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Analytical Comparison of the COP/EER of r134a and r410a refrigerants in Hybrid Solar Air Conditioning (HSAC) System using Northern Nigeria (Abuja) as a Case Study

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ABSTRACT
The HSAC power is a low carbon emission system with relatively high COP (coefficient of performance) in the sunny and humid northern Nigeria. Considering the danger posed to the environment by the use of conventional fossil power, the world is moving towards low Carbon Emission Energy sources. Nigeria as a country located in West Africa with high solar intensity and abundance of other renewable energy is yet to maximize these potentials. Nigeria still have dwindling power supply and is heavily dependent on fossil powers struggling to produce above 7000MW (Vanguard power report, 2022). for more than 200million People (National population commission). This research aims to evaluate the COP/EER of R1134a and R410a when used to design a hybrid solar HVAC in northern Nigeria. This analysis is based on HVAC capacity 20KW, which is believed to be able to power small and medium buildings. The results obtained from the comparison of both refrigerants are checked using BITZER Compressor Software. This work also referred to the energy saved using HSAC and other conventional air conditioning system.

Key Words: Fossil, Fuels, Renewable energy, HVAC, Refrigeration, Air-conditioning, Nigeria, COP, Refrigerant.

I. INTRODUCTION

One of the major power consumption in houses and buildings is the heating, ventilation air conditioning (HVAC) system, consuming more than 50% of the total power supply in the building Al-Abidi et al., (2012). HVAC also contributes in the greenhouse emission, which contributes to the depletion of Ozone layer (CO3) and fossil fuel reduction in the earth reserve Choudhury et al., (2010). Furthermore, it is observed that Fossil Fuel that contributes to more than 80% of the world energy supply is inadequate to meet the increasing energy demands of the world growing population and industries Abbasoglu et al., (2010). This has led to the exploration of solar energy as a vibrant alternative and other types of cooling technology to fossil energy. Therefore, solar energy technology is applied to an Air Conditioning system (ACs) either through thermal driven or by the use of photovoltaic panel. In order to meet alternative power demands, applying solar energy technology to HVAC has shown positive outcome in power saving Vakiloroya et al. (2012).

Solar technology is used for cooling purposes either for comfort (air conditioning) or for refrigeration (refrigerator). Comfort cooling is essential in hot climate like northern Nigeria. Cooling loads and solar radiation are going together because the time for high cooling demand approximately matches with the high solar radiation period. Hence, solar air condition technology can be applied or energy conservation or serving would be achieved through solar technologies such as solar mechanical processes, desiccant cycle and sorption cycle technologies.

It is important to install ACs in buildings especially in hot regions like Nigerian northern region, which provide comforts to the occupants of buildings. The demand for electricity during

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summer or dry season is high due to the high use of appliances that demands on power for comforts and air conditioning. A country like Nigeria with limited power supply and high demand faces a lot of problem during this period. Furthermore, power source produced from fossil fuels produce high rate of CO during this period that leads to greenhouse depletion, global warming and environmental pollution. In addition, conventional air conditioning system has effective impact on global warming ozone layer depletion based on their highly fluorinated gases (refrigerant) such as hydrochlofluorocarbon (HCFC) and hydrofluorocarbon (HFC) which is relatively higher than that produced by CO Zhao et al., (2015).

According to Ravi et al., (2015), the basic energy consumption by the building sector is about 40% while the emission of the greenhouse to the world is about 33%.

Demand of energy for heating, cooling, comfort, electricity, lighting etc., are among the major challenges of modern world. Because of the growing need for power, and the effect of fossil to the earth surface, major research is being made in the areas of renewable and alternative energy. Renewable energy is safer and more comfortable if properly harnessed. Solar energy is among the best technologies that drive cooling cycles because the higher cooling load in the summer or dry season can be achieved with the available higher solar energy during the season especially in the hot or humid climatic areas. A space can be cooled with the combination of solar thermal system and the conventional vapour compression cycle with the assistance of solar collector to reduce the power input of compressor and reach the effect of power saving Vakiloroaye et al., (2012). Fig 1.0 below is a typical hybrid solar assisted air condition (HSAC) cycle.

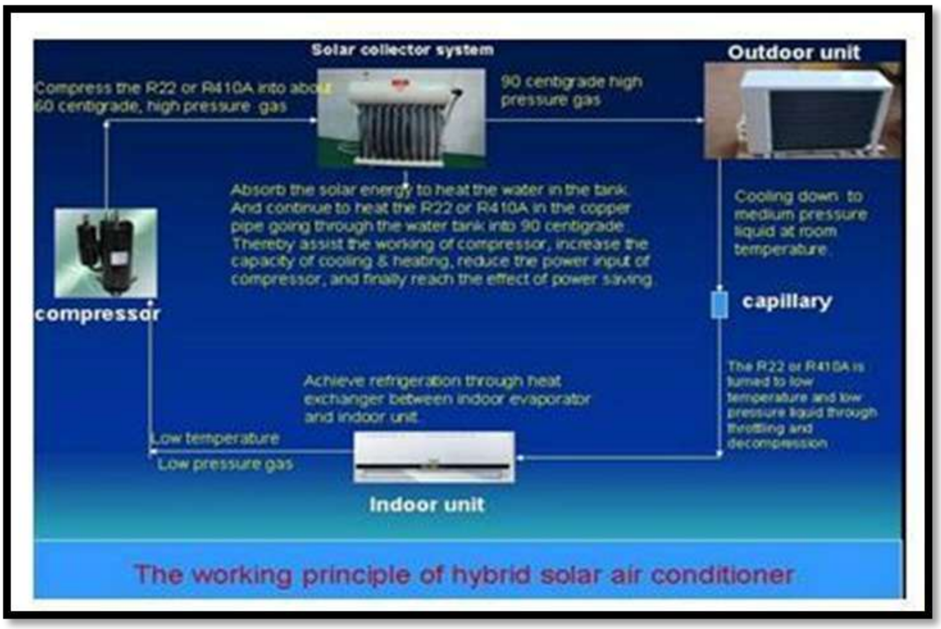

Fig1.0. (Source: https://www.alibaba.com)

II. RENEWABLE ENERGY POTENTIAL IN NIGERIA.

Nigeria is a country in sub-Sahara Africa (Lat. 4 – 14o N, Long 2 – 15oE) with abundance energy resources both conventional fossil fuels and renewable resources (Solar, hydro, wind, biomass etc.). The RE resources are available in all the three major seasons (rainy, dry and harmattan) in Nigeria. About 80% of the populace depend on forest biomass while the other RE is almost untapped or under tapped. According to Mohammed et al., (2013), the estimated RE potential of Nigeria is 697.15TJ from crop residue, 455.80TJ from animal waste and 422MW from solid waste in Lagos Metropolis area.

2.1 Solar Energy Potential in Nigeria

Nigeria has abundance of solar energy because of high sunshine. The country has average solar radiation of about 20MJ/m2 per day, 5.56Kwh/m2/day and 6hrs of sunshine on daily average. Assuming that 1% of the country's land mass is covered with solar collectors, it is possible to generate solar electricity of about 1850 x

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103GWH per day, which is 100 times more than the present electricity consumption in the country Uzoma et al., (2010).

The solar radiation intensity in the country varies from the northern (high) to the south (low), consider fig 2 below. The average monthly solar radiation potential of the northern region ranges from 7.01 – 5.62KWh/m2 per day and 5.43 – 3.53KWh/m2 for the southern region. However, the entire country has adequate solar radiation that can sustain and provide the electricity for domestic energy demand, especially in areas with low power supply Mohammed et al., (2013).

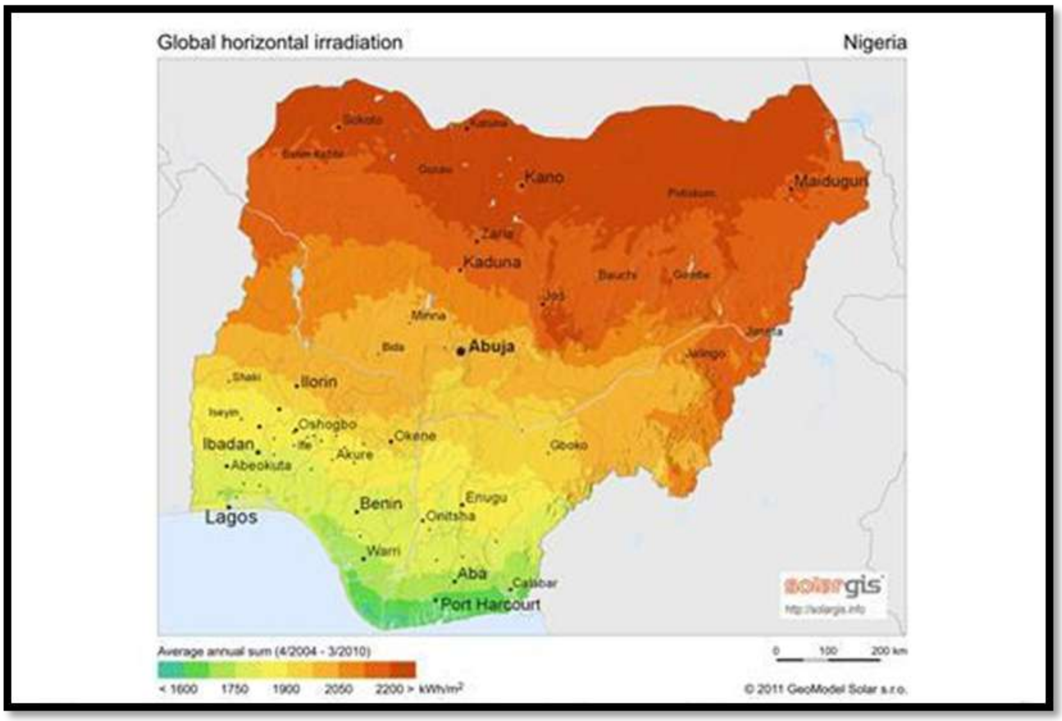

Fig 2.1 Solar irradiation of Nigeria (source: https://www.geosun.com)

2.2 Solar Energy Technology

Solar energy technology (SET) can provide the energy demands for building sectors both residential and non-residential including HVAC, domestic hot water, electricity and lighting. SE does not emit greenhouse gases or CO2 to the environment like conventional energy sources; fossil fuels. SET is applied in most places for all energy demand of buildings.

In summer period, the comfort cooling demands are at peak and so is the solar radiation, which can produce required energy to drive the cooling system. Conventional electric compressors cannot provide the required cooling demand for hottest hours with acceptable energy efficiencies Shesho, (2014).

According to Shesho (2014), solar cooling system can bring more economic advantage to the users. The initial investments are higher than the conventional vapour compression system of cooling. However, the economic advantages of solar cooling system can range from low operational cost of the system, low maintenance of the system to reduced electrical energy consumption.

2.3 Solar Cooling Processes

Solar cooling is an alternative and efficient way of using RE technologies to produce cooling for residential, commercial and industrial places. There is need for air conditioning system in residencies and other places of indoor activities especially during hot and/or humid season in hot climate areas like Nigeria. The availability of solar radiation in the areas during peak cooling load demand has made technologist and engineers to come up with the technology that will combine cooling andsolar thermal energy to conserve energy. This reduces greenhouse gas emissions and reliance on fossil fuels and becomes a more attractive technology.

SE can be utilized in different purposes, the solar cooling process can be done by converting the radiation of the solar to thermal energy by the use of solar thermal collectors to capture the heat and drive the cooling cycle system (absorption or adsorption cycle). SE can also be converted directly to electrical energy by the use of Photovoltaic (PV) panels to provide electrical power to drive VCC system Al- Alili, (2012). Solar cooling technology can be divided into three main categories Al- Alili et al., (2013): Solar electric cooling technology, solar thermal cooling technology and solar combined power / cooling technology as shown in fig. 2.5. The solar electric cooling technology is also sub divided into three sub processes as PV-Peltier cooling system, PV-VCC system and thermoelectric system. The second category, solar thermal cooling, is also sub divided into some processes as open cycle, closed cycle and thermo - mechanical system. Consider fig2.3 below.

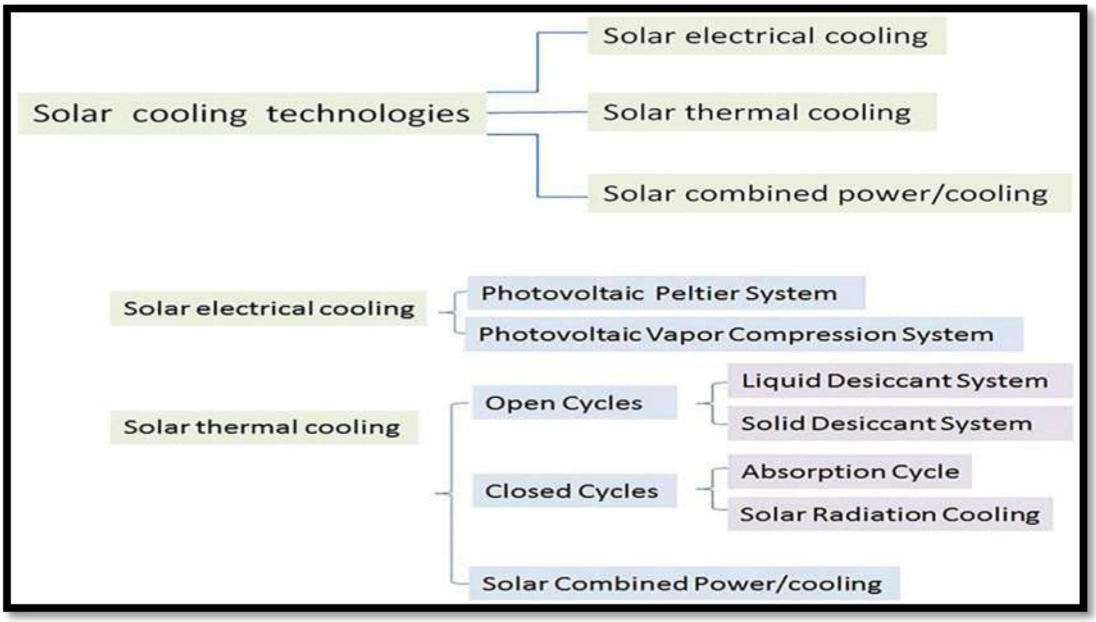

Fig 2.3: Classification of Solar cooling technology Al Alili et al (2013).

2.4 Hybrid Solar Air Conditioning System (HSAC)

Solar air conditioning system can be referred to as any use of solar energy (SE) to condition air for human or environmental uses and can be one of the processes; passive solar, solar thermal energy or Photovoltaic conversion system. The hybrid solar AC for this study uses Vacuum tube solar collector, which is highly efficient and filled with an organic fluid product. The organic fluid inside the vacuum tube solar collector is heated to a high temperature above 100oC using solar radiation and superheat the refrigerant material over the temperature that mechanical compressor can perform with electricity. The additional heat input by solar collector reduce the compressor work - load and lead to the energy saving.

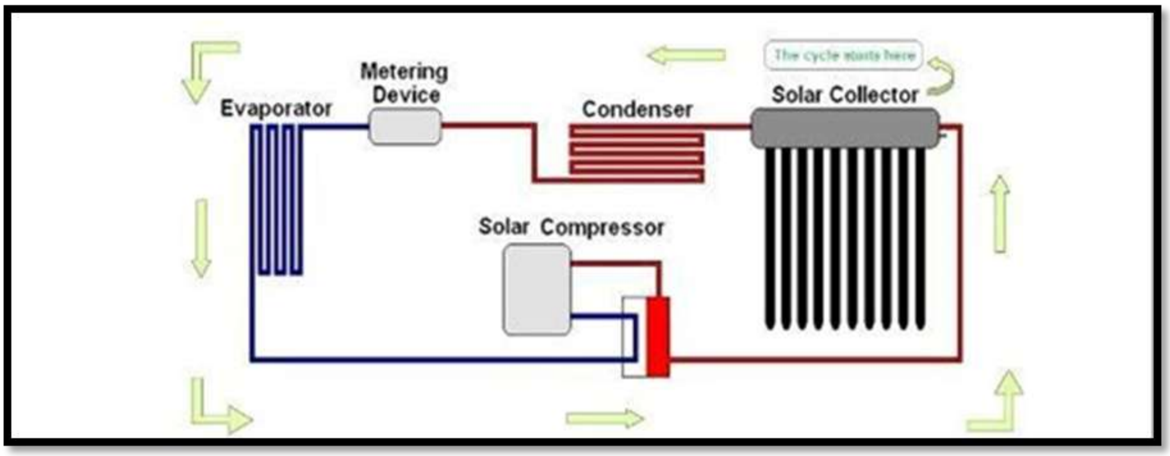

Fig 2.4.0: Hybrid solar air conditioning (https://www.mahine-history.com)

HSAC system is introduced to improve efficiency, reduce reliance on conventional vapour compression system, which consumes more energy, and contribute in greenhouse gases emission. Thermal driving technology for air conditioning was introduced in the beginning of 20th century. Smith (1940) introduced an apparatus and method for cooling in order to adjust the air moisture content by use of desiccant wheel in which operation was thermally driven. The efficiency of the smith system was improved compared to the previous technology because of the separation of cooling and dehumidification. The dependency upon electricity in the improved systems is also decreased. In subsequent years a gas engine was proposed by Maclaine-cross et al (1987), the VCC worked as the heat sink while gas engine served as the heat source for the system and the system was referred to as hybrid system.

Pennington (1951), was the first person who eliminated the need for a VCC and combine the desiccant assisted ACs with evaporative cooling. Lather Dunkle (1965) amended and modified the system to increase its efficiency; he used various heat exchangers also solar thermal energy as source of heat.

According to the research by Daou et al., (2006), Khalid, (2009) and Al-Alili et al., (2012) open cycle desiccant Assisted Air conditioning could make reasonable reduction of primary energy consumption especially by using solar thermal energy to serve as heat source for to the system.

Solar hybrid AC system shows significant advantage due to the higher-level temperature of the heat sink and the supply air for the pre – dehumidification (Burns and Mitchell, 1985; Fong et al., 2011; and Liang et al., 2011). According to Mertz (1992) and Niu et al., (2002) combination of radiant heat exchanger and open cycle AC system can reduced the primary energy consumption.

According to Wrobel et al., (2013), present pilot installation for AC systems operate with the assistances of solar thermal and geothermal energy in Germany. HVAC system can be highly efficient at different climate region worldwide with the combination of radiant heat exchanger and desiccant assisted AC system.

Chua et al., (2012) reviewed energy efficient AC summarized and categorized the efficiency of AC system into three main classes: (Novel cooling devices, innovative system designs and integration, and operational management and control).

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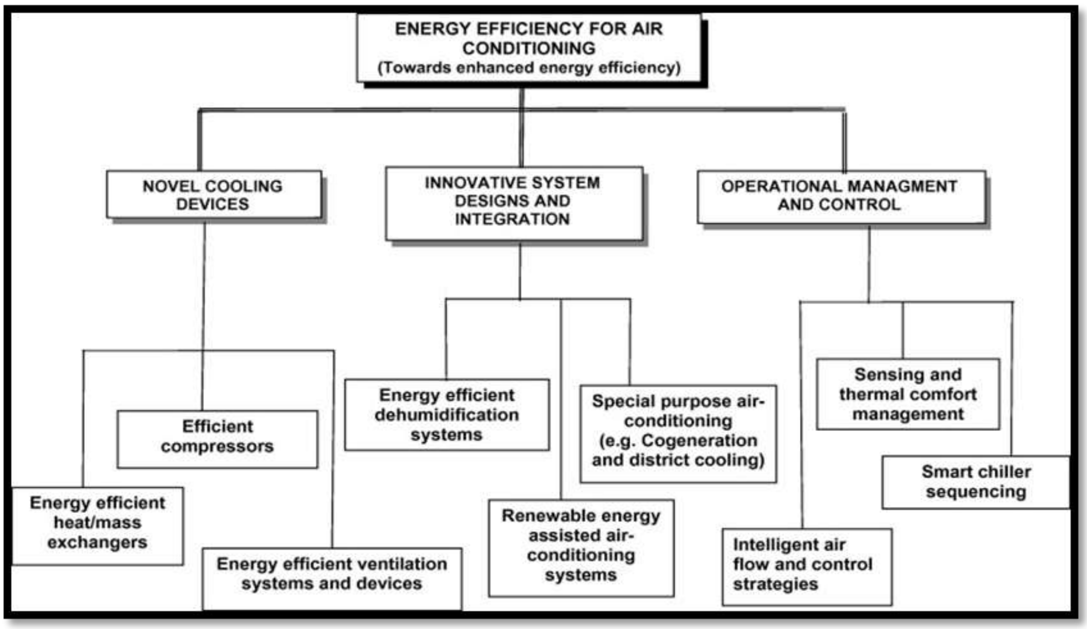

Fig 2.4.1: General outlines of energy efficiency in air conditioning (scienceDirect.com)

This review shows that the systems achieved energy efficient cooling, lower than (0.6 kW/R ton cooling) from the current (0.9 kW/ R ton), many of the above outline technology and strategies must be combined together through holistic approach.

Ha and Vakiloroaye, (2012) presented a novel research on the performance enhancement on direct expansion AC with solar vacuum collector installed between the compressor and condenser, proportional control is also proposed on the research. From the design energy saved from compressor is 6.25% compare to conventional VCC and COP increased more than commonly used design by about 6.7%.

III. METHODOLOGY

Hybrid solar air conditioner (HSAC) is used for long for comfort cooling with different technological approaches, and solar assistance is found to be a solution to energy peak load demand for air conditioning system during summer period. The HSAC system, during hot periods, can receive enough radiation from sun and deliver required cooling demand without any inconveniences because of the peak radiation it gets. Many approaches and technologies have been practised for solar air conditioning system, which includes solar mechanical processes, absorption cycles and desiccant cycles. Nigeria has enough solar potential to drive any solar system for air conditioning during summer seasons.

3.1.0 Case Study

The HSAC cooling capacity is 20kW (68,240 Btu/hr) for offices or homes using two different refrigerants R410a and R134a to see which one can give better efficiency (COP). The outcome is evaluated using the BITZER compressor software.

3.1.1 Refrigerant Analysis

Refrigerants R134a and R410a are selected as the refrigeration in the system. Both of the selected refrigerants are widely used in refrigeration systems as they are considered environmental friendly refrigerants.

3.1.2 Operating Parameters of the Air Conditioner

Table 3.1.2a - Refrigerant r134a

Cooling capacity	20KW (41.1wh/kg)
Condensing temperature	50^{o}C
Evaporating temperature	5^{o}C
Sub cool temperature	7, 10 and 12^{o}C
Super heat temperature	5^{o}C
Flow rate	483kg/h

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Table 3.1.2b - Refrigerant r410a

Cooling capacity	20kw (29.7wh/kg)
Condensing temperature	50^{o}C
Evaporating temperature	5^{o}C
Sub cool temperature	4.6, 7.8 and 10^{o}C
Super heat temperature	5^{o}C
Flow rate	673kg/h

3.1.3 System Configuration and Description

The Hybrid solar air conditioning (HSAC) system is a combination of single-stage vapour compression cycle with solar collector as additional heat input to the system with six major components: a solar vacuum tube collector, a solar storage tank, a compressor, an evaporator, an expansion valve, and a condenser. Fig 3.1.3 below shows the schematic diagram of (HSAC) the system. The refrigeration cycle starts with the combination of liquid and vapour at the evaporator inlet and at the exit, it becomes totally gas and superheated due to the heat absorbed from the conditioning space. At the inlet of the compressor, the refrigerant is super-heated, after it enters the compressor, isentropic compression take place where both the temperature and pressure of the refrigerant are increased. A heat source, solar vacuum collector is installed after a compressor uses solar energy to heat up water inside highly insulated water tank and the storage tank is connected together with solar vacuum collector to retain the temperature of the water, solar collector heats up the refrigerant at constant volume to 100^{o}C, . The superheated refrigerant at high-pressure travels from the solar collector to the condenser where the heat is rejected to the ambient air at constant pressure. At the inlet of the condenser, the refrigerant is 100% gas and at the exit of the condenser the refrigerant become saturated liquid (constant pressure heat rejection). The condensation takes place, at a pressure corresponding to latent heat rejection at50^{o}C. Usually the refrigerant is cooled to a temperature a few degrees below the latter temperature (sub-cooled). The sub-cooled refrigerant is throttled at the expansion valve, and this causes a sudden drop of temperature to the evaporator pressure (throttling is an adiabatic process) and vaporizes as it enters the evaporator and absorbs heat (constant pressure heat addition) from the refrigerated space. The cycle is completed as the vaporized refrigerant re-enters the compressor as super-heated gas.

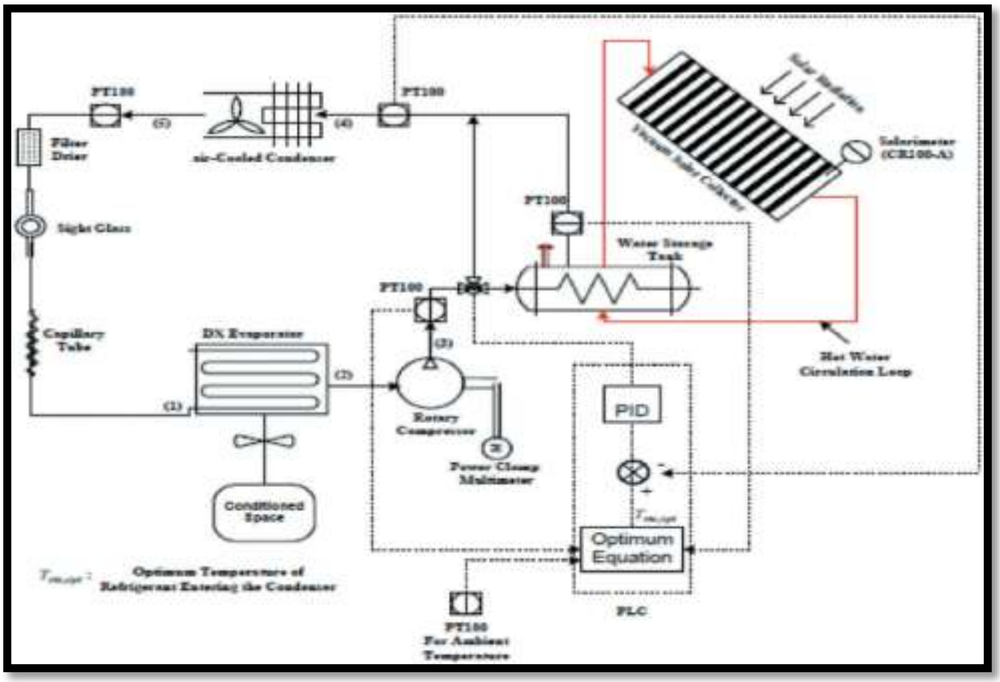

Fig 3.1.3 Schematic diagram of hybrid solar air conditioner (Ha, Vakiloroaye, 2012)

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Note: the control system and equipment required for the constantvolume heating of the refrigerant by the solar collector to 100°C is not considered in this work.

To evaluate the effect of solar assistance, the following tests will be carried out using a commercial refrigeration program.

1) The standard refrigeration cycle
a) 2-5: compressing
b) 5-6: condensing
c) 6-1: expansion
d) 1-2: evaporation
2) The solar assisted refrigeration cycle
a) 2-3: compressing
b) 3-4: solar heating (constant volume)
c) 4-6: condensing
d) 6-1: expansion
e) 1-2: evaporation

The following below is worthy of note:

a. State 3 and state 5 correspond to compressor outlet condition with and without solar assistance respectively and with equal isentropic efficiencies.
b. State 6 and state 7 corresponds to condenser outlets with equal enthalpies.

IV. RESULTS AND ANALYSIS

Figures (4.1.0 & 4.1.1) below show the clear and complete ideal vapour compression refrigeration cycle for refrigerant R134a and R410a, 1-2 (Evaporator), 2-3 (Compressor), 3-4 (Condenser) and 4-1 (Expansion device).

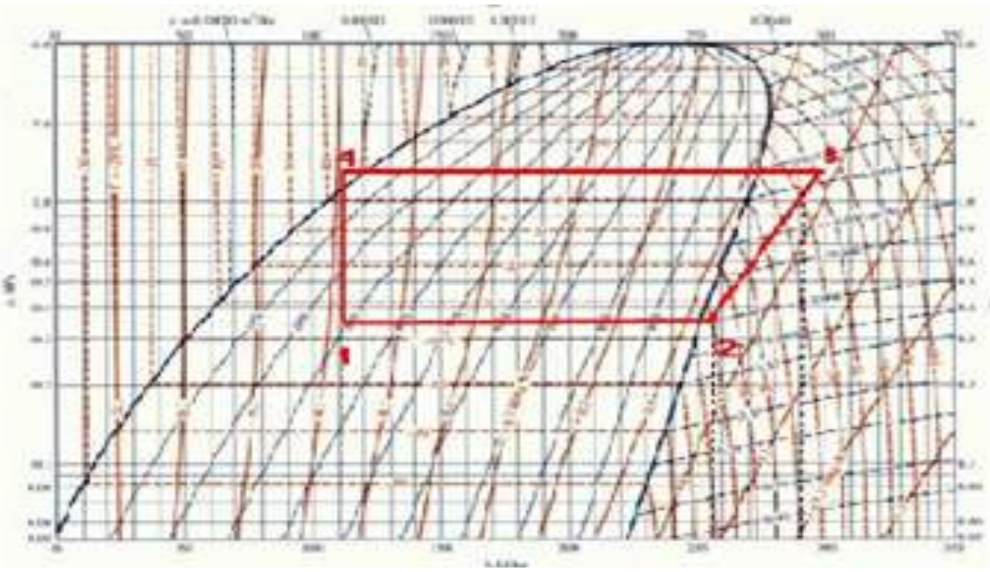

Fig 4.1.0 Ideal refrigeration cycle using r134a

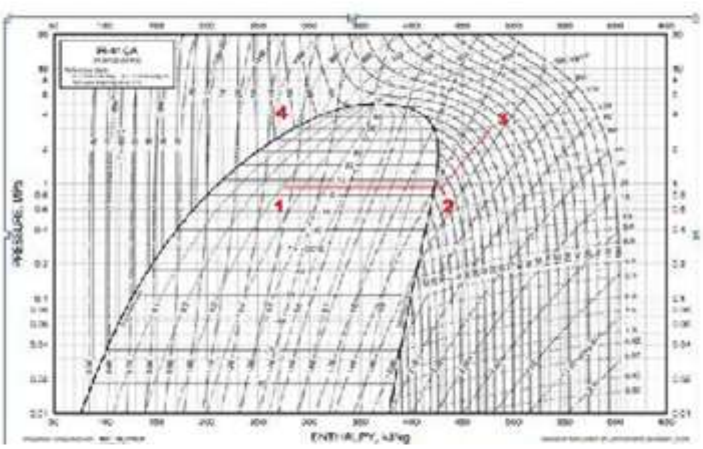

Fig 4.1.1 Ideal refrigeration cycle using r410a.

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4.2.0 Hybrid Solar Refrigeration Cycle

Hybrid solar refrigeration system includes a solar heat collector to replace part of the compressor work. The Vapour Compression Refrigeration Cycle with solar heat assistance is shown in figure (4.2a & 4.2b) for refrigerant R134a and R410a respectively. In these cycles evaporation (1-2) and condensing (4-6) are constant pressure processes. The compressor input (2-3) includes isentropic efficiency while the solar heat input (3-4) is at constant volume. The expansion (6-1) is ideally at constant enthalpy.

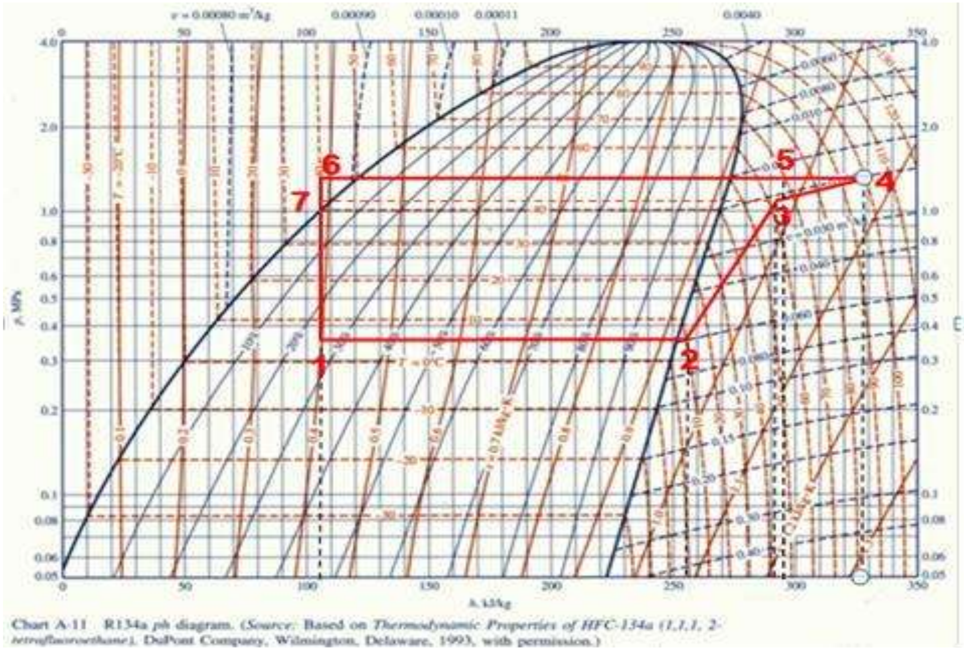

Fig 4.2a: Hybrid solar refrigeration cycle using r134a refrigerant.

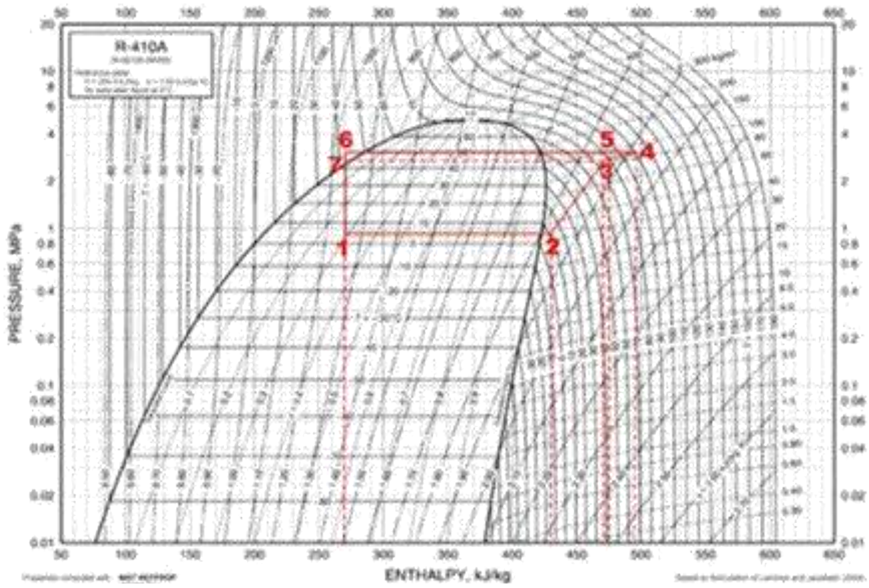

Fig4.2b: Hybrid solar refrigeration cycle using r410a refrigerant

Considering the environmental conditions of Nigeria, the operating parameters of the refrigeration system is set as given below. The refrigeration capacity of the system is assumed to be 20 kW, a capacity to satisfy the requirements of a small to medium building.

Refrigerant charts and a commercial refrigeration computer program was used to

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calculate the heat rejection, heat absorption and compressor power requirements of the designed refrigeration cycle. In all tests, for both refrigerants, the condensing temperature is set at 50°C and evaporation temperature was set at 5°C. A 5°C superheat (state 2, exit from the evaporator) was assumed for all cases. The sub-cooling temperature (state 6, exit from the condenser) however was varied between 4.6°C and 12°C.

Refrigerant charts and the commercial program was used to test the cycle with and without solar assistance. Solar heat addition is aimed at reducing the compressor power requirement. For this purpose, the compressor outlet (state 3) is adjusted to be at a lower pressure (corresponding to a lower condensing temperature), and solar heat is then supplied at constant volume (states 3-4) to increase the pressure to the designed condensing (corresponding to 50°C) pressure of the system. In all cases, the solar heating portion of the cycle is limited to 100°C.

4.3.0 Results

Table 4.3.0

Refrigerants	R134a	R410a
Cooling capacity	20kw	20kw
Condensing temperature	50^{o}C	50^{o}C
Evaporating temperature	5^{o}C	5^{o}C
Sub cooled temperature	7^{o}C	4.6^{o}C
Super heat temperature	5^{o}C	5^{o}C
Flow rate	483kg/h	673kg/h

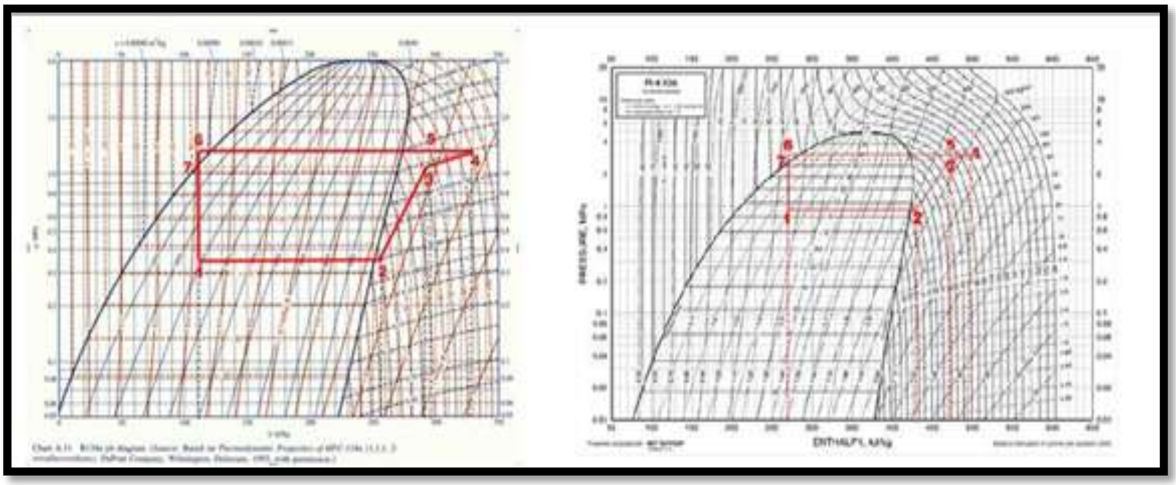

Fig 4.3.1a Hybrid solar refrigeration Cycle Using r134a refrigerant at sub cooled 7^{o}C

Fig 4.3.1b Hybrid Solar refrigeration cycle Using r134a refrigerant at sub cooled 4.6^{o}C

Table 4.3.1: Summary of refrigerant r134a at sub cooled 7, 10 and 12^{o}C and refrigerant r410a at sub cooled 4.6, 7.8 and 10^{o}C (per unit refrigerant flow rate).

	R134a			r410a		
Sub cooled	7	10	12	4.6	7.8	10
Condensing (heat removal Q_{4-6})wh/kg	63.14	64.60	65.40	60.97	62.50	63.61
Evaporating (cooling effect Q_{2-1})wh/kg	39.96	41.40	41.88	42.90	44.44	45.54
Compressor input (Q_{3-2}) kw/kg	10.26	10.26	10.26	11.09	11.09	11.09
Solar input (Q_{4-3}) kw/kg	12.90	12.90	12.90	6.93	6.93	6.93
COP/Electrical Energy ratio(EER)	3.89	4.03	4.11	3.86	4.01	4.10
Mass flowrate (kg/h)	1	1	1	1	1	1

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4.4.0 Evaluation of Results Using the BITZER Compressor Software

BITZER software was use to check and compared the results of compressor input, solar input and the EER of the systems. The result are compared to see the energy saving and the CO_2 abate per year.

Without solar heat input the refrigeration cycle for refrigerant R134a and R410a is 1-2, 2-5, 5-6 and 6-1 (as shown on the p-h chart for the refrigerants).

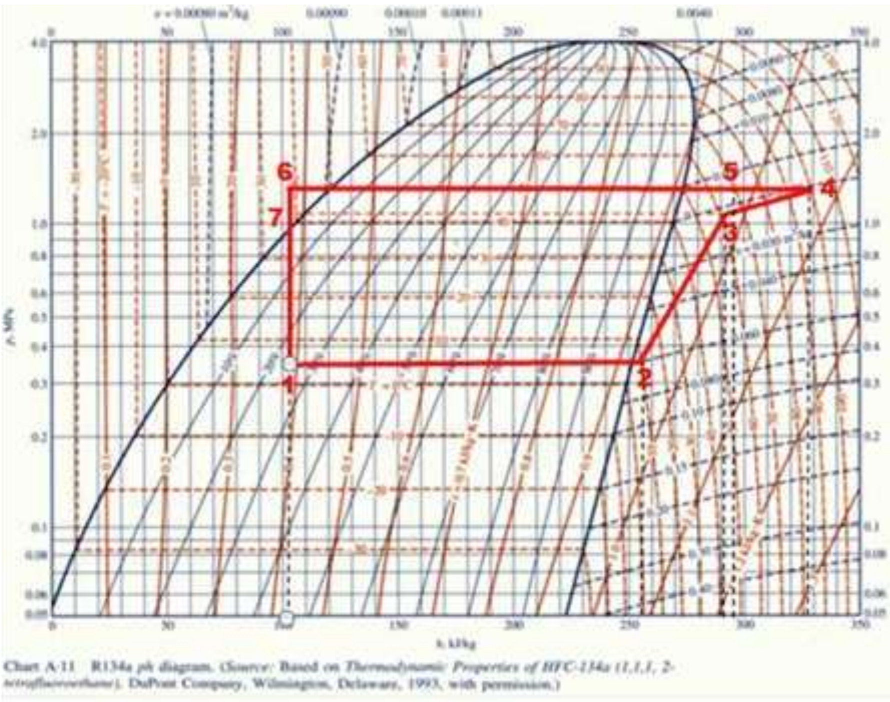


Fig4.4a: Refrigerant r134a

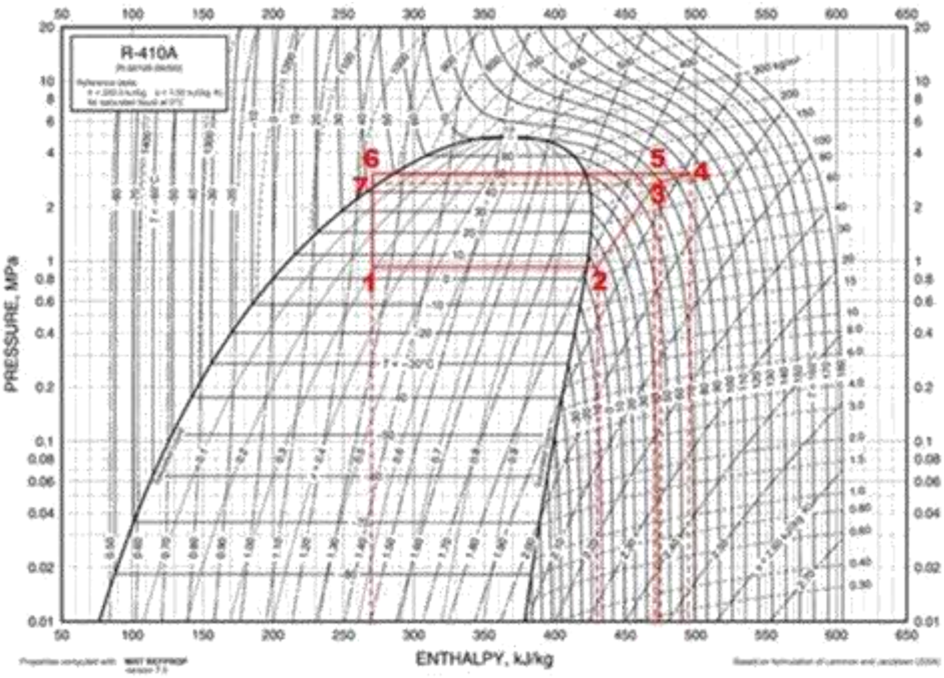
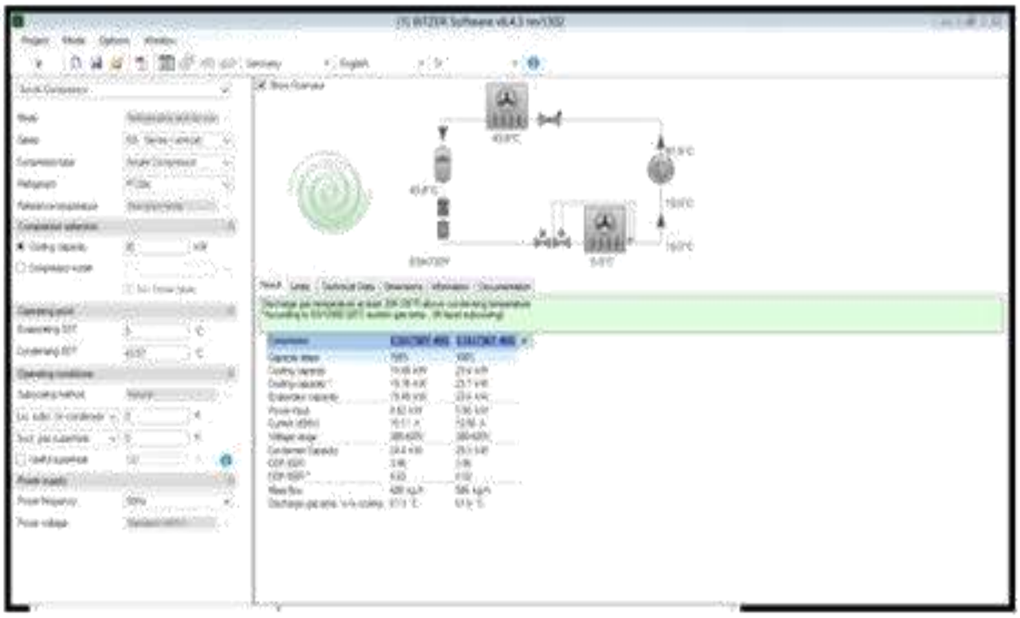


Fig4.4b: r410a Refrigerant

The BITZER Compressor Software result is shown below:
Table 4.4.1: Refrigerant r134a and r410a BITZER program output without solar input (per unit refrigerant flow rate).

Refrigerants			r134a			r410a		
Sub cooled		7	10	12		4.6	7.8	10
Condensing temperature (^oC)		50	50	50		50	50	50
Evaporating temperature (^oC)		5	5	5		5	5	5
Condensing (wh/kg)		51.75	53.00	53.83		54.38	56.16	57.20
Cooling effect (wh/kg)	40.12	41.38	42.23		42.20	43.98	45.02	
Power Input (wh/kg)		11.67	11.67	11.67		12.16	12.16	12.16
COP/EER		3.43	3.54	3.61		3.47	3.61	3.70
Mass Flowrate (kg/h)		1	1	1		1	1	1



Another manual checking was carried out to see the compressor effect with the refrigeration cycle 1, 2, 3 and 7 in figure 4.4a and 4.4b above. State 3 correspond to compressor outlet and state 7 corresponds to condenser outlets. In all tests, for both refrigerants, evaporation temperature was set at 5°C. A 5°C superheat (state 2, exit from the evaporator) was assumed for all cases. The condensing temperature is set at 43.57°C and 45°C for refrigerants R134a and R410a respectively. The sub-cooling temperature (state 7, exit from the condenser) however was varied between 0°C and 5.4°C.

Table 4.4.2 below shows refrigeration cycle 1 2 3 and 7 in **fig 4.4a and 4.4b** above at lower condensing temperature (per unit refrigerant flow rate)

Refrigerants			r134a				r410a	
Sub cooled (^oC)	0	3.5	5		0	3.2	5.4	
Condensing temperature (^oC)		43.47	43.57	43.57		45	45	45
Evaporating temperature (^oC)		5	5	5		5	5	5
Condensing (Heat removal Q_{3-7})	50.24	51.67	52.48		53.62	55.13	56.23	
Evaporating (cooling effect Q_{2-1})	39.95	41.40	42.21		42.90	44.44	45.34	
Compressor input (Q_{3-2})wh/kg	10.26	10.26	10.26		11.01	11.01	11.01	
COP/EER		3.89	4.00	4.11		3.86	4.00	4.10
Mass flow rate kg/h		1	1	1		1	1	1

4.5 Discussion

Table 4.5.0

Refrigerants		r134a			r410a	
Sub cooled temperature (^oC)	7	10	12	4.6	7.8	10
Compressor power without solar input	11.67	11.67	11.67	12.16	12.16	12.16
Compressor power with solar input (wh/kg)	10.26	10.26	10.26	11.09	11.09	11.09
COP/EER without solar input	3.43	3.54	3.61	3.47	3.61	3.70
COP/EER with solar input	3.89	4.03	4.11	3.86	4.01	4.10
Mass flowrate (kg/h)	1	1	1	1	1	1

Table 4.5.0 above compares the compressor power input and COP/EER with and without solar heat input for refrigerants r134a and r410a at different sub cooled temperatures (per unit refrigerant flow rate).

The graphical representation of the above (fig 4.5.0) is shown below.

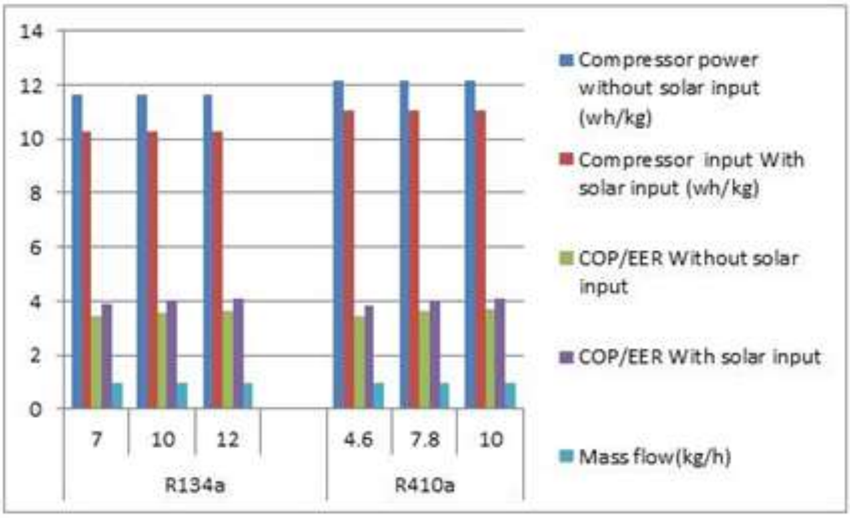


Table 4.5.0 compares compressor input and COP/EER of HSAC with conventional VCC, both of them at same parameters. From the findings, it can be seen that there are considerable difference between the compressor input with and without solar input in the system, the difference in terms of percentage decreased are 12.08% and 8.97% for the refrigerant R134a and R410a respectively. For the COP/EER, it is clearly seen from the chart that at 12^o sub cooled, there is increase of 13.85% for the refrigerant R134a and 10.81% increase for the refrigerant R410a. The annual electrical energy saved per year using this design are also considerable which result as E_s= 1130.27 kwh$_e$ per year (12.08%) for R134a and E_s= 857.76 kwh$_e$ per year (8.8%) for R410a. Similarly, the CO_2 emission avoided by this process per year per kilogram are 481.2 kg/yr and 317.4 kg/yr for R134a and R410a respectively. It is also shown that higher sub cooled temperature give better results, this corresponds with the research on Hybrid AC compared with standalone VCC carried out by Ge et al (2008). Similarly, sub cooled 12^{o}C gives higher COP/EER than sub cooled 10^{o}C. It is suggested that when designing HSAC using R134a or R410a as working fluid, higher sub cooled temperature should be used, this correspond with the research of Ha, and Vakiloroaya, (2012) on energy enhancement solar air condition, which shows that after heat rejection to the ambient by condenser, higher sub cool temperature significantly increases the overall system COP.

4.6.0 Annual Energy Savings: (Using cooling degree per day approach).

In order to calculate the energy saved per year, cooling degree per day approach have to be incorporated in the calculation. Cooling degree per days for **Abuja Nigeria station ID** (DNAA) was selected for the purpose. The table 4.6.1 below shows the cooling degree days for hot months (April- November), based on indoor temperature of 25^{O}C.

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Fig 4.6.1 – Cooling days for Abuja, Nigeria.

Description:	Celsius-based cooling degree days for a base temperature of 25.°C	
Source:	www.degreedays.net (using temperature data from www.wunderground.com)	
Accuracy:	Estimates were made to account for missing data: the "% Estimated" column shows how much each figure was affected (0% is best, 100% is worst)	
Station:	Abuja, NG (7.26E,9.01N)	
Station ID:	DNAA	
Month starting	CDD	% Estimated
01-04-15	122	30
01-05-15	102	25
01-06-15	39	10
01-07-15	48	33
01-08-15	19	18
01-09-15	32	59
01-10-15	47	48
01-11-15	92	43
TOTAL		**501**

Energy saved per year
The cooling capacity required during peak hot season for this evaluation is 20kW. The cooling degree days from table 4.4.1 is 501 degree days
The outside design temperature $T_o = 40^OC$
The indoor design temperature $T_i = 25^OC$
The effective, full capacity operation time (H_f) of the air conditioning unit is estimated as follows:

For the refrigerant R134a
Electrical energy used, E_e for the cooling purpose is thus calculated as:
a.) Without solar assistance, with 12°C sub-cooling
b.) With solar assistance with 12°C sub-cooling

Electrical Energy Saved: E_s= 1130.27 kwh_e per year (12.08%)

For the refrigerant R410a
Electrical energy used, E_e for the cooling purpose is thus calculated as:
a.) Without solar assistance, with 10°C sub-cooling
b.) With solar assistance with 10°C sub-cooling

Electrical energy saved: E_s= 857.76 kwh_e per year (8.8%)

V. CONCLUSION

Solar energy technology is promising, reliable and efficient. From the result of the research, for both of the refrigerants used, the COP/EER of the HSAC is higher than that of the conventional VCC with considerable differences, the electrical energy saved per year are also considerable.

Recommendation
Based on the evaluation using the r134a and r410a refrigerants, the followings need further evaluation and comparison.

- Based on the results of the r134a and r410a have shown little improvements on energy savings, another sets of refrigerants like r152a and r500a should be studied to see their impact on efficiency performance and energy savings.

- With respects to the system parameters, other condensing and evaporating temperature should be tested.
- Heat supplied by solar collectors should be increased to achieve higher temperatures, say 110°C.
- In most developing countries like Nigeria, the initial cost for renewable energy installation is very high. Government should provide incentives both fiscal and non-fiscal to private investors to ensure that it become competitive with conventional energy.
- The control system for the constant volume heating by the solar collector to 100°C is not included in the analysis and is recommended for further research work.

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