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Design and Engineering Economic Analysis of a Variable Refrigerant Flow (VRF) and Mini-Split Air Conditioning System

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Authors' contributions

This work was carried out in collaboration among all authors. Author ATL designed the study, performed the statistical analysis, develop procedure and wrote the first draft of the manuscript. Authors CNN and AIO carried out the heat load analysis. Authors SOG and MAS carried out the energy analysis of the project. Author KAA did the economic analysis. Author CNN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Design and Engineering Economic Analysis of two widely used Air-Conditioning (AC) systems, Mini-Split and Variable Refrigerant Flow (VRF), in the new Engineering Complex Building under the same indoor and outdoor conditions for an entire year is carried out by using Carrier Hourly Analysis Program software for cooling load estimation, and the Net Present Worth Analysis for Economic Analysis of both systems. Both systems are direct expansion air conditioning systems; hence the cooling load estimation was done using the ASHRAE transfer function method embedded within the Carrier software. Equipment to be used in analysis were selected from the Toshiba selection catalogues (Mini Split system), while that for the VRF system was selected using Toshiba simulation

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software. The annual energy analysis of both systems indicated that the VRF system will require more energy to run on an annual basis than the Mini Split system. However, the analysis was carried out without considering the part load potential energy savings of the VRF system. Net Present Worth Analysis carried out also favoured the Mini Split system in terms of Net Present Value of the systems. Based on the Engineering Economic Analysis carried out on the two systems, the overall Net Present Value for the VRF system is ₦77,891,808.66, while that of the Mini-Split system is ₦46,641,828.74. This result shows that the VRF system has a higher cost implication than the Mini-Split system. Hence, in terms of cost, the Mini-Split system is a more viable option.

Keywords: Comfort; indoor climate; HVAC system; Variable Refrigerant Flow (VRF); multi-split.

1. INTRODUCTION

In the contemporary context, lots of factors are put into consideration when designing and selecting a viable HVAC system for various applications. Designers aim to come up with the most efficient air-conditioning system which will be appreciated from the Architectural perspective, energy consumption angle, installation aspect, indoor air quality, thermal comfort and majorly from the aspect of cost implication. Literatures abound on the comparison of performance characteristics of different types of Air-Conditioning systems [1-4]. Aynur et al. posited in their work that VRF air conditioner is noted for its high energy saving potential and is expected to conserve more energy than other conventional air conditioning systems [1-2]. Similarly, in the works of Zhou et al. [4], based on the generic dynamic building energy simulation environment, Energy Plus, a new VRF module was developed and the energy usage of the VRF system was investigated. They compared the energy consumption of the VRF system with that of two conventional air-conditioning systems, namely, variable air volume (VAV) system as well as fan-coil plus fresh air (FPFA) system. Simulation results showed that the energy-saving potentials of the VRF system were expected to achieve 22.2% and 11.7%, compared with the VAV system and the FPFA system, respectively. As such, this paper focuses on establishing a comparative analysis between a Variable Refrigerant Flow and a Mini Split air conditioning system from the perspective of design as well as cost.

A new methodology was developed for the evaluation, comparison, ranking and optimum selection of an air conditioning system from different design options. The proposed methodology is based on Multi Attribute Decision Making (MADM) approach [5]. Pertinent attributes which describe the whole air conditioning system are identified in an exhaustive way. Investigation of the behaviour of HVAC system at “Vasile Alecsandri” National Theatre of Jassy, for different external conditions was carried out [6]. A 2D modelling of the building was done using ANSYSFluent software. The functionality of the HVAC system for winter and summer seasons was analysed for the scenarios when the entire spectacle hall was occupied taking into account the external conditions of Jassy and the indoor conditions of the theatre. The results established that the HVAC system is providing adequate conditions for both studied seasons.

Barot [7] reiterated the objectives of the HVAC system design as to providing thermal comfort, good indoor quality and energy conservation. It was noted that for some special HVAC projects, due to the specific design and control of the HVAC system, conventional settings may not be necessarily energy-efficient in daily operation. The HVAC system design and equipment selection for a commercial building (376 TR) is studied. The results of the study are efficient design of HVAC systems with minimum energy consumption and equipment selection based on operating and life cycle cost analysis.

2. SIMPLE INTRODUCTION OF BOTH SYSTEMS

2.1 Variable Refrigerant Flow (VRF) System

A VRF system is an air conditioning system comprising an outdoor unit containing one or more variable speed compressors (inverter or stepped), heat exchangers, accumulator, receiver, expansion device and controls, linked via a single flow and return refrigerant pipe-work system to a number of indoor units containing a fan, heat exchanger, expansion device and controls. Each system contains at least two indoor units (a system can extend to 64 indoor units) and one outdoor unit and a remote or central controller. All the indoor and outdoor units are connected via an electronic communications system and can be controlled by sophisticated software-based systems housed in the outdoor unit. The indoor units are controlled either individually or in zones with a remote or central controller which functions as a combination time clock, fan speed selector, diagnostic panel, air conditioning mode selector and temperature display unit".

It's noted that Variable refrigerant flow (VRF) systems have become popular in many countries since its introduction about three decades ago in Japan. However, they are relatively unknown in the United States. In Japan, VRF systems are used in approximately 50% of medium-sized commercial buildings (up to 70,000 ft^2 [6500 m^2]) and one-third of large commercial buildings (more than 70,000 ft^2 [6500 m^2]) [8-9].

2.2 Mini Split Air-conditioning System

A conventional mini split air conditioning system comprises of an outdoor condensing unit containing a constant speed compressor, a condenser, a receiver, a fan, and controls linked via a liquid and gas refrigerant pipe-work to the indoor unit containing the fan, the cooling coil, the thermostatic expansion valve and controls.

3. COMPARISON OF THE TWO ALTERNATE SYSTEMS

Analyses were carried out to compare the two air conditioning systems using the Olusegun Obasanjo Engineering Complex in Ibogun campus in Ogun state, Nigeria on Longitude 3.4728610°E and Latitude 6.7003410°N at about 39 meters above sea level, 94% relative humidity, and a dry season design temperature of 35°C and a rainy season design temperature of 21°C and relative humidity of about 50.2%. The Electrical Engineering Building was taken as a case study and comprises of two major divisions. The analyses comprised of detailed design analysis and Engineering Economic Analysis of both systems.

3.1 Design Analysis

Both systems are direct expansion systems, hence the analysis of the designs followed the same trend. The procedures for accomplishing the design analysis of the two systems included:

- Building survey: Architectural drawings and field sketches were taken for the building survey and the following physical aspects were considered; Building Orientation, Compass Points, Nearby permanent structures, reflective surfaces, use of spaces, physical dimensions of the spaces, construction materials (for walls, windows, roof, doors & partitions), surrounding conditions, occupancy levels and activities, lighting, appliances and thermal storage.
- Location of Equipment and Services
- Air Conditioning Load Estimate: The air conditioning load was estimated to provide the basis for selecting the most suitable air conditioning equipment for offsetting the estimated load. Carrier Hourly Analysis Program was used for estimating the air conditioning loads for the various spaces in the building. The software utilizes the ASHRAE Transfer Function Method (TFM) of cooling load calculation for estimating the heat gains from walls and roofs, windows, doors, floors, lighting, equipment, people and infiltration sources [10-11].

With the Transfer Function Method, a general mathematical relationship which defines load as a function of heat gain and time is determined for each heat gain component in a room [12]. This relationship is then used to quickly calculate loads for each hour. The mathematical relationship is expressed in what is called a Room Transfer Function Equation which looks like this:

$$Q_o = v_o q_o + v_1 q_1 + v_2 q_2 - w_1 Q_1 - w_2 Q_2$$

In this equation:

- Q_o represents a load. The subscripts refer to specific points in time. Subscript 0 is the current hour, 1 is the previous hour and 2 is two hours previous.
- q represents a heat gain. The subscripts 0, 1 and 2 have the same meaning as for loads.
- v_o, v_1, v_2, w_1 and w_2 are transfer function coefficients. Values of these coefficients vary for each type of heat gain and room due to the different heat transfer processes involved in converting each kind of heat gain into a load. ASHRAE has published tables of these coefficients for different heat gain components, room types, and building weights.

In words, the Room Transfer Function Equation says that the load for the current hour (Q_o) is a function of the heat gain for the current and preceding two hours, plus the loads for the preceding two hours. Because loads for the preceding two hours are themselves dependent on a series of heat gains for prior hours, this hour's load is really dependent on the effects of heat gains from many preceding hours.

Detailed simulations resulted in generation of both sensible and latent loads for each of the spaces, which were further used for the selection of the appropriate HVAC equipment, for the two alternate systems. Catalogues were used for selecting the equipment for the mini split air conditioning system, while Toshiba SMMS-SHRM selection module was used for selecting the equipment for the VRF air conditioning system. Detailed layout of both systems indicated that the VRF system required only four outdoor units to provide thermal comfort for the spaces served by the individual indoor units (See Fig. 1), while the Mini Split system requires as much outdoor units as the number of indoor units to provide thermal comfort for each of the spaces as shown in Figs. 2 - 8 in the appendix section.

3.2 Engineering Economic Analysis

To select the economically sound option between the VRF and the Mini-Split systems designed for the building, an Engineering Economic Analysis was carried out using the Net Present Worth Analysis for both systems [7]. In the EEA, the following costs were taken into consideration and converted into the Net Present Worth Values for proper comparisons;

- First Cost: This refers to the cost of purchasing the equipment and installing the systems i.e. all the units and piping networks.
- Annual Maintenance Cost: This refers to the cost necessary to maintain the systems on an annual basis.
- Annual Energy Cost: This refers to the electrical energy cost necessary to run the Air-Conditioning systems on an annual basis. This wass based on 9 hours of equipment usage on a daily basis, and 5 days on a weekly basis. The total kWhr of energy usage for both systems were computed using the electrical energy capacities of the A/C equipment selected.

For computation of the Net Present Worth Values of the various future cost components, the formula below was used with an interest rate of 12%

$$P = F\ (P/F,\ i\%,\ n)$$

&

$$P = A\ (P/A,\ i\%,\ n)$$

Where,
P = Present Worth of estimated future cost
F = Estimated future cost
I% = Interest rate
N = Number of years
A = Estimated annual cost

A breakdown of the various cost components as used for analysis of both systems is given:

VRF System First Cost: N29,737,609.30

Mini Split System Net Present Worth: N22,124,696.60

VRF System Annual Maintenance Cost converted to the Net Present Worth: N30,381,428.50

Mini Split System Annual Maintenance Cost converted to the Net Present Worth: N11,503,125.14

VRF System Annual Energy Cost converted to the Net Present Worth: N17,772,770.86

Mini Split System Annual Energy Cost converted to the Net Present Worth: N13,014,007.00

VRF System Net Present Worth: N77,891,808.66

Mini Split System Net Present Worth: N46,641,828.74

4. RESULTS AND DISCUSSION

Based on the design analysis carried out, the layout as shown in the appendix section indicates that the VRF system requires only four outdoor condensing units to serve all the indoor air conditioning units in the building. This system hence aesthetically improves the look of the building which is a major Architectural consideration, while the mini-split system requires a single space for each of the outdoor units which definitely requires an angle iron bracket or a condensing unit shelter for each of the outdoor units which becomes an extra consideration by the Structural Engineer and definitely comes with a cost implication.

Based on the Engineering Economic Analysis carried out on the two systems, the overall Net Present Value for the VRF system is ₦77,891,808.66, while that of the Mini-Split system is ₦46,641,828.74. This result shows that the VRF system has a higher cost implication than the Mini-Split system. Hence, in terms of cost, the Mini-Split system is a more viable option.

However, it should be noted that a number of parameters were left out of consideration during the analysis. Of utmost importance is the annual energy estimation of the VRV system at Part Load Operation which requires a detailed simulation of the electrical energy consumption with respect to the cooling load at different points in time. This simulation would have resulted in a lesser value for the electrical energy consumption as compared to the actually estimated value.

From Fig. 9, it is observed the initial cost of the two systems are close. However, using a 15% of initial cost as annual maintenance cost builds up the maintenance cost of the VRF system over the period of time used for the analysis. The difference in the initial cost of the two systems is due largely to the newness of the VRF into the market. With time the VRF system is bound to cost less than the mini-split system as demand for the product increases.

Also as noted, the analysis of cost is based on full-load, where all the units are working at maximum capacity. However, under part-load conditions the gains of the VRF systems will be obvious. Gains such as the lower energy consumption of the outdoor unit under part-load conditions, which may bring the energy cost of the VRF system lower than that of the mini-split since most of the energy demand of the VRF is for the outdoor unit. This is due to the presence of multiple compressor and variable speed compressor that enable good part load performance permitting capacity modulation to serve 7% to 100% of the cooling or heating loads. Furthermore, the efficiency of the systems were not considered in the analysis, which will affect the performance and the energy cost over the duration of usage. The HVAC systems operation's daily time period has between 30% and 70% of the system working on maximum capacity where the VRF system efficiency is high.

Another energy gain of the VRF system has to do with its abilities to provide good zone control, saving energy and cost by not conditioning zones that are unoccupied and also providing capability to condition single zones off hours at a reasonable cost.

5. CONCLUSION

Technical and performance characteristics indicate that the Variable Refrigerant Flow System is a better air conditioning option than the Mini Split Air Conditioning system. However, the Economic Analysis carried out favored the Mini Split air conditioning system ahead of the VRF system. To come up with a more detailed Engineering Economic Analysis of both systems, a further research would be necessary for the estimation of the actual energy consumption of both systems as this would result in a more concise figure for the systems since energy cost is a major consideration during the actual running of the systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

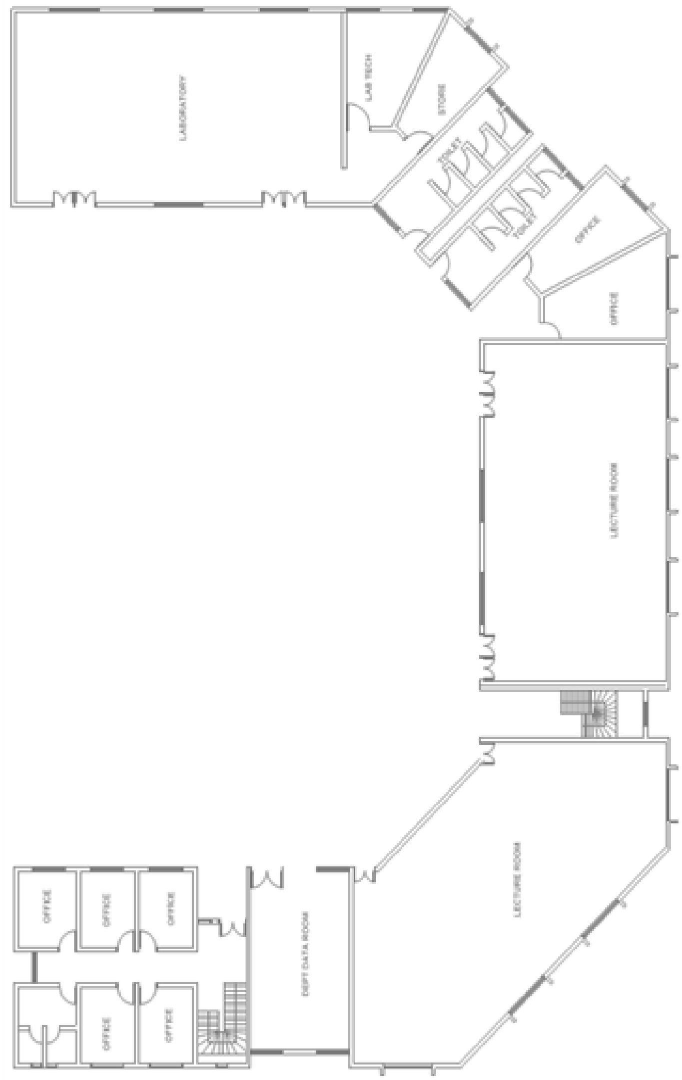

Fig. 1. Ground floor plan

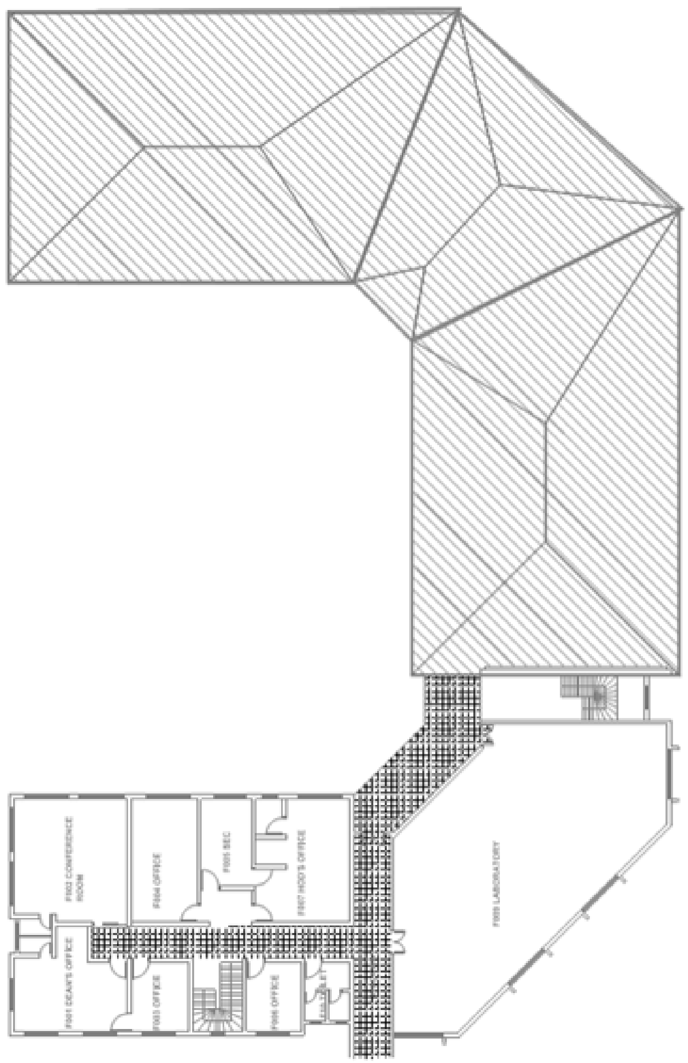

Fig. 2. First floor plan

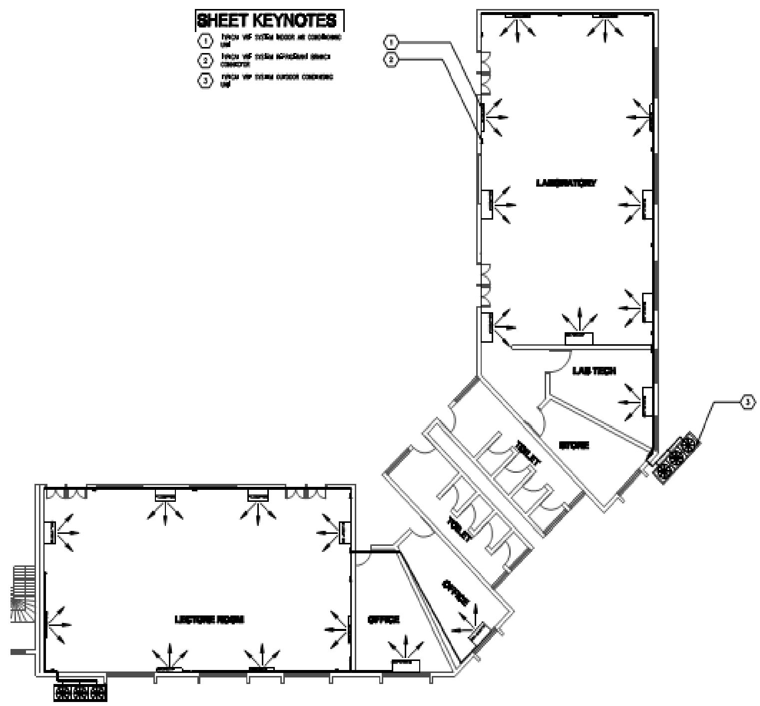

Fig. 3. VRF System Division 1 Ground Floor Plan

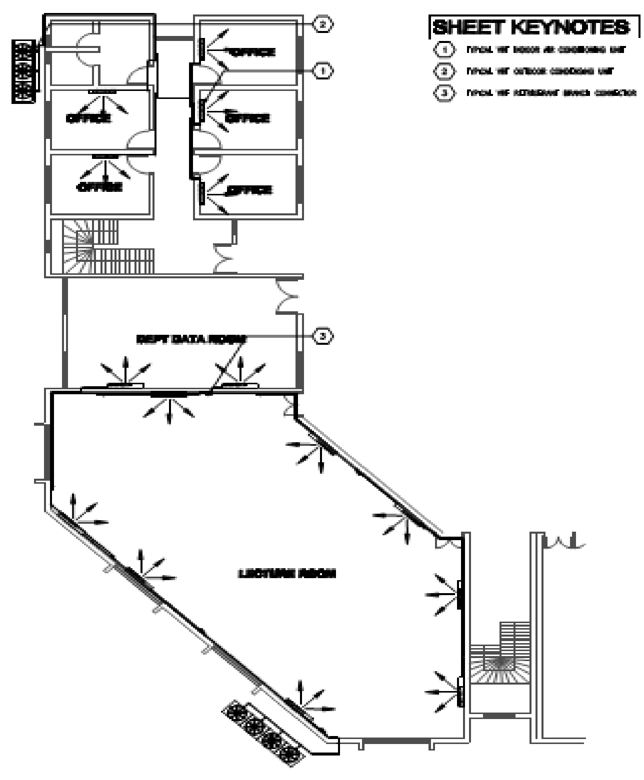

Fig. 4. VRF System Division 2 Ground Floor Plan

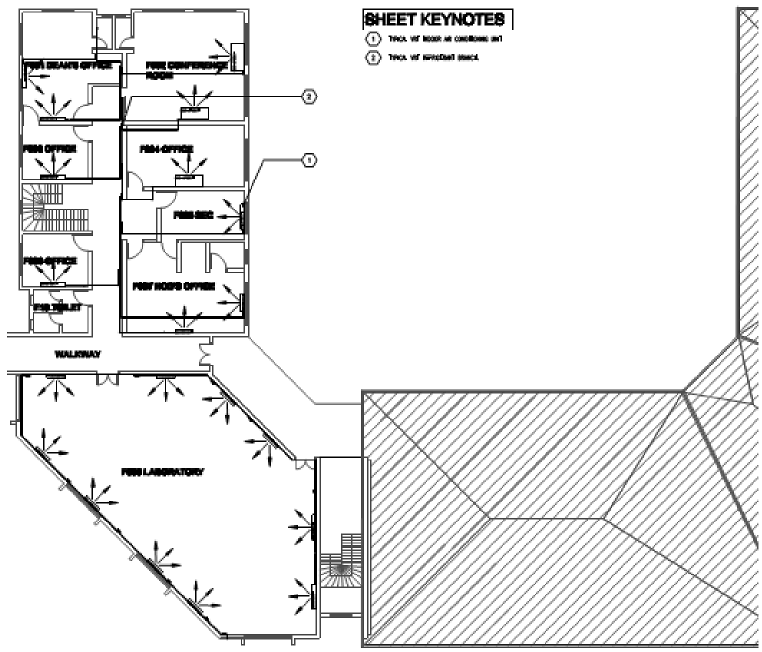

Fig. 5. VRF System Division 2 First Floor Plan

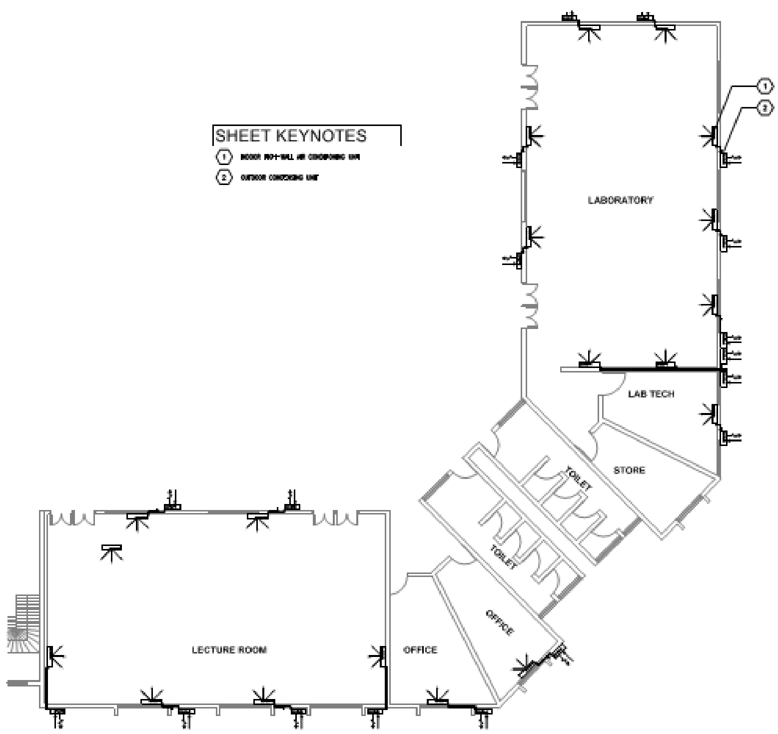

Fig. 6. Mini-Split System Division 1 Ground Floor Plan

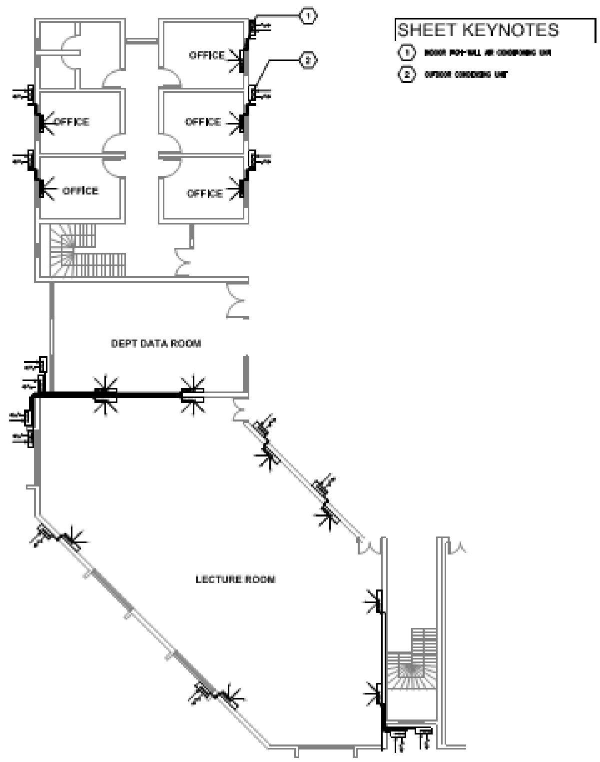

Fig. 7. Mini-Split System Division 2 Ground Floor Plan

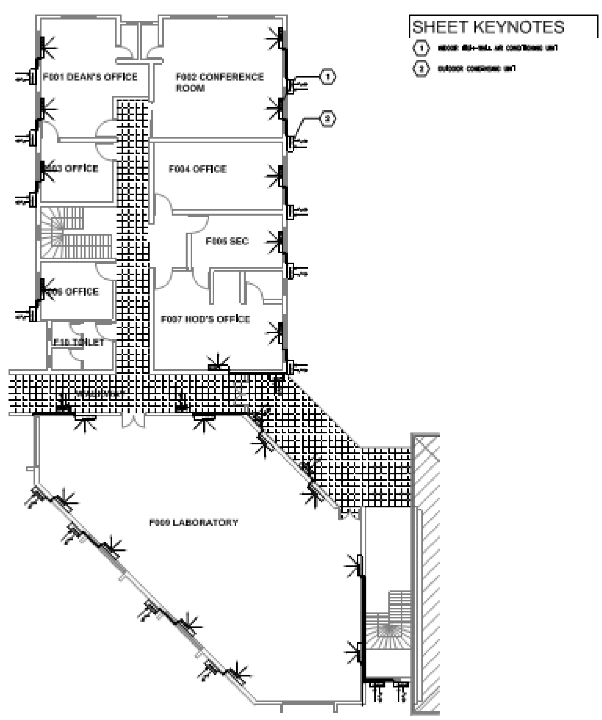

Fig. 8. Mini-Split System Division 2 First Floor Plan

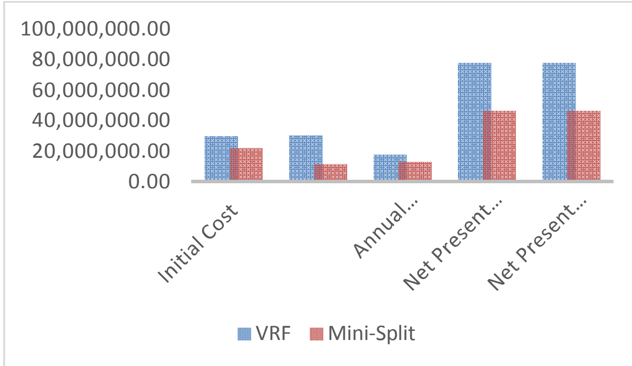

Fig. 9. Comparative cost analysis of VRF and mini-split systems.

Design Loads and Building Data

- Building Orientation: the orientation of the building was considered with respect to:

i Compass Points: The building is located in the College of Engineering and Technology, Ibogun Campus, behind the department of Computer Engineering. The orientation of the building was carefully studied with the rising and setting of the sun which also reflected on the Architectural drawings. The orientation of the building is shown in the floor plans as shown in Figs. 1 and 2.

ii Nearby Permanent Structures: Based on the building orientation, it is sparsely shielded.

iii Reflective Surfaces: The building is surrounded by grasses on the floor, hence a ground reflectance of 0.2 will be used.

- Use of Spaces: There are five types of spaces which will be treated within the building which are; Lecture rooms, office spaces, data room, laboratories and toilets. In all, the building comprises of thirty-four spaces, each of which will be given a space tag for easy recognition. The tags given to each of the spaces is as shown in Table 1.
- Physical dimensions of the spaces: The lengths, widths, and heights of the spaces were gotten from Architectural drawings and site visits during the survey process. The drawings included the floor plans, the Sectional drawings showing interior details and the Elevation drawings. The dimensions of each of the spaces are given in Table 1 according to the space tags.
- Ceiling Height: During survey, the ceiling height was gotten from Architectural drawings and site visits as shown in Table 1.
- Construction Materials: The construction materials which are used for construction were gotten from the Architect, and consists of the following listed materials;

i Wall Construction: The external wall is made of 15mm plaster on the exterior, 195mm block wall and 15mm plaster on the interior resulting in an overall U-Value of 1.722W/m^2/K.

ii Roof Construction: The roof of the building comprises of asbestos, air-space, wood, and aluminium sheet, with an overall U-Value of 1.461W/m^2/K.

iii Ceiling Construction: The building does not have any false ceilings; hence no ceiling constructions are used.

iv Floors: The floor of the first floor comprises of floor tiles, screed, and concrete, with an overall U-Value of 0.986W/m^2/K while the ground floor has a U-Value of 0.2W/m^2/K.

v Partitions: The wall partitions have a U-Value of 1.722W/m^2/K.

vi Windows material: The window material used comprises of Aluminium with thermal breaks and 6mm clear glazing with an overall U-Value of 6.884W/m^2/K and a shading coefficient of 0.880.

vii Door Material: The door used has an overall U-Value of 1.703W/m^2/K and a glass U-Value of 3.293W/m^2/K.

Table 1. Building usage and dimensions

S/N	Tag	Space usage	Floor area (m^2)	Height (m)
1	F001	Dean's Office	27.6	4.2
2	F002	Conference Room	41.2	4.2
3	F003	Office Space	12	4.2
4	F004	Office Space	24.4	4.2
5	F005	Secretary's Office	13.2	4.2
6	F006	Office Space	11.4	4.2
7	F007	HOD's Office	31.3	4.2
8	F008	Laboratory	79	4.2
9	F009	Laboratory	90.4	4.2
10	F10	Toilet	8.1	4.2
11	F11	Toilet	1.6	4.2
12	F12	Toilet	1.6	4.2
13	G001	Laboratory	76.5	4.0
14	G002	Laboratory	114.7	4.0
15	G003	Lab Tech	23.8	4.0
16	G004	Office Space	22.8	4.0
17	G005	Office Space	26.4	4.0
18	G006	Lecture Room	88.8	4.0
19	G007	Lecture Room	88.8	4.0
20	G008	Lecture Room	95.4	4.0
21	G009	Lecture Room	98.2	4.0
22	G10	Data Room	51.2	3.6
23	G11	Office Space	12.1	3.6
24	G12	Office Space	12.1	3.6
25	G13	Office Space	12.1	3.6
26	G14	Office Space	12.1	3.6
27	G15	Office Space	12.1	3.6
28	G16	Store	18.7	3.6
29	G17	Toilet	27.4	3.6
30	G18	Toilet	25.5	3.6
31	G19	Toilet	13	3.6

- Surrounding Conditions: During the survey process, the surrounding conditions of the various spaces were considered based on the activities carried out in adjacent spaces. Adjacent spaces which will not be conditioned are treated as partitions to the space.
- People: This is a major source of both sensible and latent heats and will be estimated based on reasonable assumptions for each of the spaces. As the exact number of people to occupy the various spaces is not known prior to usage of the spaces, a reasonable assumption will be made which will be standardized for each of the spaces. The assumption will assume an occupancy in terms of square meters per person as given below:

  i. Lecture Rooms: 4.5m^2/person
  ii. Office spaces: 4 people
  iii. Conference Room: 4.5m^2/person
  iv. Laboratory: 4.5m^2/person

- Lighting: The general type of lighting used for the building is the free hanging fluorescent. Prior to space usage, the exact wattage of all the lighting fixtures are not known, hence, a general lighting of 12W/m^2 will be used to compute the lighting loads for all spaces (data extracted from www.bsjonline.co.uk, journal of the Chattered Institution of Building Services Engineers)
- Appliances: A number of spaces will be equipped with appliances to be accounted for during design conditions. The spaces with the appliances to be estimated for during design are as listed below;
  i. Lecture Rooms: 10Watts/m^2

ii. Office spaces: 25Watts/m^2
iii. Conference Room: 25Watts/m^2
iv. Laboratory:25Watts/m^2

- Thermal Storage: This has to do with the system operating schedule, which will be assumed as a common schedule for the different types of spaces based on the heat gain profile. The operating schedules to be assumed during the design phase are:

i. Lecture Rooms: The schedule will be a fractional schedule for occupants as it will deal with the percentage change in the number of occupants within the space. Two hourly profiles will be used for the heat gain simulation for lighting, equipment (if any), and occupancy. The heat gain profiles are:
   - Weekday Profile: This profile will assume a 50% gain at 8 am, 100% gain from 9 pm to 4 pm, and a 50% gain at 5 pm. This profile will be used for computing heat gains from Monday through Friday.
   - Weekend profile: This will assume a 0% heat gain for all hours from Saturday through Sunday; hence no simulation will be carried out on the Weekend.

ii. Office Spaces: This will also include two heat gain profiles which are similar to that of the lecture hall. The profiles are:
   - Weekday Profile: This profile will assume a 50% gain at 8 am, 100% gain from 9 pm to 4 pm, and a 50% gain at 5 pm. This profile will be used for computing heat gains from Monday through Friday.
   - Weekend profile: This will assume a 0% heat gain for all hours from Saturday through Sunday; hence no simulation will be carried out on the Weekend.

iii. Laboratory: The profile for the laboratory will be assumed to be similar to that of the lecture hall and office spaces as the exact operating schedule of the laboratory is not yet known. The profiles are:
   - Weekday Profile: This profile will assume a 50% gain at 8 am, 100% gain from 9 pm to 4 pm, and a 50% gain at 5 pm. This profile will be used for computing heat gains from Monday through Friday.
   - Weekend profile: This will assume a 0% heat gain for all hours from Saturday through Sunday; hence no simulation will be carried out on the Weekend.

iv. Conference Room: This will also use a profile similar to that of the office spaces as given below:
   - Weekday Profile: This profile will assume a 50% gain at 8 am, 100% gain from 9 pm to 4 pm, and a 50% gain at 5 pm. This profile will be used for computing heat gains from Monday through Friday.
   - Weekend profile: This will assume a 0% heat gain for all hours from Saturday through Sunday; hence no simulation will be carried out on the Weekend.

Table 2. Spaces input data

S/N	Tag	OA ventilation requirements (l/s)	Overhead lighting (W/m^2)	Occupancy	Electrical Equipment (W/m^2)	Wall exposure (m^2)	Roof Exposure	Infiltration (ACH)	Partitions (m^2)
1	F001	40	12	4 people	25	N (16.9) W (26.1)	W (13.8) E (13.8)	0.5	33.2
2	F002	91.6	12	4.5 m^2/person	25	N (26.2) E (25.7)	E (41.2)	0.5	20.2
3	F003	40	12	4 people	25	W (13.3)	W (12.0)	0.5	29.4
4	F004	40	12	4 people	25	E (15.1)	E (24.4)	0.5	23.5
5	F005	40	12	4 people	25	E (11.6)	E (13.2)	0.5	21.0
6	F006	40	12	4 people	25	W (12.6) S(1.6)	W (11.4)	0.5	42.8
7	F007	40	12	4 people	25	E (14.7)	E (31.3)	0.5	21
8	F008	75.6	12	4.5 m^2/person	25	W (14.7) SW (35.7)	SW(47.4) NE (31.6)	0.5	59.6
9	F009	200.9	12	4.5 m^2/person	25	SW (32.3) S (23.1) E (5.1)	NE (45.2) SW (45.2)	0.5	58.4
10	G001	170	12	4.5 m^2/person	25	N (40.0) E (30.6) W (30.6)	E (38.0) W (38.0	0.2	-
11	G002	254.9	12	4.5 m^2/person	25	E (41.4) W (47.8)	E (57.0) W (57.0)	0.2	14.4
12	G003	40	12	4 people	25	E (22.0)	H (23.8)	0.2	26.9
13	G004	40	12	4 people	25	SE (17.6)	H (22.8)	0.2	29.6
14	G005	40	12	4 people	25	S (22.6)	H (26.4)	0.2	9.2
15	G006	157.9	12	4.5 m^2/person	10	N (71.2)	N (44.4) S (44.4)	0.2	30.4
16	G007	157.9	12	4.5 m^2/person	10	S (71.2) W (4.0)	N (44.4) S (44.4)	0.2	16.0
17	G008	169.6	12	4.5 m^2/person	10	N (4.8) NE (15.6) S (22.2)	NE (47.7) SW (47.7)	0.2	36.0

S/N	Tag	OA ventilation requirements (l/s)	Overhead lighting (W/m^2)	Occupancy	Electrical Equipment (W/m^2)	Wall exposure (m^2)	Roof Exposure	Infiltration (ACH)	Partitions (m^2)
18	G009	174.6	12	4.5 m^2/person	10	SW (32.4) E (4.8) N (4.8) NE (16.0) E (4.8) SW (32.4)	NE (49.1) SW (49.1)	0.2	-
19	G10	57	12	9 m^2/person	25	W (23.2) W (19.8) E (19.8) N (9.7)	-	0.2	44.1
20	G11	40	12	4 people	25	W (10.8)	-	0.2	25.2
21	G12	40	12	4 people	25	E (10.8) S (9.8)	-	0.2	17.3
22	G13	40	12	4 people	25	W (10.8)	-	0.2	25.2
23	G14	40	12	4 people	25	E (10.8)	-	0.2	10.8
24	G15	40	12	4 people	25	E (10.8) N (14.4) W (4.0)	-	0.2	10.8

Table 3. Sensible and latent cooling loads for various spaces

SPACE	ZONE LOADS	DESIGN COOLING COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.8 °C / 34.1 °C OCCUPIED T-STAT 23.0 °C		
		Details	Sensible (W)	Latent (W)
1) F001 (Dean's Office)	Window & Skylight Solar Loads	6 m²	1255	-
	Wall Transmission	37 m²	981	-
	Roof Transmission	28 m²	1718	-
	Window Transmission	6 m²	479	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	4 m²	35	-
	Partitions	33 m²	463	-
	Ceiling	0 m²	0	-
	Overhead Lighting	414 W	365	-
	Task Lighting	0 W	0	-
	Electric Equipment	690 W	624	-
	People	4	210	240
	Infiltration	-	228	1105
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	636	135
	>> Total Zone Loads	**-**	**6996**	**1480**
2) F002 (Conference Room)	Window & Skylight Solar Loads	12 m²	1649	-
	Wall Transmission	40 m²	1243	-
	Roof Transmission	41 m²	2589	-
	Window Transmission	12 m²	857	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	18 m²	143	-
	Partitions	20 m²	283	-
	Ceiling	0 m²	0	-
	Overhead Lighting	618 W	539	-

SPACE	ZONE LOADS	DESIGN COOLING COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.8 °C / 34.1 °C OCCUPIED T-STAT 23.0 °C		
		Details	**Sensible (W)**	**Latent (W)**
	Task Lighting	0 W	0	-
	Electric Equipment	1030 W	924	-
	People	9	536	724
	Infiltration	-	347	1655
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	911	238
	>> Total Zone Loads	**-**	**10021**	**2617**
3) F003 (OFFICE)	Window & Skylight Solar Loads	2 m²	497	-
	Wall Transmission	11 m²	278	-
	Roof Transmission	12 m²	780	-
	Window Transmission	2 m²	160	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	0 m²	0	-
	Partitions	29 m²	410	-
	Ceiling	0 m²	0	-
	Overhead Lighting	180 W	158	-
	Task Lighting	0 W	0	-
	Electric Equipment	300 W	271	-
	People	4	210	240
	Infiltration	-	99	477
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	286	72
	>> Total Zone Loads	**-**	**3151**	**789**
4) F004 (OFFICE)	Window & Skylight Solar Loads	3 m²	425	-
	Wall Transmission	12 m²	416	-
	Roof Transmission	24 m²	1584	-
	Window Transmission	3 m²	214	-
	Skylight Transmission	0 m²	0	-

SPACE	ZONE LOADS	DESIGN COOLING		
		COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.8 °C / 34.1 °C OCCUPIED T-STAT 23.0 °C		
		Details	Sensible (W)	Latent (W)
	Door Loads	0 m²	0	-
	Floor Transmission	12 m²	99	-
	Partitions	24 m²	330	-
	Ceiling	0 m²	0	-
	Overhead Lighting	366 W	319	-
	Task Lighting	0 W	0	-
	Electric Equipment	610 W	547	-
	People	4	205	240
	Infiltration	-	205	969
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	434	121
	>> Total Zone Loads	**-**	**4779**	**1330**
5) F005 (SECRETARY'S OFFICE)	Window & Skylight Solar Loads	2 m²	319	-
	Wall Transmission	9 m²	322	-
	Roof Transmission	13 m²	857	-
	Window Transmission	2 m²	161	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	13 m²	106	-
	Partitions	21 m²	295	-
	Ceiling	0 m²	0	-
	Overhead Lighting	198 W	173	-
	Task Lighting	0 W	0	-
	Electric Equipment	330 W	296	-
	People	4	205	240
	Infiltration	-	111	530
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	284	77
	>> Total Zone Loads	**-**	**3127**	**847**

SPACE	ZONE LOADS	DESIGN COOLING COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.8 °C / 34.1 °C OCCUPIED T-STAT 23.0 °C		
		Details	**Sensible (W)**	**Latent (W)**
6) F006 (OFFICE)	Window & Skylight Solar Loads	2 m²	497	-
	Wall Transmission	12 m²	292	-
	Roof Transmission	11 m²	741	-
	Window Transmission	2 m²	160	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	3 m²	21	-
	Partitions	43 m²	597	-
	Ceiling	0 m²	0	-
	Overhead Lighting	171 W	151	-
	Task Lighting	0 W	0	-
	Electric Equipment	285 W	258	-
	People	4	210	240
	Infiltration	-	94	452
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	302	69
	>> Total Zone Loads	**-**	**3322**	**762**
7) F007 (HOD'S OFFICE)	Window & Skylight Solar Loads	3 m²	425	-
	Wall Transmission	12 m²	403	-
	Roof Transmission	31 m²	2031	-
	Window Transmission	3 m²	214	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	13 m²	106	-
	Partitions	21 m²	295	-
	Ceiling	0 m²	0	-
	Overhead Lighting	470 W	409	-
	Task Lighting	0 W	0	-
	Electric Equipment	783 W	702	-

SPACE	ZONE LOADS	DESIGN COOLING COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.8 °C / 34.1 °C OCCUPIED T-STAT 23.0 °C		
		Details	Sensible (W)	Latent (W)
	People	4	205	240
	Infiltration	-	263	1232
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	505	147
	>> Total Zone Loads	**-**	**5559**	**1620**
8) F008 (LABORATORY)	Window & Skylight Solar Loads	6 m²	1170	-
	Wall Transmission	44 m²	1007	-
	Roof Transmission	79 m²	5064	-
	Window Transmission	6 m²	479	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	0 m²	0	-
	Partitions	60 m²	815	-
	Ceiling	0 m²	0	-
	Overhead Lighting	1185 W	1043	-
	Task Lighting	0 W	0	-
	Electric Equipment	1975 W	1786	-
	People	18	1054	1389
	Infiltration	-	653	3132
	Miscellaneous	-	0	0
	Safety Factor	10% / 10%	1307	452
	>> Total Zone Loads	**-**	**14379**	**4972**
9) F009 (LABORATORY)	Window & Skylight Solar Loads	6 m²	612	-
	Wall Transmission	54 m²	1204	-
	Roof Transmission	90 m²	5791	-
	Window Transmission	6 m²	479	-
	Skylight Transmission	0 m²	0	-
	Door Loads	0 m²	0	-
	Floor Transmission	0 m²	0	-

SPACE		ZONE LOADS	DESIGN COOLING		
			COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.8 °C / 34.1 °C OCCUPIED T-STAT 23.0 °C		
			Details	**Sensible (W)**	**Latent (W)**
		Partitions	58 m²	799	-
		Ceiling	0 m²	0	-
		Overhead Lighting	1356 W	1194	-
		Task Lighting	0 W	0	-
		Electric Equipment	2260 W	2043	-
		People	20	1206	1589
		Infiltration	-	748	3540
		Miscellaneous	-	0	0
		Safety Factor	10% / 10%	1408	513
		>> Total Zone Loads	**-**	**15484**	**5642**
10)	G001 (LAB)	**>> Total Zone Loads**	**-**	**14699**	**2787**
11)	G002 (LAB)	**>> Total Zone Loads**	**-**	**21235**	**4178**
12)	G003(LAB TECH)	**>> Total Zone Loads**	**-**	**5042**	**672**
13)	G004 (OFFICE)	**>> Total Zone Loads**	**-**	**4148**	**636**
14)	G005 (OFFICE)	**>> Total Zone Loads**	**-**	**4571**	**606**
15)	G006 (LR)	**>> Total Zone Loads**	**-**	**15791**	**3234**
16)	G007 (LR)	**>> Total Zone Loads**	**-**	**14063**	**2874**
17)	G008 (LR)	**>> Total Zone Loads**	**-**	**14767**	**3451**
18)	G009 (LR)	**>> Total Zone Loads**	**-**	**15422**	**3574**
19)	G10 (DDT)	**>> Total Zone Loads**	**-**	**6765**	**1290**
20)	G11 (OFFICE)	**>> Total Zone Loads**	**-**	**2092**	**449**
21)	G12 (OFFICE)	**>> Total Zone Loads**	**-**	**2057**	**449**
22)	G13 (OFFICE)	**>> Total Zone Loads**	**-**	**2092**	**449**
23)	G14 (OFFICE)	**>> Total Zone Loads**	**-**	**1754**	**451**
24)	G15 (OFFICE)	**>> Total Zone Loads**	**-**	**2317**	**451**

Table 4. VRF system equipment selection

S/N	Space tag	Selected equipment	Qty (No)	Cost/Unit ₦	Installation Cost/Unit ₦	Total cost ₦	Electrical Rating/unit (kW)	Total electrical rating (kW)
1	F001	MMK-APO241H	2	207,400	25,000	464,800	0.102	0.204
2	F002	MMC-APO361H	2	223,400	30,000	506,800	0.091	0.182
3	F003	MMK-APO241H	1	207,400	25,000	232,400	0.102	0.204
4	F004	MMC-APO361H	1	223,400	30,000	253,400	0.091	0.091
5	F005	MMK-APO241H	1	207,400	25,000	232,400	0.102	0.102
6	F006	MMK-APO241H	1	207,400	25,000	232,400	0.102	0.102
7	F007	MMK-APO181H	2	166,400	30,000	392,800	0.102	0.204
8	F008	MMK-APO241H	5	207,400	25,000	1,162,000	0.102	0.51
9	F009	MMK-APO241H	5	207,400	25,000	1,162,000	0.102	0.51
10	G001	MMK-APO241H	4	207,400	25,000	929,600	0.102	0.408
11	G002	MMC-APO361H	5	223,400	30,000	1,267,000	0.091	0.455
12	G003	MMC-APO361H	1	223,400	30,000	253,400	0.091	0.091
13	G004	MMC-APO271H	1	207,400	30,000	237,400	0.050	0.050
14	G005	MMC-APO361H	1	223,400	30,000	253,400	0.091	0.091
15	G006	MMC-APO271H	4	207,400	30,000	946,600	0.050	0.2
16	G007	MMK-APO241H	4	207,400	25,000	929,600	0.102	0.408
17	G008	MMK-APO241H	4	207,400	25,000	929,600	0.102	0.408
18	G009	MMK-APO241H	4	207,400	25,000	929,600	0.102	0.408
19	G10	MMK-APO241H	2	207,400	25,000	464,800	0.102	0.204
20	G11	MMK-APO151H	1	160,200	30,000	190,200	0.092	0.092
21	G12	MMK-APO151H	1	160,200	30,000	190,200	0.092	0.092
22	G13	MMK-APO151H	1	160,200	30,000	190,200	0.092	0.092
23	G14	MMK-APO151H	1	160,200	30,000	190,200	0.092	0.092
24	G15	MMK-APO181H	1	166,400	30,000	196,400	0.102	0.102

Table 5. Mini-split equipment selection

S/N	Space Tag	Selected equipment (Indoor) (Outdoor)	Qty (No)	Cost/Unit ₦	Installation cost/Unit ₦	Total Cost ₦	Electrical Rating/unit (kW)	Total Electrical Rating (kW)
1	F001	RAS-18SA-ES RAS-18SKP-ES	2	154,440	20,000	348,880	1.68	3.36
2	F002	RAS-24SA-ES RAS-24SKP-ES	2	194,740	38,948	467,376	2.45	4.9
3	F003	RAS-18SA-ES RAS-18SKP-ES	1	154,440	20,000	174,440	1.68	1.68
4	F004	RAS-24SA-ES RAS-24SKP-ES	1	194,740	38,948	233,688	2.45	2.45
5	F005	RAS-18SA-ES RAS-18SKP-ES	1	154,440	20,000	174,440	1.68	1.68
6	F006	RAS-18SA-ES RAS-18SKP-ES	1	154,440	20,000	174,440	1.68	1.68
7	F007	RAS-18SA-ES RAS-18SKP-ES	2	154,440	20,000	348,880	1.68	3.36
8	F008	RAS-18SA-ES RAS-18SKP-ES	5	154,440	20,000	872,200	1.68	8.4
9	F009	RAS-18SA-ES RAS-18SKP-ES	5	154,440	20,000	872,200	1.68	8.4
10	G001	RAS-24SA-ES RAS-24SKP-ES	4	194,740	38,948	934,752	2.45	9.8
11	G002	RAS-24SA-ES RAS-24SKP-ES	5	194,740	38,948	1,168,440	2.45	12.25
12	G003	RAS-24SA-ES RAS-24SKP-ES	1	194,740	38,948	233,688	2.45	2.45
13	G004	RAS-24SA-ES RAS-24SKP-ES	1	194,740	38,948	233,688	2.45	2.45
14	G005	RAS-24SA-ES RAS-24SKP-ES	1	194,740	38,948	233,688	2.45	2.45
15	G006	RAS-24SA-ES RAS-24SKP-ES	4	194,740	38,948	934,752	2.45	9.8

S/N	Space Tag	Selected equipment (Indoor) (Outdoor)	Qty (No)	Cost/Unit ₦	Installation cost/Unit ₦	Total Cost ₦	Electrical Rating/unit (kW)	Total Electrical Rating (kW)
16	G007	RAS-18SA-ES RAS-18SKP-ES	2	154,440	20,000	348,880	1.68	3.36
17	G008	RAS-24SA-ES RAS-24SKP-ES	4	194,740	38,948	934,752	2.45	9.8
18	G009	RAS-24SA-ES RAS-24SKP-ES	4	194,740	38,948	934,752	2.45	9.8
19	G10	RAS-24SA-ES RAS-24SKP-ES	2	194,740	38,948	467,376	2.45	4.9
20	G11	RAS-13SA-ES2 RAS-13SKP-ES2	1	92,345	18,469	110,814	1.2	1.2
21	G12	RAS-13SA-ES2 RAS-13SKP-ES2	1	92,345	18,469	110,814	1.2	1.2
22	G13	RAS-13SA-ES2 RAS-13SKP-ES2	1	92,345	18,469	110,814	1.2	1.2
23	G14	RAS-13SA-ES2 RAS-13SKP-ES2	1	92,345	18,469	110,814	1.2	1.2
24	G15	RAS-18SA-ES RAS-18SKP-ES	1	154,440	20,000	174,440	1.68	1.68

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