; the third option would be seven (7) floor standing and 7 ERV; fourth would be a combination of 5 ceiling concealed and 7 ERV, a fifth would be the combination of 8 ceiling cassette and 7 ERV and lastly would be a combination of wall-mounted and 7 ERVs. The following phase evaluates the following options presented in Table-3. At the same time, the Development Phase presents the specifications of the selected options.

## 3.3 EVALUATION PHASE

The basis of the selection of the options would be the system that would be practical, meet the required functions and provide the lowest cost starting from the initial up to the end of life of the equipment considering the inflation rate and operating and initial cost in 10 years at full load capacity (equipment are running at maximum power). By referring to Table-1A, 2A, 3A, and 5A the following costs were evaluated. Table-4 shows the Annual Operating Cost at Full Load Capacity in 10 Years.

Table-4: Annual Operating Cost of 5 Options

| Options | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 5,590,378 | 5,902,077 | 6,231,155 | 6,578,580 | 6,945,377 | 7,332,626 | 7,741,465 | 8,173,100 | 8,628,802 | 9,109,911 |
| 2 | 5,831,245 | 6,156,373 | 6,499,629 | 6,862,024 | 7,244,625 | 7,648,558 | 8,075,013 | 8,525,246 | 9,000,581 | 9,502,420 |
| 3 | 5,182,696 | 5,471,663 | 5,776,743 | 6,098,832 | 6,438,880 | 6,797,888 | 7,176,913 | 7,577,071 | 7,999,540 | 8,445,564 |
| 4 | 5,945,168 | 6,276,648 | 6,626,611 | 6,996,086 | 7,386,161 | 7,797,986 | 8,232,772 | 8,691,801 | 9,176,423 | 9,688,066 |
| 5 | 6,072,111 | 6,410,669 | 6,768,104 | 7,145,468 | 7,543,873 | 7,964,491 | 8,408,561 | 8,877,391 | 9,372,361 | 9,894,929 |

Table-4 shows the five options generated from the creative phase's annual operating costs (at full load capacity). It showed that among the five options, option 3 yielded the lowest annual operating cost. And including the initial cost, options 1, 2, 3, 4 and 5 summed up an overall cost of ₱73,733,472, ₱77,090,515, ₱69,665,391, ₱79,853,922, ₱82,403,758 respectively. The results only indicated that the appropriate combination of equipment to yield the lowest overall cost is Option 3. However, the first three options that yielded the lowest cost would still be considered in the development phase to further assess the options in terms of costs and the actual locations of the equipment.

### 3.4 Development Phase

This phase further evaluates the selected options on how these options would appear when reflected on the project plan. Figure 3 presents the equipment symbols found in Figures 4, 5, and 6. Figure 4 showed the actual locations of the ducts, AHU, and outdoor units for option 1; Figure 5 showed the actual location of the four ceiling concealed and three precoolers with their corresponding outdoor unit; Figure 6 showed the actual location of six floor standing with 7 ERVS and their corresponding outdoor units.

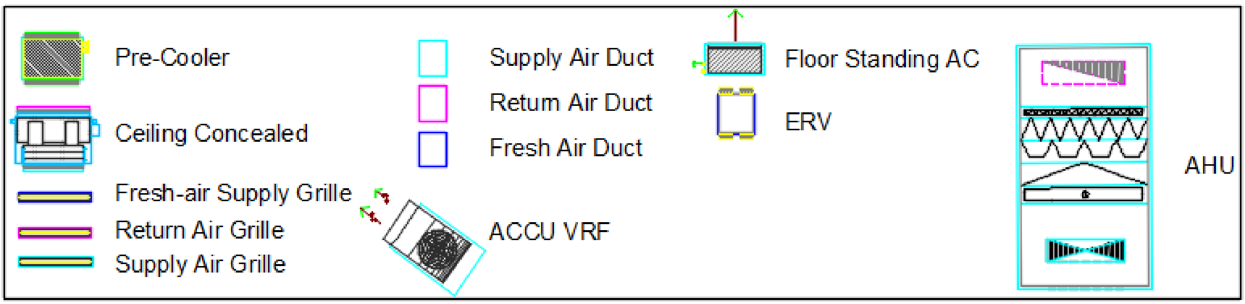



Figure 3. Equipment Symbols

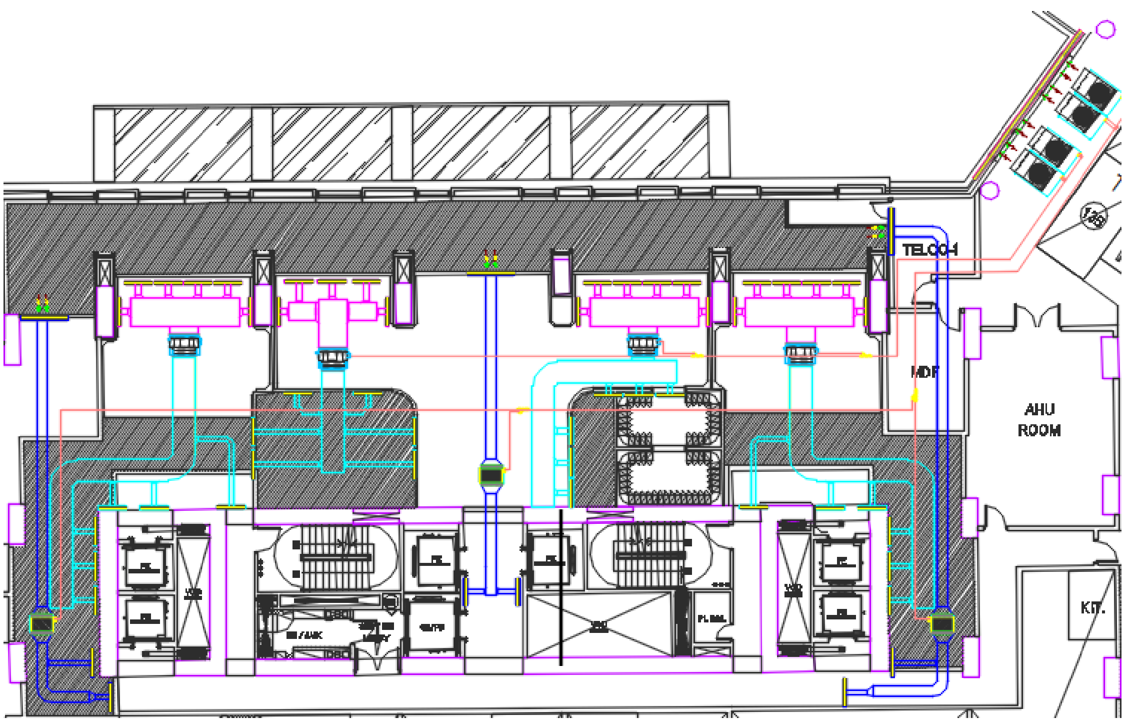



Figure 4. Layout for Option 1 at Mezzanine of Ground Floor

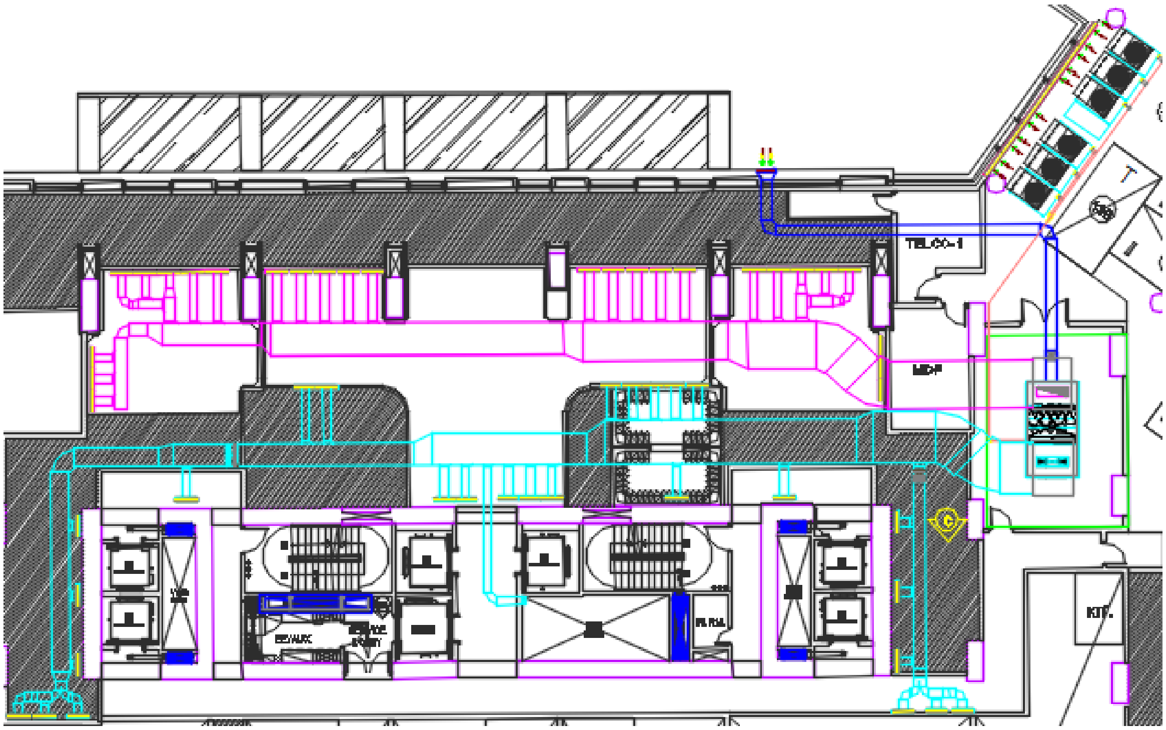


Figure 5. Layout for Option 2 at Mezzanine of Ground Floor

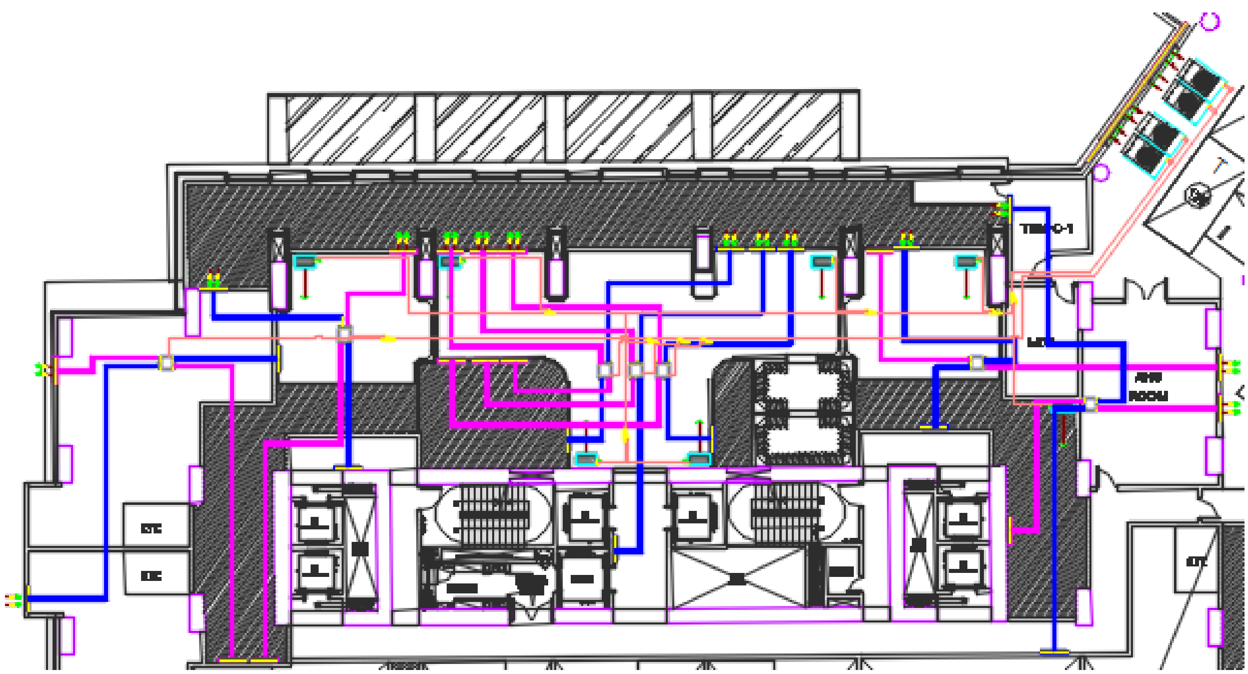


Figure-6. Layout for Option 3 at Mezzanine of Ground Floor

The options that were formulated and evaluated yielded that option 3 was also the best option in terms of space requirement, installation, and maintenance, for it requires lesser duct runs than other options without considering the duct and grille dimensions.

## 4. Conclusions

Using VE, the required functions were analyzed in the VE job plan. From the study results, option three was deemed the best alternative for the project to meet the basic and secondary functions and deliver it at a minimum cost for ten years. This is because of the lower energy consumption of the ERVs and Floor Standing ACs compared to other equipment types, which had a major impact on the calculation of the overall cost. In addition, there are cases where other units are best for a certain project, and that is why options must be generated before installation using VE. VE selected the best possible alternatives to perform the basic functions at a lower cost. It was also deemed that using VE in the design stage of the HVAC system could reduce the energy consumption of infrastructure through appropriate equipment selection conducive to the project's functional requirements.

Utilizing VE in the cost and functional analysis of the required HVAC system provided the stakeholders with the type of AC indoor units to choose if the priority only considers the minimum overall cost. Fermilab (2008) also conducted a similar study where he proposed a list of VE items that could have a huge potential for cost reductions. Such as the relocation and configuration of the chilled water plant, HVAC systems, and alternative materials for the pipes. Different researches do also apply VE during the design and construction stage of engineering projects. At the same time, detailed calculations were proposed and evaluated to reduce costs. However, this study selected the appropriate type of equipment that would have the minimum initial and operating cost for the project.

The methodologies presented in this paper could also be used in other engineering projects where the initial and operating costs must be minimized. However, even though this study conducted the VE job plan in the HVAC systems to determine the appropriate HVAC equipment for the said project; it must be taken into consideration that the equipment and duct installation, and annual maintenance cost of the equipment should be included in the study to have a much more accurate result. Additionally, the values of the initial costs of the equipment were based on the average market value. Furthermore, this study only considered that the equipment selected is always running at a full load capacity. Thus, it is recommended that the duct installation cost, including its dimensions, annual maintenance cost, the varying loads of the project, should be included for further studies.

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## Biographies

**Px** is Registered Mechanical Engineer and Registered Master Plumber in the Philippines. He is a graduate student of Master of Science in Engineering Management at Mapua University, Manila, Philippines and earned his Bachelor of Science in Mechanical Engineering at Pamantasan ng Lungsod ng Maynila, Manila, Philippines. He only started his professional career in 2019 as a Mechanical Design Engineer. His interests are engineering and management.

**Maria Victorina D. Rada** has 20 years of experience in various fields of Industrial Engineering and Research with areas concerning Continuous Improvement, Engineering Statistics, Work Design, Measurement and Improvement, Impact Assessments, Management and Financial Planning. 11 years working experience in SAP solutions covering from planning and design up to implementation and support.

**Ma. Janice J. Gumasing** is a Professor of the School of Industrial Engineering and Engineering Management at Mapua University, Philippines. She has earned her B.S. degree in Industrial Engineering and a Master of Engineering degree from Mapua University. She is a Professional Industrial Engineer (PIE) with over 15 years of experience. She is also a professional consultant of Kaizen Management Systems, Inc. She has taught courses in Ergonomics and Human Factors, Cognitive Engineering, Methods Engineering, Occupational Safety and Health, and Lean Manufacturing.

# Appendix

Table-1A: HVAC Equipment Data

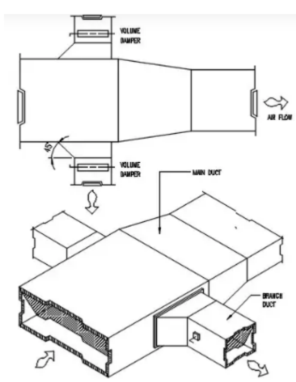
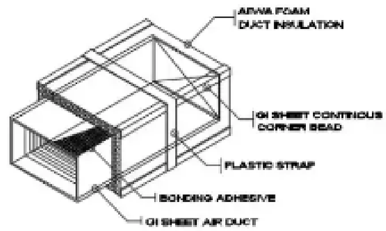
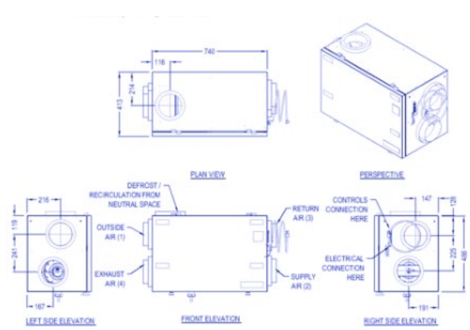
| Row | **Typical Range of Capacities for VRF-Indoor Units (Ceiling Cassette, Ceiling Concealed and Floor Standing** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total Cooling Capacity | | Sensible Cooling | Supply Air | External Static Pressure | Entering Air Temperature | | Fan Motor | Electrical Characteristics | | |
| | (TR) | (Watts) | (Watts) | (LPS) | (Pascal) | (°C) DB | (°C) WB | (Watts) | (Volts) | (Phase) | (Hertz) |
| 1 | 3.19 | 11,200 | 8,380 | 633 | 200 | 23.89 | 16.95 | 580 | 230 | 1 | 60 |
| 2 | 6.37 | 22,400 | 16,710 | 966 | 200 | 23.89 | 16.95 | 1140 | 230 | 3 | 60 |
| 3 | 7.96 | 28,000 | 20,940 | 1200 | 200 | 23.89 | 16.95 | 1410 | 230 | 3 | 60 |
| | **VRF Pre-Cooler** | | | | | | | | | | |
| 4 | 7.96 | 28,000 | 16,900 | 583 | 190 | 33 | 28 | 500 | 380 | 3 | 60 |
| | **Energy Recovery Ventilators (ERV)** | | | | | | | | | | |
| 5 | 3.07 | 10,810 | 6,486 | 277 | 135 | 33 | 28 | 968 | 240 | 1 | 60 |
| | **Air Handling Unit (AHU)** | | | | | | | | | | |
| 6 | 43.6 | 153,600 | 125,400 | 6742 | 500 | 27 | 19.52 | 8,700 | 400 | 3 | 60 |

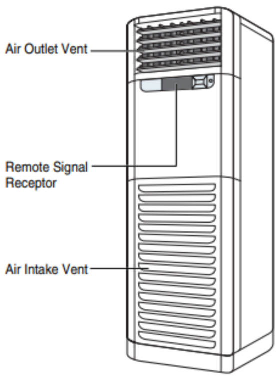
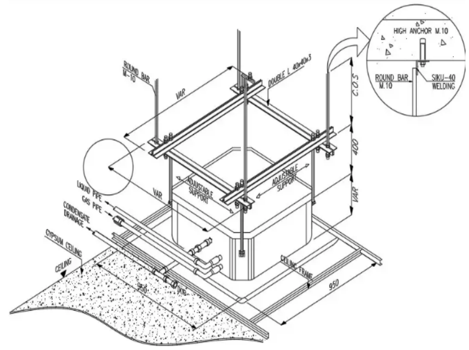
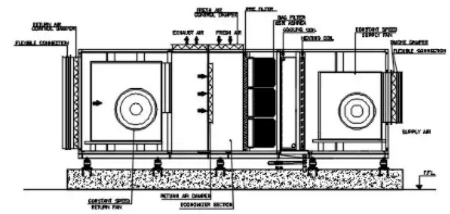
Table-2A: Data for AC Outdoor Units

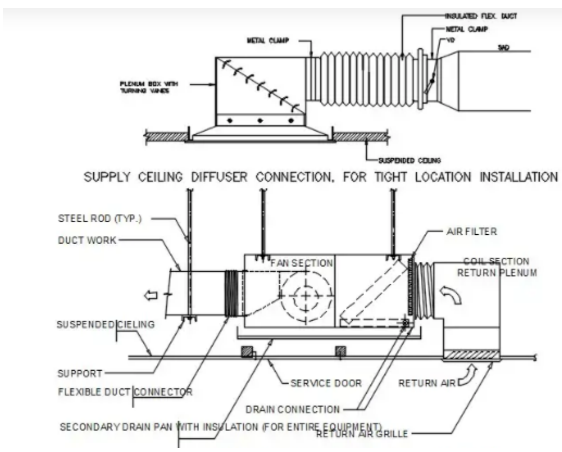
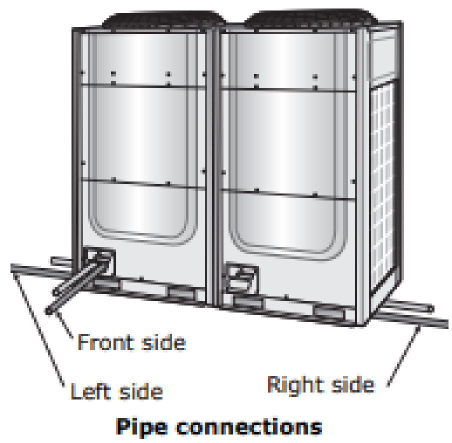
| Row | Cooling Capacity | EER | Total Power Input | Compressor Power Output | Fan Motor | Electrical Characteristics | | | Weight | Dimensions in mm | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (TR) | (%) | (KW) | (KW) | (KW) | Volts | Phase | Hertz | (kg) | H | W | D |
| 1 | 22.75 | 10.00 | 20.8 | 19.75 | .92 x 2 | 400 | 3 | 60 | 486 | 1650 | 2440 | 740 |
| 2 | 24.12 | 10.00 | 21.4 | 19.18 | .92 x 3 | 400 | 3 | 60 | 625 | 1650 | 3060 | 740 |
| 3 | 32.28 | 10.00 | 28.9 | 28.28 | .92 x 3 | 400 | 3 | 60 | 638 | 1650 | 3060 | 740 |
| 4 | 38.40 | 10.00 | 40.66 | 32.4 | .92 x 3 | 400 | 3 | 60 | 780 | 1650 | 3660 | 740 |
| 5 | 44.94 | 10.00 | 60 | 40 | .92 x 5 | 400 | 3 | 60 | 830 | 1650 | 4720 | 740 |

Table-3A: Configurations for AC Indoor and Outdoor Units

**AC Indoor Units**

| Duct Take-off Detail | Duct Installation Details | ERV Details |
|---|---|---|
|  |  |  |
| Reference: Cadbull (1) | Reference: Cadbull (2) | Reference: microsite.caddetails |

| Floor Standing Details | Ceiling Cassette Details | AHU Details |
|---|---|---|
|   Reference: LG Manual |  Reference: Cadbull (4) |  Reference: Cadbull (3) |

| Ceiling Concealed/ Pre-cooler Details | ACCU VRF DETAILS (UPBLAST) |
|---|---|
|   Reference: Cadbull (5) |   Reference: Trane |