Performance Analysis of Solar Hybrid Air-Conditioning System with Different Operating Conditions.

Sandeep Kumar¹, D. Buddhi², Mr. Hari Kumar Singh³
GyanVihar School of Engineering and Technology, Jaipur

Abstract: In our global, consumption of electricity are repeatedly increases and reduction of fossil fuel resources have brought about a significant role in the development of eco-friendly and energy-efficient technologies. Now a day solar hybrid air conditioning system is used to reduce the consumption of electricity. This paper introduced about performance analysis of solar hybrid air conditioning system which consists of R410a vapour compression refrigeration cycle cascaded with solar driven. Analysis the coefficient of performance (cop) of system and also optimize operation are obtained at different mode a heating and cooling. The system was calculated hourly variation of temperature and of different parameters such that evaporator cooling capacity, condenser air inlet and outlet temperature, compressor inlet and outlet refrigerant temperature, water temperature and refrigerant temperature after coming out from water tank and also calculated the various parameter from this reading such as relative humidity, humidity ratio, dew point temperature and enthalpy of inlet and outlet evaporator. Calculated the coefficient of performance were calculated at various parameter work done.

1. Introduction:
Non-stop use of different source of non-renewable energy is the result of hike the fuel price and produce large amount of harmful gas emanation in our environment. Heating, ventilation and air conditioning (HVAC) system are liable for about 50% of the total energy consumption in building. They also lead to the reduction of the valuable fossil fuel sources and production of the greenhouse. Gases which are known to cause ozone layer depletion. However, the world is God gifted with different forms of the energies like solar, wind, tidal and geothermal etc. Hence, the coming era shows the dependency on the renewable sources of energy. Solar energy is pure, clean and available the entire world, mainly suitable in areas with high solar radiation. An increasing demand for energy is a worldwide involvement for the energy conservation and shedding of energy resources. Direct energy conservation technology is used in air conditioning system to utilise a solar thermal system which can be used to provide heat and are also provide air-conditioning by using vapour absorption technology. There is entire world involvement to increase the Cop of Air-conditioning system as the demand air – conditioning system growing rapidly. Solar hybrid Air-Conditioning system is a new technology to use in few regions. It is same as exit air conditioning only difference is that hot water is used by the help of solar energy to reduce the electricity consumption. An Air-Conditioning based on vapour compression cycle has the following main components:-

- a) Compressor
- b) Condenser
- c) Expansion device
- d) Evaporator

In this post-compressor system is the pressure of the refrigerant gas at high pressure, which increases the conditioning temperature which is above ambient temperature. The performance of the system affected by a pressure increase which is generally used to increase the temperature of the cooling air which leads to a reduction coefficient of performance. Therefore, if the compressor work can be reduced by the application of solar energy to increase the heat sink temperature of the condenser. Hybrid solar cooling system consist water tank attached
with solar tubes to heat water. Thus, the objective of this project is to perform analysis of solar hybrid air conditioning system with different fan speed of evaporator.

2. Working of solar hybrid air-conditioning system:

The hybrid solar air conditioner consists of six main components: a compressor, a condenser air cooling, an expansion device, an evaporator, a vacuum solar collector and a storage tank of hot water. The schematic diagram of the arrangement is shown in Fig. 6.1. The cycle starts with a mixture of refrigerant liquid and vapor entering the evaporator (point 1). The heat of the hot air is absorbed by the evaporator coil. During this process, the state of the coolant is liquid gowns and becomes superheated at the evaporator outlet. The super-heat steam enters the compressor (point 2), where increasing pressure increases the refrigerant temperature. Vacuum solar panel installed after the compressor uses sunlight to heat water. An insulated water storage tank is connected to the vacuum solar collector to maintain the temperature of the water. Refrigerant the compressor passes through the copper coil within the heat exchange tank (point 3). When the air-conditioned room reaches the required temperature, the compressor is off. This additional kinetic energy helps to stay out longer, reducing its duty cycle and thus increasing the average COP system. However, during the compressor operating time in conditions of full load, the additional heat absorbed by the refrigerant in the water storage tank must be rejected in the condenser, which requires a slightly larger condenser zone.

After the storage tank, a further reduction of the temperature takes place in the condenser and leads to de-superheat (point 4); thus, the refrigerant liquid is sub-cooled as it enters the expansion device (point 5). Sub-cooling prevents flash gas formation before the expansion device and increases Refrigeration effect of the evaporator. The sub-cooling of high-pressure refrigerant flows through the capillary tube, thereby reducing both the pressure and temperature.

The air conditioner is a device that consists of a condenser, expansion valves, evaporators, solar tubes, stabilizer AC and refrigerant gas R410 A / 1.0 kg already discussed above. The hybrid air conditioner runs on both electricity and solar energy. Solar tubes convert thermal energy into electrical energy that runs the air conditioner and produces the necessary cooling effect to the room. With the capacity of 0.6 kWh per half-hour of electricity consumption. Solar tubes are used for heat absorption capacity of boiling water 2.63 to 2.92 lit. on a day. The amount of 93% of the absorption capacity of electricity produced by the individual solar tube is 2 KW. In this era solar hybrid air conditioner used more because it is environmentally friendly and does not produce any harmful gases. Hybrid solar air conditioning system reduces power consumption than normal air conditioner. This air conditioning 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’. But in hybrid solar cooling system consists of solar evaporator water storage tank, vacuum tubes and the valve. This also called the Single stage-vapor compression solar air conditioner. Earlier in solar air conditioner R-11 and R-12 compressor gases are widely used but now it reduce because it is harmful in environment. Now a day R-410a refrigerant is generally used. It is eco-friendly.

Fig. 2.2 Schematics diagram of hybrid solar air-conditioning system.

3. Construction and Material Requirement:

General AC system consumed more electricity so; this electrical consumption can be reduce by using Solar Hybrid AC system. It provides heat to water at 105°C and store heat at day and utilise heat at night. In this project ITR system has been taken for study. In compression refrigeration system, there are two different pressure conditioning. One is called the high pressure side and other is low pressure side. High pressure side includes the discharge line, condenser and expansion valve. The low pressure side includes the evaporator, piping from the expansion valve to the evaporator and suction line.

The equipment’s with their specification are as follow:-

![Fig2.1 flow diagram of solar hybrid air-conditioning system.](image-url)
a) Evaporator
b) Compressor.
c) Expansion valve.
d) Condenser.
e) Solar tube(vacuum tubes/evacuated tubes).
f) Refrigerant gas R410A.
g) Water tank.

**a. Evaporator**

Evaporator is in lower pressure side. It consists of coils of pipe in which the liquid-vapour refrigerant at low pressure and temp. is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporisation from the medium which is to be cooled.

![Evaporator of Solar hybrid air conditioning](image)

**Fig 3.1** Evaporator of Solar hybrid air conditioning

**a) Compressor**

The low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet, where it is compressed to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through then delivery.

**a) Condenser**

In systems involving the transfer of heat, a condenser is a device or apparatus used to condense a substance from its gaseous to the liquid state by cooling. In doing so, latent heat is given by the substance and will be transferred to the condenser coolant. In systems involving the transfer of heat, a condenser is a device or apparatus used to condense a substance from its gaseous to the liquid state by cooling. In doing so, latent heat is given by the substance and will be transferred to the condenser coolant.

![Condenser of solar hybrid air conditioning system](image)

**Fig 3.3** Condenser of solar hybrid air conditioning system.

**b) Capillary tube**

The capillary tube is one of the limiting devices most commonly used in refrigeration systems and air conditioning. The capillary tube is a copper tube very small internal diameter. It is of very great length and is wound several turns to occupy less space. The internal diameter of the capillary tube used for refrigeration and air conditioning range from 0.5 to 2.28 mm.

**c) Water storage tank.**

The storage water in water tank is heated by the vacuum solar collector uses solar radiation. For this project, 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. The selective coating is provided onto the outer surface of a glass tubes vaulted at one end. The heat is then transferred from the storage water to an immersed heat exchanger, which passethrough the storage tank. The refrigerant state at the immersed coil inlet is determined from the compressor model. For the solar storage tank with a coiled pipe used as a heat exchanger, it is assumed that the free flow for water is dependent on the temperature generated via the density difference, the water flow is laminar, and the storage water is only heated by the solar collected circuit.

![Evacuated tube attached with water storage tank](image)

**Fig 3.4** Evacuated tube attached with water storage tank.

**d) Evacuated Tube:**

In Evacuated tube consist of two glass tubes which are present in which top and bottom side of glass tube are called fuse which is made up of Aluminium base layer, and the inner side tubes is solar heat absorber. Inner tube of evacuated tubes is made up of Borosilicate type material which has excellent characteristics of light transparency (> 92% and 2mm thick). The name evacuated tubes derived, the space between the two tubes is evacuated and form vacuum, therefore evacuated
tubes is known as vacuum solar tubes. When silver-colour barium layer which soak up gases in evacuated tubes turns to white colour, it means vacuum is lost and it indicate that vacuum tubes has a fault.

4. Experimental set-up

Experimental work is carried out using solar hybrid air conditioning, as shown in fig 5.1. Experimental set-up is mainly composed of two parts- an air-conditioned room served by the evaporator unit and condensing unit combined with solar evacuated tube with water tank. In this system compressor using eco-friendly refrigerant R410A as a working fluid. The amount of refrigerant filled in the system is 1kg. The design air flow rate of evaporator is 550 m³/h. cooling capacity of evaporator is 12000 Btu/h and heating capacity of evaporator is 13000 Btu/h. condenser in the system consist of an air-cooled tubes and uses a coated fin tube. The design air flow rate of the condenser axial fan is 2300 m³/h and its rated power input is 40 W. The collector is integrated at a tilted angle of 12° and oriented towards south. The solar collector is made of 10 evacuated tubes with a length of 80 cm and diameter of 18 cm. The two pressure gauges are attached in the side of high pressure side and low pressure side. This system was calculated the following parameters are measured: meteorological parameters (global solar radiation, ambient temperature and ambient relative humidity), storage tank water temperature, indoor temperature and relative humidity, temperature of the refrigerant entering and leaving water storage tank, compressor, condenser, evaporator and capillary tube, total power consumption of the plant, refrigerant suction and discharge pressure, and refrigerant pressure after the hot water storage tank.

In this project, there are many T-type thermocouple is at 12 point to measure a temperature of this point such as:

**Scheme of Thermocouple**

1. Two thermocouples (T1 and T2) are attached at point suction side and another two thermocouples (T3 and T4) attached at discharge side of evaporator to measure inlet air of wet bulb and dry bulb of both side of evaporator.
2. One thermocouple is attached at point inside water tank to measure water temperature of water tank.

**Performance Evaluation**

In the solar hybrid air conditioning system was taken reading several days under normal weather condition. The T-type Thermocouple wires were positioned at different point in the solar system. The solar evacuated tubes tilted at angle 12° and north faced. Experiment on the solar system was performed in the days of Feb-June 2016 in Jaipur, Rajasthan, India. The test was conducted between 9:00 am to 9:00 pm solar time and night time also. The reading of different temperature was taken at the interval of every ½ hours.

The reading is taken using various parameters which are as follows:

1) Water tank temperature.
2) Energy Consumption.

To study the effect of evaporator blower speed and solar evacuated tubular collector parameters solar hybrid air conditioner on its performance, the following strategies have been planned.

**Case A**

- With water in storage tank and Solar ETC exposed to the sun.

**Case B**

- With water in storage tank and Solar ETC unexposed to the sun.

We have taken reading of above cases in different dates. There are too many data so, we take one example:-
On March 3, 2106, experiments were conducted at lowest speed of evaporator blower (The evaporator blower has 3 speeds viz. high speed, medium and low speed). The experiments were conducted from 9:15 AM to 2:45 PM. On the day, as per the performance strategy planned, the system was operated under normal condition i.e. the ETC tank was filled with 20 lit. water and the ETC tubes were exposed to the sun.

During the course of experiment the following parameters were recorded at on time interval of 30 minutes.

1. Evaporator suction dry bulb temperature.
2. Evaporator suction wet bulb temperature.
3. Evaporator discharge dry bulb temperature.
4. Evaporator discharge wet bulb temperature.
5. Water temperature of ETC tank.
6. Room temperature.
7. Ambient temperature.

<table>
<thead>
<tr>
<th>Time</th>
<th>Inlet Dry Bulb Temp. (°C)</th>
<th>Inlet Wet Bulb Temp. (°C)</th>
<th>Outlet Dry Bulb Temp. (°C)</th>
<th>Outlet Wet Bulb Temp. (°C)</th>
<th>Water Temp. (°C)</th>
<th>Room Temp. (°C)</th>
<th>Ambient Temp. (°C)</th>
<th>Energy Electrical consumption difference (kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:15</td>
<td>25.07</td>
<td>25.97</td>
<td>25.97</td>
<td>29.75</td>
<td>37.2</td>
<td>28</td>
<td>30</td>
<td>0.101</td>
</tr>
<tr>
<td>09:45</td>
<td>26.03</td>
<td>17.03</td>
<td>6</td>
<td>6.3</td>
<td>32.71</td>
<td>27</td>
<td>28</td>
<td>0.5</td>
</tr>
<tr>
<td>10:15</td>
<td>27.06</td>
<td>15.73</td>
<td>8.96</td>
<td>1.0</td>
<td>17.47</td>
<td>27</td>
<td>29</td>
<td>0.6</td>
</tr>
<tr>
<td>10:45</td>
<td>28.00</td>
<td>5.56</td>
<td>5.52</td>
<td>10.38</td>
<td>32.64</td>
<td>27</td>
<td>33</td>
<td>0.6</td>
</tr>
<tr>
<td>11:15</td>
<td>29.07</td>
<td>16.7</td>
<td>7.64</td>
<td>7.18</td>
<td>33.83</td>
<td>27</td>
<td>34</td>
<td>0.6</td>
</tr>
<tr>
<td>11:45</td>
<td>29.77</td>
<td>15.5</td>
<td>7.46</td>
<td>7.06</td>
<td>34.44</td>
<td>27</td>
<td>35</td>
<td>0.6</td>
</tr>
<tr>
<td>12:15</td>
<td>30.5</td>
<td>18.58</td>
<td>7.46</td>
<td>7.06</td>
<td>37.69</td>
<td>27</td>
<td>36</td>
<td>0.6</td>
</tr>
<tr>
<td>12:45</td>
<td>29.12</td>
<td>15.03</td>
<td>8.33</td>
<td>1.86</td>
<td>30.38</td>
<td>28</td>
<td>36</td>
<td>0.6</td>
</tr>
<tr>
<td>13:15</td>
<td>27.72</td>
<td>22.4</td>
<td>9.73</td>
<td>3.10</td>
<td>19.28</td>
<td>25</td>
<td>36</td>
<td>0.6</td>
</tr>
<tr>
<td>13:45</td>
<td>27.72</td>
<td>22.06</td>
<td>9.51</td>
<td>3.73</td>
<td>19.36</td>
<td>25</td>
<td>37</td>
<td>0.6</td>
</tr>
<tr>
<td>14:15</td>
<td>27.77</td>
<td>20.5</td>
<td>9.93</td>
<td>5.5</td>
<td>17.23</td>
<td>28</td>
<td>37</td>
<td>0.6</td>
</tr>
<tr>
<td>14:45</td>
<td>27.72</td>
<td>22.36</td>
<td>9.59</td>
<td>3.75</td>
<td>19.24</td>
<td>27</td>
<td>34</td>
<td>0.6</td>
</tr>
<tr>
<td>15:15</td>
<td>31.5</td>
<td>22.19</td>
<td>13.47</td>
<td>5.23</td>
<td>23.86</td>
<td>20</td>
<td>35</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table 1: Observation of all temperature with water in tank and Solar ETC exposed to the sun. Total Electricity consumption in 6hrs. = 7kwh

RESULT & 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) = Refrigeration effect/ Work input

- Refrigeration effect (δQ) = mΔh

Where, δQ = mΔh

Q = Amount of heat in KJ
m = Air mass flow rate in kg/s
Δh = (h₁ − h₂) Enthalpy change in KJ/Kg.

Where, m was measured using anemometer and h₁ & h₂ were calculated using psychometric chart at the given dry and wet temperature.

- Calculation of work input = Energy consumption (kwh) / (kW)

Time of operating system (h) / (kW)

Take an example of

On March 3, 2106, experiments were conducted at lowest speed of evaporator blower (The evaporator blower has 3 speeds viz. high speed, medium and low speed). The experiments were conducting from 9:15 AM to 3:15 PM. On the day, as per the performance strategy planned, the system was operated under normal condition i.e. the ETC tank was filled with 20 lit. water and the ETC tubes were exposed to the sun.

The following parameters were calculated using psychometric chart at given dry and wet bulb temperature both for suction and discharge of evaporator.

1. Relative humidity (%).
2. Humidity Ratio (W).
3. Dew point temperature (°C).
4. Enthalpy (kJ/kg)

The reading of the day are tabulated in table 1 and graph is plotted in figure 1

Table 2: Coefficient of performance with Time on 3rd March 2016 (with water and Solar ETC tubes were exposed to the sun).

<table>
<thead>
<tr>
<th>Time</th>
<th>Enthalpy (kJ/kg)</th>
<th>Enthalpy change (kJ/kg)</th>
<th>mΔh (kJ/s)</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:45</td>
<td>20.73</td>
<td>29.73</td>
<td>2.99</td>
<td>2.57</td>
</tr>
<tr>
<td>10:15</td>
<td>25.65</td>
<td>30.53</td>
<td>3.08</td>
<td>2.65</td>
</tr>
<tr>
<td>10:45</td>
<td>27.13</td>
<td>26.61</td>
<td>2.69</td>
<td>2.31</td>
</tr>
<tr>
<td>11:15</td>
<td>24.07</td>
<td>32.03</td>
<td>3.23</td>
<td>2.78</td>
</tr>
<tr>
<td>11:45</td>
<td>23.64</td>
<td>30.11</td>
<td>3.04</td>
<td>2.62</td>
</tr>
<tr>
<td>12:15</td>
<td>23.64</td>
<td>30.24</td>
<td>3.05</td>
<td>2.63</td>
</tr>
<tr>
<td>12:45</td>
<td>25.3</td>
<td>28.86</td>
<td>2.91</td>
<td>2.51</td>
</tr>
<tr>
<td>01:15</td>
<td>28.2</td>
<td>37.58</td>
<td>3.79</td>
<td>3.27</td>
</tr>
<tr>
<td>01:45</td>
<td>28.13</td>
<td>32.66</td>
<td>3.29</td>
<td>2.84</td>
</tr>
<tr>
<td>02:15</td>
<td>27.07</td>
<td>31.7</td>
<td>3.2</td>
<td>2.76</td>
</tr>
<tr>
<td>02:45</td>
<td>28.32</td>
<td>33.51</td>
<td>3.38</td>
<td>2.91</td>
</tr>
<tr>
<td>03:15</td>
<td>30.26</td>
<td>30.53</td>
<td>3.08</td>
<td>2.65</td>
</tr>
</tbody>
</table>

- mass flow rate (ṁ) = 0.101 kg/s
Different Conditions

With water and Solar ETC tubes were exposed to the sun 1.4m/s

Average COP

With water and Solar ETC tubes were unexposed to the sun 1.4m/s

Average COPs of different date with different conditions (At low speed 1.4m/s)

Table 8.15: Variation of average COP with respect to different conditions.

<table>
<thead>
<tr>
<th>Date</th>
<th>Evap. Air speed</th>
<th>Average COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>03-03-2016 Case A</td>
<td>1.4m/s</td>
<td>1.71</td>
</tr>
<tr>
<td>04-03-2016 Case A</td>
<td>1.4m/s</td>
<td>2.36</td>
</tr>
<tr>
<td>05-03-2016 Case B</td>
<td>1.4m/s</td>
<td>2.4</td>
</tr>
<tr>
<td>06-03-2016 Case B</td>
<td>1.4m/s</td>
<td>2.6</td>
</tr>
</tbody>
</table>

CONCLUSION

- It improves the efficiency of solar system.
- In this analysis the coefficient of performance (COP) in this condition (with water and uncovered solar tubes) is better than other condition.
- In this analysis the high pressure of refrigerant is recoded up to 450 kg/cm² and low pressure up to 100 kg/cm² on 3 march 2016.
- In this experiment, the system has been attaining the coefficient of performance (COP) approx. 4.79 on 17 march 2016.

REFERENCES