PERFORMANCE EVALUATION OF A SOLAR HYBRID AIR-CONDITIONER

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Keywords:

Solar Hybrid Air-Conditioner;
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A B S T R A C T

This research presents a solar hybrid air-conditioning system with R410a refrigerant. The sole aim was to compare the performance of a solar hybrid air-conditioner with that of the conventional split-unit air-conditioning systems in the market today. From the experiments conducted, the room temperature of a solar hybrid air conditioner was found to be :27.2, 27.0, 27.0, 27.2, 27.2, 27.0, 28.0, and 29.5 while that of the conventional air conditioner was found to be:69,66,64,66,73,69,66,62 indicating that solar hybrid system had lower values in terms of room temperature than that of the split units air conditioner. Laboratory results, field assessments, and simulations clearly established that hybrid air conditioners can deliver substantial energy savings and demand reduction. Therefore, in the present study, performance evaluation of the solar hybrid system with that of the split units is used to develop approximate analytical solutions for heat transfer in boundary layer flow and heat transfer.

NOMENCLATURE

LP-Low Pressure

HP-High Pressure

T_1-The compressor inlet temperature

T_2-The compressor outlet temperature

T_3-The condenser inlet air temperature

T_4-The condenser outlet air temperature

T_5-The evaporator outlet air temperature

T_6-The evaporator inlet air temperature

T_7-The evaporator 2 outlet air temperature

T_8-The evaporator 2 inlet air temperature

S_1-Room temperature setup

S_2 –Room 2 temperature

D_1-Room temperature difference

SP – setting low pressure

PD – low pressure difference

CM-Compressor

E_1-Evaporator fan speed 1

OF-Out fan

L_1-Thermal load

V_5-Valve 5

V_6-Valve 6

COP-Coefficient of performance

Q = Amount of heat in KJ

ṁ = Air mass flow rate in kg/s

$\Delta h = (h_1 - h_2)$ Enthalpy change in KJ/Kg.

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1. INTRODUCTION

The energy consumption for residential buildings constitutes one-third of the world's primary energy demand, while many today would argue that the demand increases rapidly as a result of the increase in population growth and the need to improve standards of living in the world. (Olatomiwa et al., 2015). Non-stop use of different source of non-renewable energy is as a result of the hike in fuel price and production of large amount of harmful gas into the atmosphere (Sandeep et al., 2016). Air conditioning (AC) controls the temperature, relative humidity, movement and purity of the air for human comfort. (Olatomiwa et al., 2015), (Modera et al., 2018), (Tyagia et al., 2012), (Sandeep et al., 2016). There is an increase in demand for the production of air conditioning. Nowadays improving standards of ventilation, global environmental awareness and increasing concerns about indoor air quality have tremendous impact on changing the design of air-conditioners. Solar air conditioner is one which uses solar energy to produce cold or hot air and do not pollute the environment (Saudagar et al., 2016); (Schlepp & Schultz,1984). An addition of a thermal heat exchanger to this type of system, as investigated by this work, has the potential to be an effective way of maximizing the system's solar energy generation potential in a cost-effective manner (Ariff Rahman Bin Ishak, 2014) the pressure-volume and temperature-entropy diagram for simple AC refrigeration cycle is shown in the figure 1.

(a) (b)
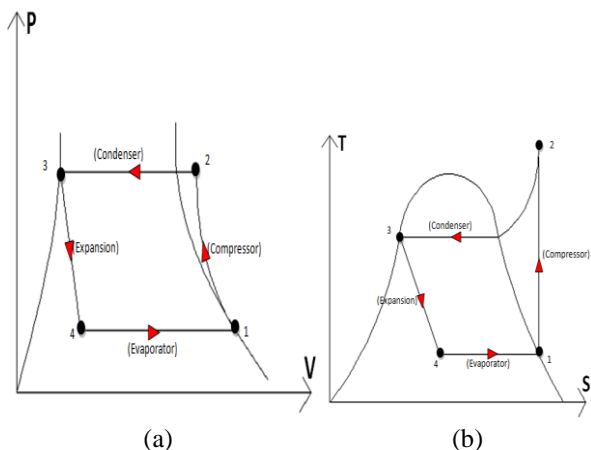
Figure 1. PV and TS diagram of Conventional AC Refrigeration Cycle (Ariff Rahman Bin Ishak, 2014)

The PV and TS diagram of Conventional AC Refrigeration Cycle (Ariff Rahman Bin Ishak, 2014) shows that vapor compresses isentropically from point $1 \rightarrow 2$, and this increases the pressure from the evaporator to the condenser. At 2, phase change occurs as a result of constant heat rejection as the vapor enters the condenser (Kumar et al., 2016). At 3, latent heat is removed, then the liquid refrigerant passes through the expansion valve in order to ensure that the enthalpy is constant and the pressure is reduced. (Ariff Rahman Bin Ishak,2014)


(a) (b)
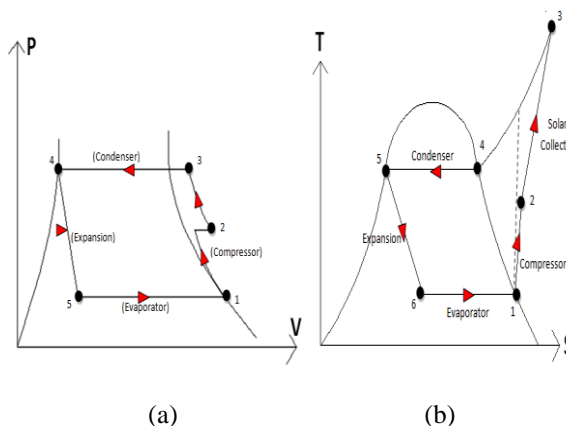
Figure 2. PV and TS diagram of Designed Hybrid Solar AC Refrigeration Cycle (Ariff Rahman Bin Ishak, 2014)

Point 1 and 2 in the PV and TS diagram of designed hybrid solar AC Refrigeration Cycle (Ariff Rahman Bin Ishak,2014) are the respective design parameters for the electric compressor outlet and solar compressor outlet. Since Point 2 is the solar compressor outlet, the parameters varies with the availability of solar radiation. Point 1 and 2 are closely related, thus both are precisely controlled so that electric compressor will supply additional compression power during low solar radiation period. (Ariff Rahman Bin Ishak, 2014) Point 1, 3 and 4 are kept constant as the conventional system to achieve the same cooling capacity Hybrid air conditioners are more efficient than conventional air conditioning technologies(Koli, 2019). Hybrids has multiple subsystems that are selected for specific climates and applications. Ideally, energy flow between subsystems is organized to gain more advantages, and operation of each subsystem is coordinated so that a single machine operates in many discrete modes to provide only the needed capacity with the least resource consumption. Researchers have proposed and evaluated many unique hybrid system architectures. Laboratory studies, field assessments, and simulations have clearly established that hybrid air conditioners can deliver substantial energy savings and demand reduction (Kaidir et al., 2017). These studies have indicated annual energy savings for cooling and ventilation between 30-90%, depending on climate, application, and technology. However, it is difficult to make an informed assessment about which hybrid systems are most appropriate for different buildings in different climates. Most researchers have employed a mix of first-principle and empirical methods to model particular hybrid systems by means of complex component by component models.

Given the complexity of this process, no researcher has conducted a thorough parametric assessment of a wide variety of hybrid systems in different climates and applications. Since every researcher employs different analytical methods and uses different performance assessment metrics, literature review to compare the various hybrid systems evaluated in separate studies only provides limited insight. Consequently, thorough

assessment of alternative hybrid strategies has heretofore been infeasible for engineers in practice. In response to these challenges, through this project we developed a generalized empirical method to model the performance of hybrid unitary air conditioners within building energy simulations (Modera et al., 2018). This research will be based on the performance analysis of a solar-hybrid air conditioning system in other to provide the cooling and heating energy demands of a residential building. This research showed why the utilization of green sources of energy results in low exergy efficiency of about 10 percent, since solar and geothermal energy conversion facilities are considerably exergy destructive. However considerable saving in fossil fuels and reduction in green house effects are observed.

(Gugulothu et al., 2015) stated that water and energy were the basis necessity for humans in other to live a normal life on earth. Solar energy technologies have proved to be useful for the developing and under developed countries in order to sustain their energy needs. Solar cooling is a good example of addressing climate changes. Long term data should be used to prove the feasibilities of air conditioning systems. (Saudagar et al., 2016) reviewed new solar based air conditioning techniques. These techniques used solar energy to produce cold or hot air and do not pollute the environment. (Saudagar et al., 2016) and (Naskar et al., 2018) reported the application of Air-Conditioner increases day to day as home appliances and in industry from the last decade.
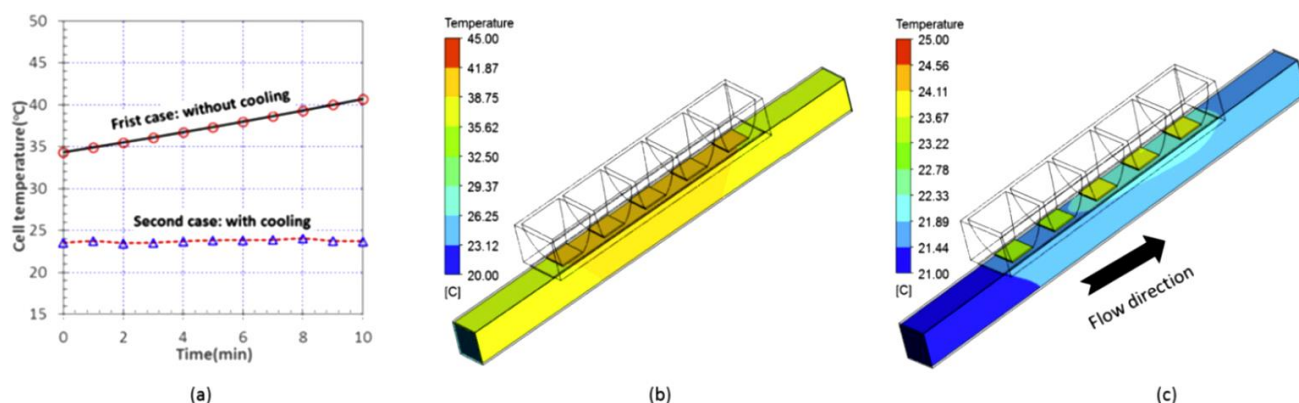
Figure 3. Predicted mean cell of a hybrid solar air- conditioner (Avijit & Hasan, 2018)

Today, the predicted mean cell of a hybrid solar air-conditioner consumption of electricity decreased repeatedly and reduction of fossil fuel resources brought about a significant role in the development of eco-friendly and energy efficient technologies. (Sandeep et al., 2016), (Kaidir et al., 2017) reported the performance of the hybrid air- conditioning system. For a chosen regeneration temperature, the hybrid system is economically up to certain humidity level compared to split unit air condition alone (Abbasi et al., 2016), (Avijit & Hasan, 2018) Therefore, in the present study, performance evaluation of the solar hybrid system with that of the split units is used to develop approximate analytical solutions for heat transfer in boundary layer flow and heat transfer.

2. MATERIALS AND METHOD

The hybrid solar system comprises six main components: a compressor, air-cooled condenser, an expansion device, an evaporator, conventional solar collector and a storage tank of hot water. The schematics is shown in figure 4 below. The refrigerant contains a mixture of liquid and vapor and they enter the evaporator (point-1). Evaporator coil absorbs the heat from hot air the liquid becomes superheated at the evaporator outlet, and enters the compressor (point 2), where increasing pressure causes

increase in refrigerant temperature. The vacuum solar panel installed after the compressor heats up the water. An insulated water storage tank is connected to the vacuum solar collector in other to maintain the temperature of water. Refrigerant from the compressor now passes through the copper coil in heat exchange tank (point 3). Once the conditioned air temperature reaches the required temperature, the compressor would automatically go off. However, during the compression stage, the additional heat absorbed must be rejected in the condenser. Further reduction will occur at point 4; thus, the sub-cooled liquid finds its way to the expansion device at point 5.

The figure 4 shows the flow diagram of solar hybrid system (Sandeep et al., 2016).It is paramount to note the hybrid air conditioner runs on both electricity and solar energy. In this era, hybrid solar air - conditioner used more because it is environmentally friendly and does not produce any harmful gases. Hybrid solar system reduces power consumption than normal air conditioner. This system uses solar energy as heat that is as additional heat sources to help the more energy required operating the cooling process of the solar system typical air conditioning to reduce consumption 'energy'. Now a days R-410a refrigerant is generally used because it is eco-friendly (Sandeep et al., 2016).
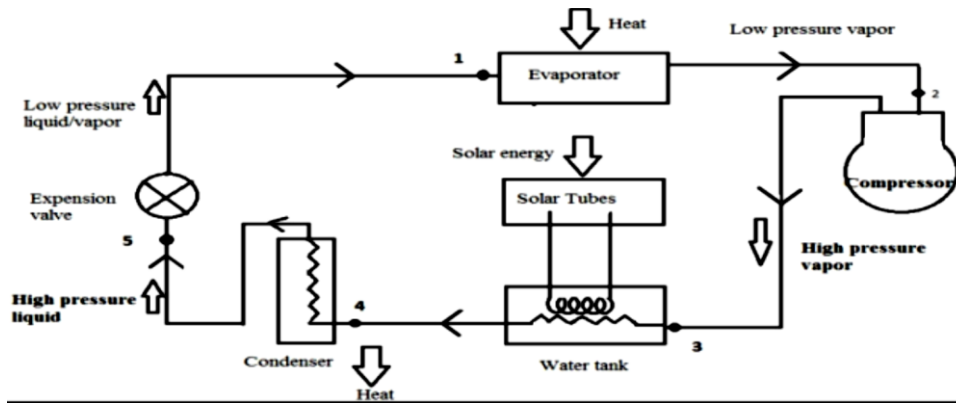
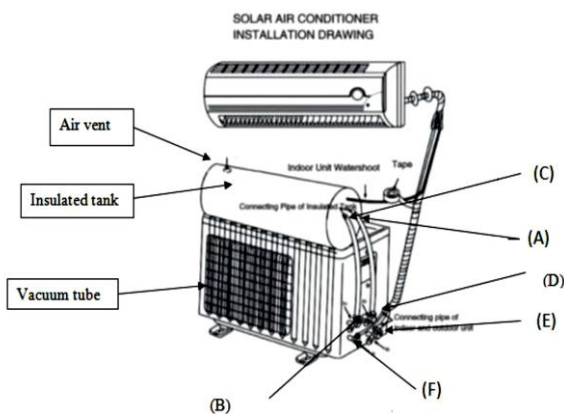**Figure 4.** Flow diagram of solar hybrid system (Sandeep et al., 2016).

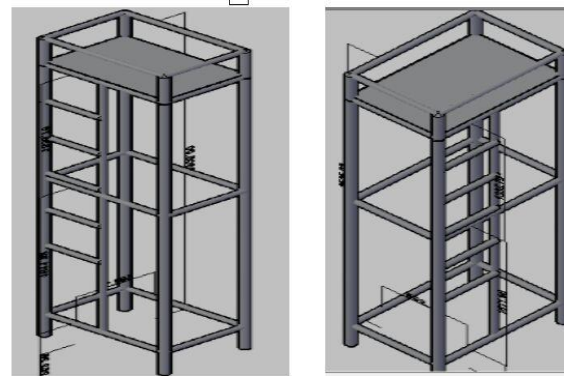**Figure 5**. Schematics diagram of hybrid solar air-conditioning system (Sandeep et al., 2016).

Figure 7. Showing the structures used to mount the solar hybrid air conditioner (mm)
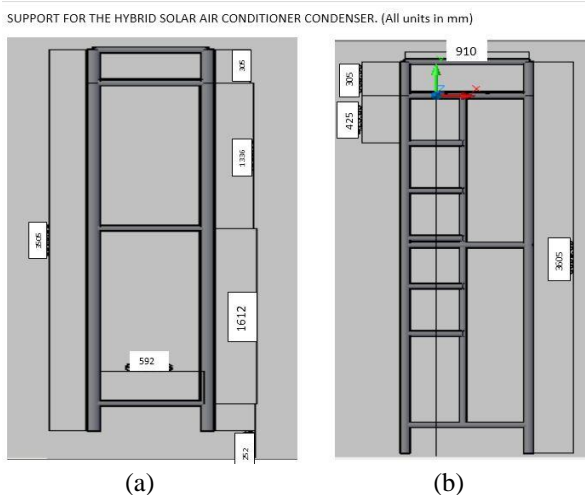

Figure 6. Side view of a solar hybrid air conditioner support (mm)

2.1 Experimental Set Up

In figure 8, the schematic of the measurement setup is shown. The green dots are the pressure gauges (referred to as P), the red dots are the temperature sensors (referred to as T). Before and after each component the temperature is measured to be able to calculate the energy balances. Also for several points the pressure is measured. From the combined results of pressure and temperature the enthalpy of the refrigerant can be calculated.
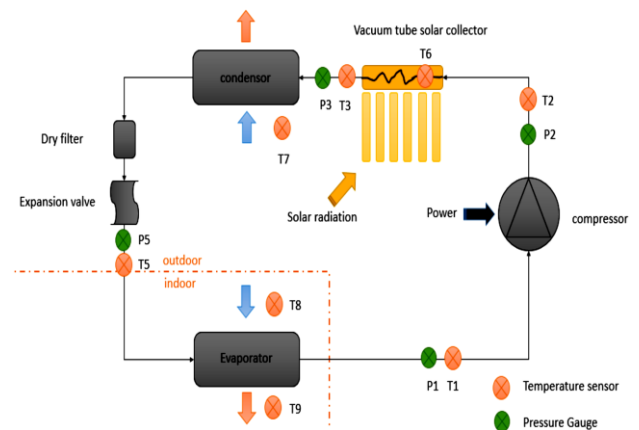

Figure 8. Schematic of measurement setup (Sandeep et al., 2016)

2.2 Evaporator

Evaporator is in lower pressure side. The evaporator consists of coils of pipe wound round that will permit the liquid-vapor refrigerant at low pressure and temperature to be evaporated and changed into vapor refrigerant at low pressure and temperature.

2.3 Capillary tube

This is the best metering devices used today in refrigeration systems and air conditioning industries. It consists of copper tube of minute internal diameter. It is of very great length and is wound several turns to occupy less space.

2.4 Water storage tank.

The storage water in water tank is heated by the vacuum solar collector uses solar radiation. For this research, a vacuum solar tube is a two- layered glass tube and vacuum is provided in between them. Therefore, there is a required very good insulation barrier, preventing losses of heat due to convection and conduction.

2.5 Compressor

The compressor absorbs the low pressure and temperature vapor refrigerant from evaporator through the compressor inlet, and compress it to a high pressure and temperature. This high pressure and temperature vapor refrigerant is discharged into the condenser through the outlet.

2.6 Condenser

This system involves the transfer of heat. In doing so, latent heat is given off by the substance and will be transferred to the condenser coolant.

2.7 Evacuated tube Solar Collector

Solar powered system needs solar collector which working by absorbing radiation from the sunlight and converting them into heat.
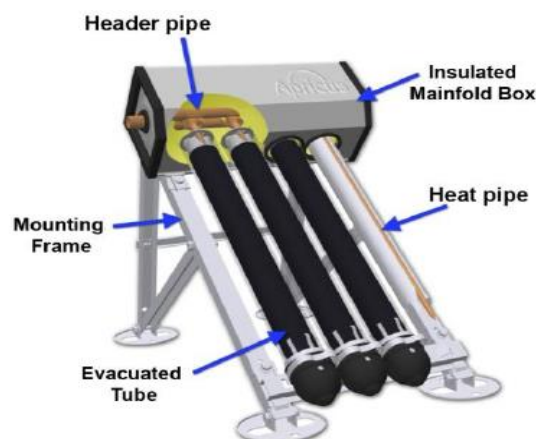

Figure 9. Evacuated tube Solar Collector (Sandeep et al., 2016).
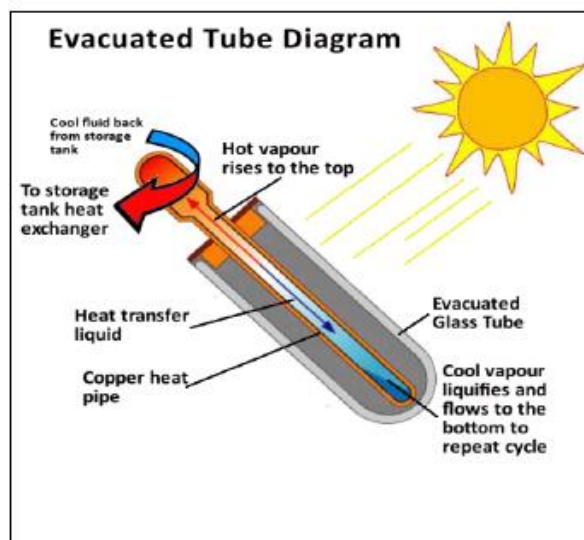
Figure 10. Vertical cross-section of the evacuated tube (Sandeep et al., 2016)

2.8 Thermo-syphon Systems

The system involve water which flows when it becomes hotter, thus rise to the tube of the tank or tube as the cooler water will sinks. This system did not involve any pump or equipment to operate and are more reliable.

Figure 11. Critical Component of the evacuated tube.(Sandeep et al., 2016).

The performance of the solar water heater is depending on type of collector use. There are four options provided with evacuated tube as the extracting heat unit. They are heat pipe, U-tube, pipe in pipe and direct water flow. The mechanisms of transferring heat are different in each of the unit. The most common usage is by using heat pipe and U-tube. The performance of the solar water heater is dependent on type of collector use. After being tested side by side, it was found that the convection heat pipe performance is the best.

Table 1. Performance Evaluation

Model No.			TKF(R)-26GW	TKF(R)-35GW	TKF(R)-60GW	TKF(R)-72GW
Power Supply：220-240VAC, 1PH, 50Hz						
Performance						
Capacity	Cooling	Btu/h	9000	12000	20000	24000
		W	2600	3500	6000	7200
	Heating	Btu/h	10000	13000	22000	27000
		W	2900	3800	6600	7900
Noise	Indoor	dB(A)	≤40	≤42	≤46	≤50
	Outdoor	dB(A)	≤50	≤52	≤56	≤58
Air Circulation		m³/h	500	550	850	1150
Suitable Area		m²	11~17	15~23	25~42	30~48
EER		W/W	3.64	3.89	3.88	3.82
		Btu/h/w	12.42	13.27	13.24	13.03
Power Consumption						
Power Input	Cooling	W	650~770	800~1025	1350~1560	1700~1900
	Heating	W	650~780+350	800~1050+350	1350~1590+350	1700~1950+350
Rated Current	Cooling	A	3.00~3.60	3.70~4.80	6.30~7.30	8.00~8.90
	Heating	A	3.00~3.65+1.6	3.70~4.90+1.6	6.30~7.50+1.6	8.00~8.90+1.6
Vacuum Tube	Diameter*Length*Pcs		47mm*500mm*10	47mm*500mm*10	47mm*620mm*11	47mm*620mm*11
Dimensions						
Indoor Unit	Net	mm	802*265*190	880*286*203	940*300*220	1080*220*300
	Shipping	mm	860*325*255	935*350*270	1003*360*280	1136*285*360
Outdoor Unit	Net	mm	790*260*540	790*260*540	850*300*755	940*300*755
	Shipping	mm	910*370*610	910*370*610	950*410*760	990*400*770
Water Tank	Shipping	mm	910*400*330	910*400*330	980*400*370	980*400*370
Vacuum Tube	Shipping	mm				
Weight						
Indoor Unit	Net/Gross	kg	9/10.5	10/11.5	16/17.5	20/22
Outdoor Unit	Net/Gross	kg	31/34	38/40	50/52	55/58
Solar Collector	Net/Gross	kg	13/15	13/15	16/17	16/17
Loading Qty	in 20feet	sets	66	66	49	46
	40HQ	sets	162	162	120	112
Quotation						
Freon:R410						
Cooling only	Ex-work price	USD	**422.0**	**464.0**	**642.0**	707.0
Cooling &Heating	Ex-work price	USD	**435.0**	**476.0**	**655.0**	727.0

Above bold numbers in Table 1 means that the electrical heater is on when tank water temp is <65℃. Parameters in the form are measured in the rated working state: when cooling; outdoor unit dry/wet-bulb temp 35/24℃, indoor unit dry/wet-bulb temp 27/19℃; when heating, outdoor unit dry/wet-bulb temp 7/6℃, indoor unit dry/wet-bulb 20/15℃, changes may appear according to real working state.

Comparative analysis between the solar hybrid air-conditioner and conventional hybrid air conditioner was conducted on Feb-June 2016 at green house technology department, Skill G Nigeria Limited, 4A Asa Street, Off

Gana, Maitama Abuja in other to ascertain the performance analysis of a solar hybrid air conditioning and conventional air-conditioner, and to state if the performance was better than the normal system in the market today.

The reading is taken using the following parameters:
1) Water tank temperature.
2) Energy Consumption.
3) Room temp.
4) Ambient temp.

3. RESULTS AND DISCUSSION

The experiment was conducted with help of solar hybrid air conditioner using various parameters and to compare the performance, the coefficient of performance (COP) was calculated using the following formula:

Coefficient of Performance (COP) $= \dfrac{\text{Refrigeration effect}}{\text{work input}}$ (1)

Refrigeration effect $(\delta Q) = \dot{m}\Delta h$ (2)

Where, $\delta Q = \dot{m}\Delta h$
Q = Amount of heat in KJ
$\dot{m}$ = Air mass flow rate in kg/s
$\Delta h = (h_1 - h_2)$ Enthalpy change in KJ/Kg.
Where, $\dot{m}$ was measured using anemometer and $h_1 \& h_2$ were calculated using psychometric chart at the given dry and wet temperature.

Calculation of work input $= \dfrac{\text{energy consumption (kwh)}}{\text{Time of operating system (h)}}$ (kW) (3)

$Time of operating system$ (h)
1. Relative humidity (%).
2. Humidity Ratio (W).
3. Dew point temperature (°C).
4. Enthalpy (kj/kg)

Table2. Coefficient of performance with Time

Time	Enthalpy (kj/kg)	Enthalpy change kj/kg	ṁΔh kj/s	COP
09:45	20.73	29.73	2.99	2.57
10:15	25.65	30.53	3.08	2.65
10:45	27.13	26.61	2.69	2.31
11:15	24.07	32.03	3.23	2.78
11:45	23.64	30.11	3.04	2.62
12:15	23.64	30.24	3.05	2.63
12:45	25.30	28.86	2.91	2.51
01:15	28.20	37.58	3.79	3.27
01:45	28.13	32.66	3.29	2.84
02:15	27.07	31.7	3.20	2.76
02:45	28.32	33.51	3.38	2.91
03:15	30.26	30.53	3.08	2.65
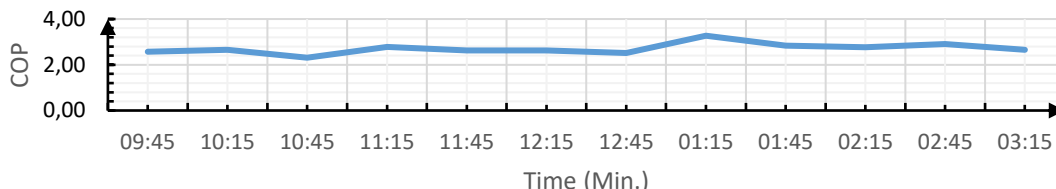
Figure 12. Coefficient of performance with Time

Table 3. Analysis of solar hybrid air conditioner temperature measurement

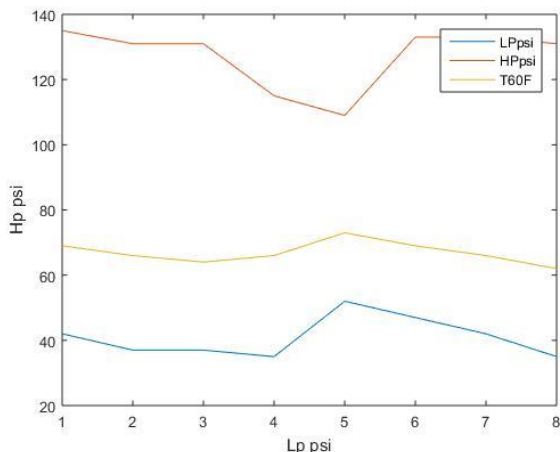| Time	Suction Inlet Dry Bulb Temp. (°C)	Suction Inlet Wet Bulb Temp. (°C)	Discharge Outlet Dry Bulb Temp. (°C)	Discharge Outlet Wet Bulb Temp. (°C)	Water Temp. (°C)	Room Temp. (°C)	Ambient Temp. (°C)	Energy Electrical consumption difference (kwh)
09:15	26.97	26.97	26.97	26.97	49.75	27.2	28	
09:45	26.30	17.91	6.00	63.00	63.71	27.0	28	0.5
10:15	27.66	19.72	8.39	8.63	74.87	27.0	29	0.6
10:45	28.98	19.00	8.39	8.63	83.94	27.2	29	0.6
11:15	27.87	19.70	9.06	9.52	83.01	27.2	33	0.6
11:45	28.77	19.00	7.66	7.89	84.44	27.0	34	0.6
12:15	28.50	19.04	7.46	7.69	87.69	27.0	35	0.6
12:45	29.11	19.13	8.23	7.69	89.39	28.0	36	0.6
01:15	31.72	22.40	9.73	8.46	92.29	29.5	36	0.6
01:45	31.72	21.09	9.50	9.73	92.05	29.5	37	0.6
02:15	29.77	20.50	9.03	9.50	91.72	28.0	37	0.6
02:45	29.72	21.36	9.59	10.75	94.24	27.5	34	0.6
03:15	31.50	21.09	10.43	12.52	103.85	29.5	33	0.6

Figure 13. Room temperature varies with increase in time for solar hybrid air-conditioner

The hybrid systems tend to cool the temperature of the room for a very long time, before the room heats up again. As the hybrid solar air-conditioner parameters increases, the rate of heat transferred through the solar tubes increases while the temperatures in the room drops. Also the results also shows that the ratio of the convective heat transferred to the conductive heat transferred has much effect on the temperature distribution along the hybrid solar system, the rate of heat transferred at the base of the solar hybrid tubes and the coefficient of performance of the system. As the coefficient of heat transferred h increases, the ratio of the coefficient of heat transferred and the thermal conductivity of the solar tubes material increases at the base of the system and eventually, the temperature distribution along the solar tubes, especially at the tip of the tubes increases. This shows that coefficient of performance of the solar air conditioning is achieved at high values of the geothermal region.

Table 4. Cooling system of a conventional air conditioning system.

S/N	$S_1{}^0F$	$D_1{}^0F$	$T_5{}^0F$	$T_6{}^0F$	V_5	$S_2{}^0F$	$D_2{}^0F$	$T_7{}^0F$	$T_8{}^0F$	$V_6{}^0F$	LP(psi)	HP(psi)	CM	OF	t(mins)
1	64	9	66	69	ON	68	9	69	75	ON	42	135	ON	ON	2:30
2	64	9	60	66	ON	68	9	64	71	ON	37	131	ON	ON	5:00
3	64	9	59	64	OFF	68	9	62	69	ON	37	131	ON	ON	7:50
4	64	9	66	66	OFF	68	9	60	66	OFF	35	115	OF	OF	10:00
5	64	9	73	73	ON	68	9	71	71	OFF	52	109	On	On	12:30
6	64	9	66	69	ON	68	9	75	75	ON	47	133	ON	ON	15:00
7	64	9	62	66	ON	68	9	71	71	ON	42	133	ON	ON	17:30
8	64	9	59	62	OFF	68	9	68	68	ON	35	131	ON	ON	20:00

In addition, the figures also depicts the effects of nonlinear parameters on the coefficient of performance of the conventional air conditioning system. The results justified that nonlinear thermal conductivity parameter, the thermo-geometric term and the radiation number have direct and established effects on the rate of heat transfer at the base of the conventional air conditioner.
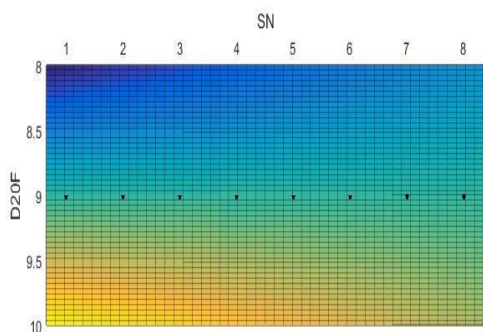

Figure 14. The rate of heat transfer at the base of the conventional air conditioner

Finally this analysis established that the numerical values of the solar hybrid air conditioning coefficient of performance decreases with increasing the radiative parameter while the numerical values of the coefficient of performance of the split units air conditioner increases with increasing the radiative parameter. Comparative analysis between the solar hybrid air-conditioner and conventional hybrid air conditioner was conducted on Feb-June 2016 at green house technology department, Skill G Nigeria Limited, 4A Asa Street, off Gana, Maitama Abuja in other to ascertain the performance analysis of a solar hybrid air conditioning and conventional air-conditioner, and to state if the performance was better than the normal system in the market today

4. CONCLUSION

The hybrid solar air-conditioning is a new innovation that is rocking the world today. Its sole aim was to provide better comfort, efficiency and it has less effect on the ecosystem. The system is able to achieve up to 29% energy saving during daytime, thus significantly reduces the electricity peak load during the day. The main modifications needed are AC compressor, higher capacity condenser and evacuated tube solar collector. When compared with the conventional systems today, the solar hybrid air-conditioner performed better, the conventional system has a higher room temperature thereby making the compressor to perform more work in order to achieve better cooling while the solar hybrid air conditioner requires lesser work to achieve its cooling.

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