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Cooling Load Estimation for Educational Building Utilizing VRV/VRF Air Conditioning System

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Abstract:- The objective of this work is to estimate the HVAC energy consumption of an educational building using different air conditioning systems. The building is located in Meshref area, in Kuwait. The cooling load as well as light and electric appliances load of the building are estimated using Hourly Analysis Program (HAP). Three different HVAC systems were investigated in this work, namely, "Packaged DX Fan-Coil Rooftop", "Variable Air Volume - Single Fan - Dual Duct" (VAV) and a Rooftop Variable Refrigerant Flow with Dedicated Outdoor Air System (VRF). Results showed that the energy bill when using VRF is 33% less than that of VAV, and 27% less than that of the PKG type. Although the capital cost of the VRF is higher than that of the other HVAC systems, but it is higher energy efficiency can pay for that in a short time.

Keywords:- *Cooling Load, Variable Refrigerant Volume (VRV), Variable Refrigerant Flow (VRF), Hourly Analysis Program (HAP).*

I. INTRODUCTION

Kuwait is an arid area, with hot weather conditions most of the year. Air conditioning (AC) systems are vital and extensively used in every place in the country to ensure comfort conditions for the equitation. However, the air conditioning load represents about 70% of the power generation in Kuwait. Accurate cooling load estimation and optimum AC system design can play a significant role to reduce the energy consumption in this sector. The standard codes and procedures from the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) and the Ministry of Electricity and Water in Kuwait (MEW) will be used though all the work steps. Different methods of calculating air-conditioning cooling load for the purpose of sizing A/C equipment are approved by MEW in Kuwait and can be used (MEW, 2014). The proposed methods consider the thermal storage effect of the space, the hourly values of the outdoor temperatures, solar radiation and other weather parameters. For instance, these methods can be used: (a) Heat Balance (HBM), (b) Transfer Function (TFM), (c) Time Radiant Series (TRS) and (d) Total Equivalent Temperature Difference (TETD), (ASHRAE, 2012). The above-mentioned calculation methods require computer iteration or heavy computational spread-sheet analysis and are not suitable for the hand calculation.

Designing an AC system on the other hand, is art of optimization and selection of the proper Heating, Ventilation and Air Conditioning (HVAC) equipment among the number of system alternatives available in the market. The optimum AC system is the system that can provide the required comfort conditions for the occupancy as well as for the sensitive equipment, at minimum cost and highest efficiency and most environmental green effect. Variable Refrigerant Volume (VRV) or Variable Refrigerant Flow (VRF) are two terms but refers to the same HVAC system technology. VRV systems were invented by Daikin® during the early 1980's, and they registered the VRV term as an official trademark for them. All other companies use VRF for their similar HVAC systems. Eventually, VRF is more common term for these types of systems, and this is the term that will be used for the rest of the article.

A variable refrigerant flow is classified as a multi-split HVAC system that controls refrigerant flow to control separable zones to residential consumer's needs. VRF specific components regulate refrigerant flow control for system performance and reliability, (Hernandez & Fumo, 2020). In this work, the cooling load for an educational building will be estimated utilizing VRF system. Hourly Analysis Program (HAP 5.1) software will be used for this purpose.

Cooling load represents the total heat gain by the air-conditioned space which must be removed by the air conditioning system. The space gains heat through two sources, external and internal heat gain source. External heat gain includes: (a) Conduction solar energy through the building envelope. (b) Radiation solar energy enters through windows. (c) Warm air infiltrates through cracks and ventilation system. While internal heat gain includes the heat generated within the space from the people, lighting, electrical and combustion appliances. Table 1 presents the outdoor design conditions for interior regions in Kuwait; more than 2.5 km from the coast. The highest conditions (DBT °C/°F: 48.0/118.4 and WBT °C/°F: 22.1/71.8) will be utilized in the calculation for proper sizing of the system. Table 1:- Outdoor Design Conditions for Kuwait for Interior Region, (MEW, 2014)

shows the indoor design conditions according to (MEW, 2014).

II. BUILDING DESCRIPTION

A facility building owned by one of the educational institutes in Kuwait will be modelled and simulated for the cooling load estimation and HVAC system design. The building consists of, ground, first and second floors, each floor is 330 m^2 of area. The building contains six classrooms, two computer labs, a workshop and a 3D printing lab, among other service facilities. The plan views of the three floors are shown in Fi, Fig , and Fig . The ground floor contains mainly a workshop and a 3D printing lab which contribute to the appliance load of the space. The workshop equipment specifications are shown in Table 2:- Outdoor and Indoor Design Conditions for Kuwait, (MEW, 2014)

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III. WALLS, ROOF, AND WINDOWS CONSTRUCTIONS

The external walls of the building, the roof and windows construction specifications are shown in Table 3:- Workshop and 3D Printing Lab Equipment Power Rating

, Table 5, and Table 5:- Roof Layers Details (Inside to Outside)

. The floor Overall U-Value of 0.5 W/(m²·K) is used in the HAP software.

- *Wall Details*

The building external walls has a light colour, with Overall U-Value 0.4.05 W/(m²·K). The details of the roof contracture layers are shown in Table 3:- Workshop and 3D Printing Lab Equipment Power Rating

- *Roof Details*

The outside surface of the roof has light colour, with Overall U-Value 0.331 W/(m²·K). The details of the roof contracture layers are shown in Table 5

- *Windows Details*

Two types of windows are used in this facility building; both are similar in contractions but different in dimensions.

IV. HAP SOFTWARE INPUT

The Hourly Analysis Program (HAP) was used to perform the sizing and simulation calculation for the cooling load and system capacity. The software database includes the weather data and solar intensity for Kuwait around the year. However, the design outdoor dry bulb temperature was updated to match the MEW specification, where the outdoor DBT used in this case was 48.0ºC. Table 6:- Windows Construction Details

shows the weather input data to HAP, while Fig shows the total solar heat gain on the sides of the building during July.

The building was divided into number of zones, each zone represents a space in the building, summary of the spaces and zones used in this simulation are shown in **Error! Reference source not found.**.

For the energy simulation, the electricity tariff for the governmental building of 25 fils/kWh (0.08 $/kWh) is used.

V. RESULTS AND DISCUSSION

In this work, VRF air conditioning system is simulated using HAP. For comparison purposes, the same building with the same inputs were simulated using two different air conditioning systems, which are “Variable Air Volume - Single Fan - Dual Duct” (VAV) and “Packaged DX Fan-Coil Rooftop” (PKG) systems. The three systems were first sized to fit the cooling load requirement for the building, then the building energy usage for HVAC and non-HVAC equipment are estimated using HAP.

A. Energy Consumption of Different HVAC Systems

HAP software was utilized to simulate the energy consumption and annual cost for three different HVAC systems, namely “Packaged DX Fan-Coil Rooftop”, “Variable Air Volume - Single Fan - Dual Duct” (VAV) and a Rooftop Variable Refrigerant Flow with Dedicated Outdoor Air System (VRF). The annual total energy consumption for HVAC and non-HVAC usage are presented in Fig . It is clear that the annual energy consumption for the VRF is the least among other systems. It is worth to mention that the non-HVAC energy consumption; due to lightening and other electric appliances; are equal for the three systems, the only difference is in the amount of energy consumption for cooling the building. The results are in good agreement to that obtained by (Park, Yun, & Kim, 2017).

The cost of annual electric energy consumption by the three HVAC systems is illustrated in Fig . Again, the cost of the lights and electric equipment is almost constant for the three system and the difference is in the cost of cooling energy only, with minimum cost is for VRF system. These results are obtained for unit energy cost of 0.08$/kWh.

Monthly energy cost for the different HVAC systems is depicted in Fig . As expected, the highest energy consumption occurs during the summer months. The energy consumption for VRF still the minimum during the year.

The difference in annual energy cost between the three HVAC system is shown in Fig . The VAV system is the highest in energy cost, 33% higher than the VRF, while the PKG system is 27% higher than the VRF.

Based on the above results, the VRF system consume the least amount of energy for cooling in monthly and yearly bases. For these reasons the VRF is further simulated and investigated more deeply in the next section.

B. *Dedicated Outdoor Air System (DOAS) Sizing Summary for VRF Rooftop*

The VRF system is sized using HAP software. The required capacity of the system is shown in Table 7:- Summary of the Building Load used in HAP

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The monthly electric energy consumption and cost for the proposed educational building are shown in Fig and Fig. The electricity bill will be maximum during the summer months. The energy consumption for non-HVAC is almost constant during the year, summer vacation is not considered in this simulation because some educational institute have summer courses.

VI. CONCLUSIONS

The air conditioning system of an educational building in Kuwait City was simulated and investigated in this work. The building consists of three floors and includes 6 classrooms, 2 computer labs, and a workshop among other services and facilities. The Hourly Analysis Program (HAP 5.1) is used to evaluate the cooling load and to estimate the required capacity of the HVAC equipment. HAP is also used to simulate the energy required by the building (for HVAC and non-HVAC) and estimate the monthly and annual energy bill. Three different HVAC systems were simulated and compared together. Variable Refrigerant Flow (VRF) HVAC systems showed the lowest energy consumption and hence energy cost among other systems. Although the capital cost of the system is relatively higher than other conventional systems, but its high energy efficiency which resulted in lower energy cost, can pay for this extra cost.

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FIGURES

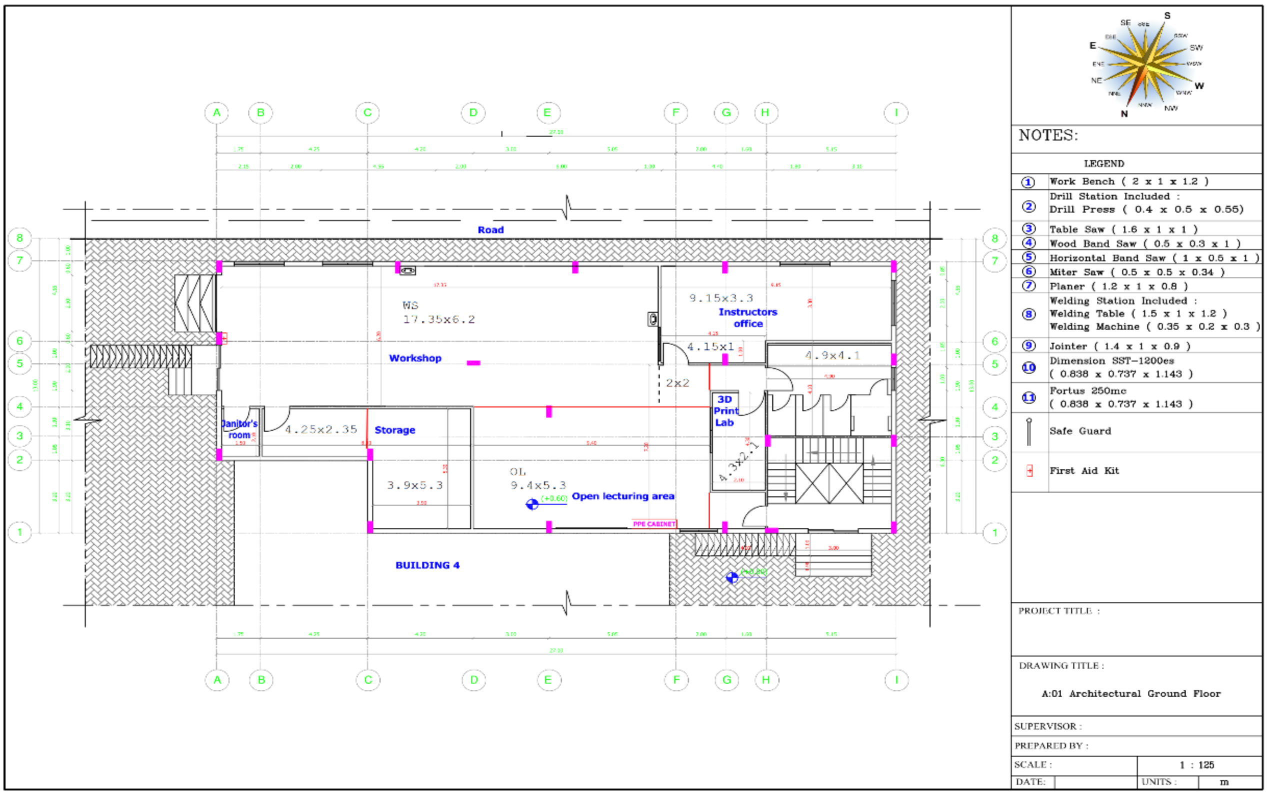

Fig 1:- Ground Floor Plan

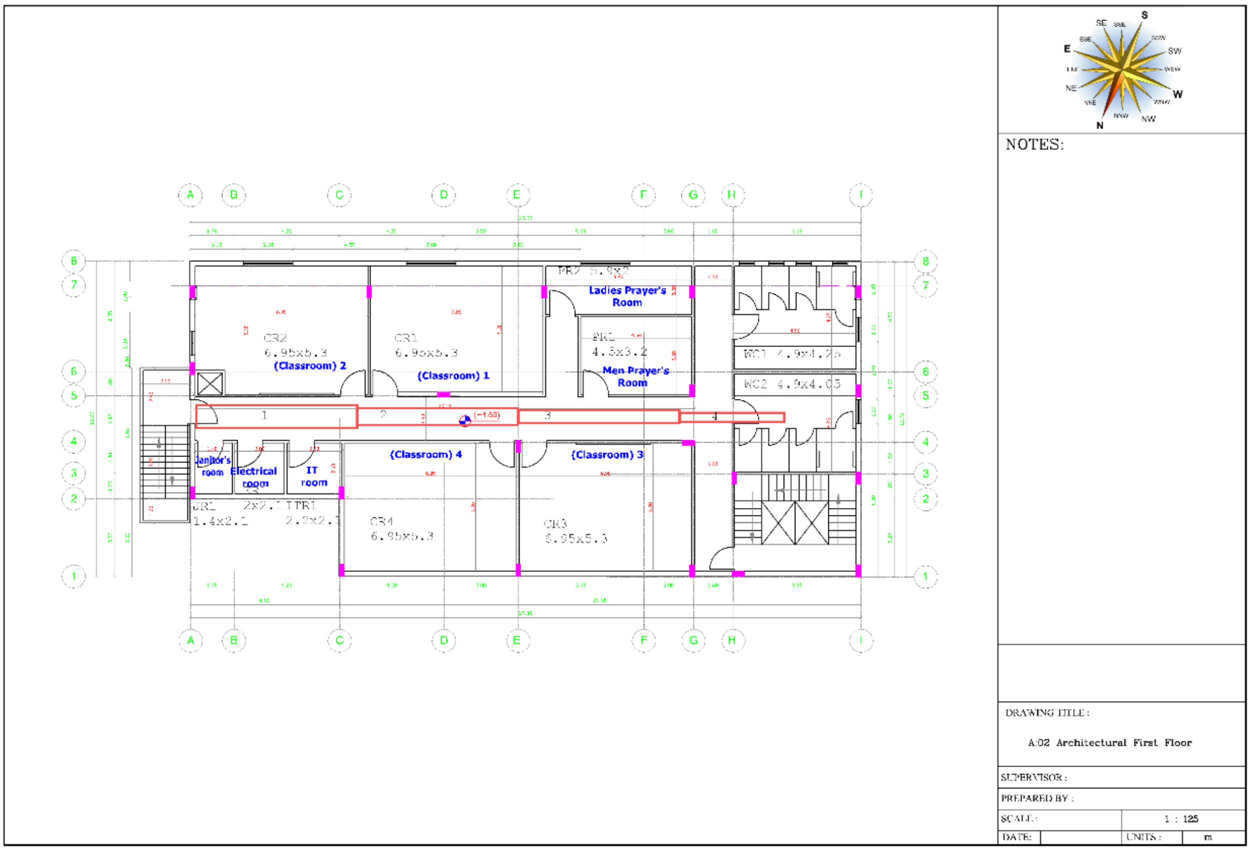

Fig 2:- First Floor Plan

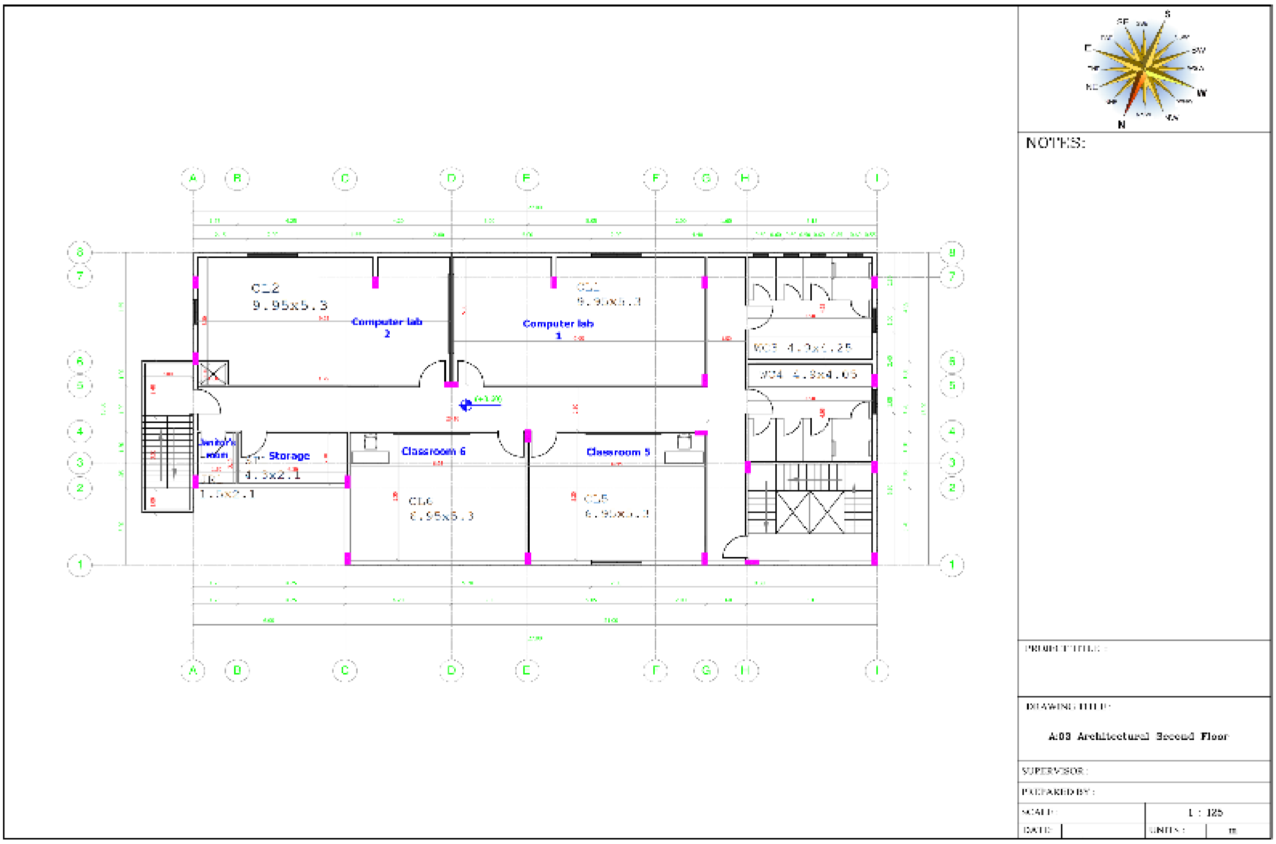

Fig 3:- Second Floor Plan

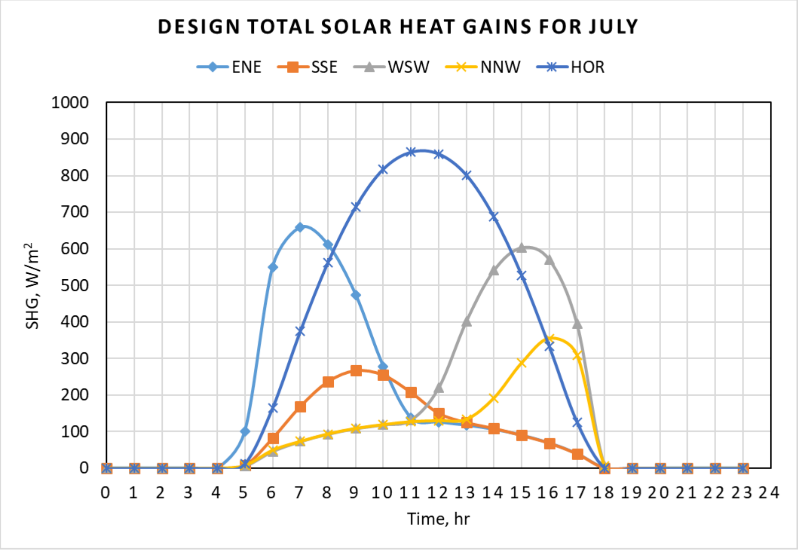

Fig 4:- Total Solar Heat Gain for July through the Directions of the Building

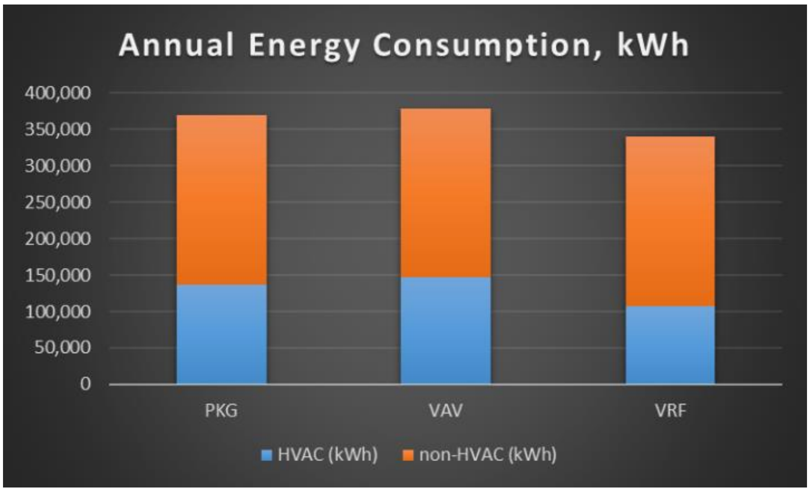

Fig 5:- Annual Energy Consumption for Different HVAC Systems

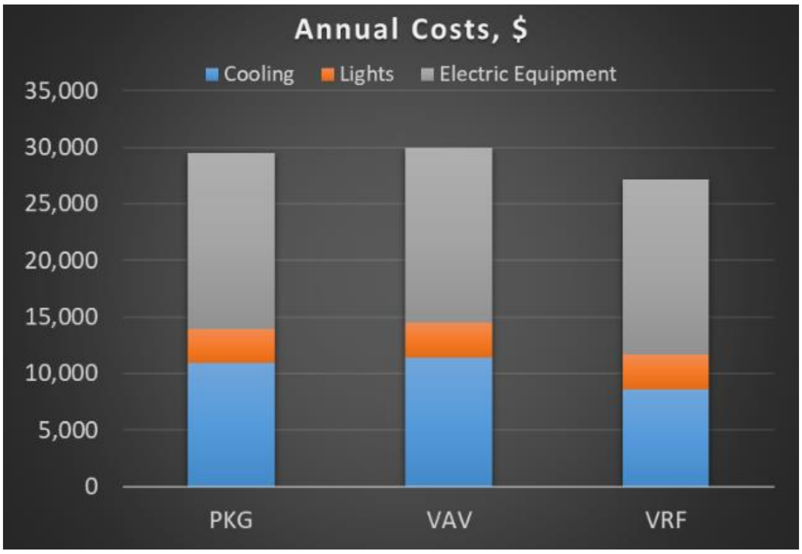

Fig 6:- Annual Energy Cost for Different HVAC Systems

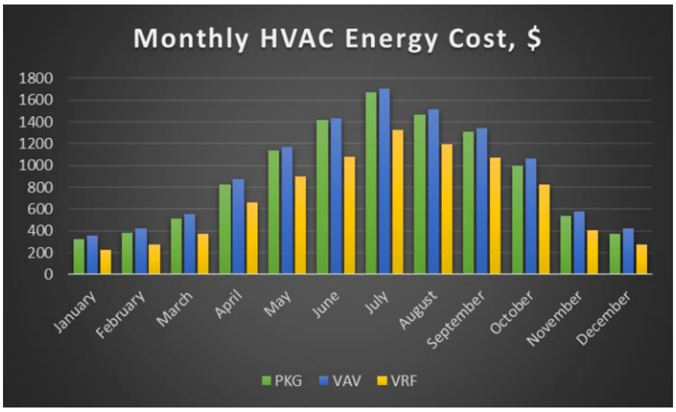

Fig 7:- Monthly Energy Consumption for Cooling for Different HVAC Systems

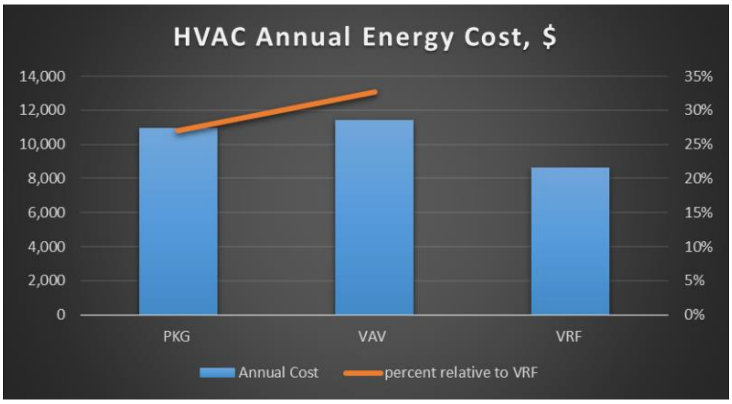

Fig 8:- Annual Energy Cost for Cooling of Different HVAC Systems

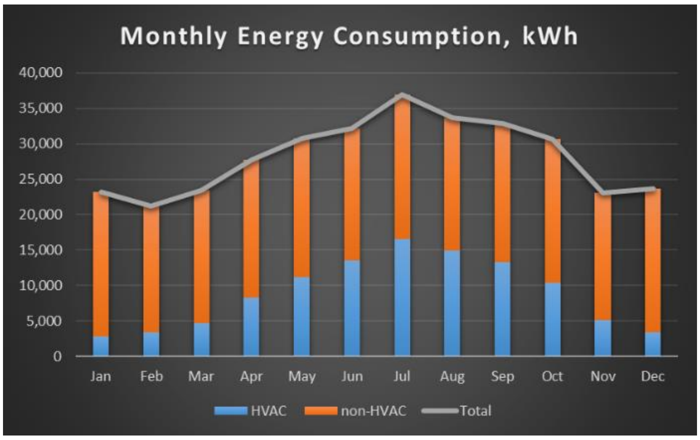

Fig 9:- Monthly Energy Consumption for VRF System

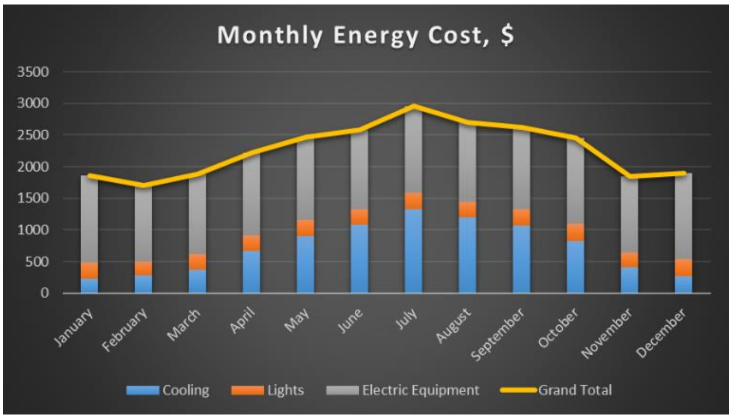

Fig 10:- Monthly Energy Cost for VRF System

TABLES

Frequency (%)	DBT °C (°F)	WBT °C (°F)
1.0	48.0 (118.4)	22.1 (71.8)
2.5	47.0 (116.6)	22.1 (71.8)
5.0	46.2 (115.2)	22.1 (71.8)

Table 1:- Outdoor Design Conditions for Kuwait for Interior Region, (MEW, 2014)

Summer, °C (°F)		
Outdoor		Indoor
DBT	Table 1 above	23.9 (75.0)
WBT		17 (62.5)
RH		50%
DR	13.3 (24.0)	-

Table 2:- Outdoor and Indoor Design Conditions for Kuwait, (MEW, 2014)

Code	Equipment	Unit Power **kW**	# of units	Total Power		
				kW	**BTU/hr**	
3DP	Dimension SST-1200es	1.54	3	4.62	15764.09	**21018.79**
	Fortus 250 mc	1.54	1	1.54	5254.70	
WS	Milling machine	3.73	1	3.73	12727.29	**112259.46**
	Welding stations	3.68	4	14.72	50226.72	
	Drilling machine	0.38	6	2.25	7677.32	
	Table saws	1.50	2	3.00	10236.42	
	Band saws	1.12	3	3.36	11464.80	
	Mitre saws	1.80	2	3.60	12283.71	
	Planer	2.24	1	2.24	7643.20	
Total power				**39.06**	**133278.25**	

Table 3:- Workshop and 3D Printing Lab Equipment Power Rating

Layers	**Thickness mm**	**Density kg/m^3**	**Specific Heat kJ / (kg K)**	**R-Value $(m^2 \cdot K)/W$**	**Weight kg/m^2**
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
Gypsum board	15.875	800.9	1.09	0.09866	12.7
102mm common brick	101.600	1922.2	0.84	0.13977	195.3
RSI-1.9 batt insulation	88.900	8.0	0.84	1.97560	0.7
4-in face brick	101.600	2002.3	0.92	0.07626	203.4
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	**307.975**	**-**		**2.46956**	**412.2**

Table 4:- Wall Layers Details (Inside to Outside)

Layers	Thickness mm	Density kg/m³	Specific Ht. kJ / (kg K)	R-Value (m²·K)/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
Acoustic tile	19.050	480.6	0.84	0.31524	9.2
22 gage steel deck	0.853	7833.0	0.50	0.00002	6.7
102mm LW concrete block	101.600	608.7	0.84	0.26683	61.8
RSI-2.3 batt insulation	101.600	8.0	0.84	2.25782	0.8
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	**223.103**	**-**		**3.01919**	**78.5**

Table 5:- Roof Layers Details (Inside to Outside)

	Window 1	**Window 2**
Dimensions (W × H)	2.0 × 1.85	1.0 × 1.5
Frame Type	Aluminium with thermal breaks	
Internal Shade	Roller Shades - White - Opaque	
Gap type	6 mm air space	
Overall Shade Coefficient	0.297	
Overall U-Value	3.038	3.064

Table 6:- Windows Construction Details

Design Parameters		
City Name	Kuwait City	
Location	Kuwait	
Latitude	29.2	Deg.
Longitude	-48.0	Deg.
Elevation	54.9	m
Summer Design Dry-Bulb	48.0	°C
Summer Coincident Wet-Bulb	22.1	°C
Summer Daily Range	15.4	K
Winter Design Dry-Bulb	3.3	°C
Winter Design Wet-Bulb	-0.1	°C
Atmospheric Clearness Number	1.00	
Average Ground Reflectance	0.20	
Soil Conductivity	1.385	W/(m-K)
Local Time Zone	-3.0	hours
Consider Daylight Savings Time	No	

Table 7:- Weather Design Parameters

Room Name	**Code**	**Floor #**	**Floor Area m^2**	**# ppl**	**Lighting load BTU/hr**	**Equip. Load BTU/hr**
3D Printing Lab	3DP	GRD	9.0	5	2925.7	21019
Instructor's Office	ISO		34.3	5	11127.6	1030
Janitor's Room	JR0		3.2	2	1020.6	95
Open Lec. Area	OL		49.8	30	16141.4	1495
Storage	ST0		30.7	2	9932.8	920
Toilet	WC0		20.1	5	6509.0	603
Workshop	WS		94.2	30	30526.7	112259
Class Room	CR1	1st	36.8	30	11934.3	1105
Class Room	CR2		36.8	30	11934.3	1105
Class Room	CR3		36.8	30	11934.3	1105
Class Room	CR4		36.8	30	11934.3	1105
Elec. Room	ER1		4.2	2	1360.8	126
IT Room	ITR1		4.6	2	1496.8	139
Janitor's Room	JR1		2.9	2	952.5	88
Prayer Room	PR1		14.4	10	4665.5	432
Prayer Room	PR2		11.8	10	3823.1	354
Toilet	WC1		20.8	5	6747.2	625
Toilet	WC2		19.8	5	6429.6	595
Comp. Lab	CL1	2nd	52.7	30	17085.8	1582
Comp. Lab	CL2		52.7	30	17085.8	1582
Class Room	CR5		36.8	30	11934.3	1105
Class Room	CR6		36.8	30	11934.3	1105
Janitor's Room	JR2		3.2	2	1020.6	95
Storage	ST1		9.0	2	2925.7	271
Toilet	WC3		20.8	5	6747.2	625
Toilet	WC4		19.8	5	6429.6	595

Table 7:- Summary of the Building Load used in HAP

	Cooling [kW]
Peak Coincident Indoor Unit Loads	108.7
Estimated Piping / Line Losses	0.7
Total Required ODU Capacity	109.3

Table 8:- VRF Outdoor Unit Sizing Data

- Note: VRF piping/line losses are based on typical loss factors for this class of equipment. Actual line loss varies widely from one product to another. Therefore, when selecting equipment, it is critical to consult manufacturer's guidance to utilize actual line loss data.