Experimental Investigation of Solar Powered Air-Conditioning System in a Car

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Abstract Fossil fuels are of greater importance in transport systems because when it is burnt, produces significant amounts of energy to move the vehicle along. Generally usage of the air-conditioning system in the transportation will increase the usage of the fossil fuel thereby increases pollution rate. The additional energy resources such as solar energy can be used in a vehicle to generate adequate energy to power the air-conditioning system instead of solely depending on the fossil fuel, which increases the fuel consumption rate in an engine. The solar panel allows it to absorb the sun's energy and turn it into electricity can be utilized to power the air-conditioning system in a car. Thereby the consumption of fossil fuel is lowered. Besides, this application, benefits the environment as it produces lower carbon which minimizes the effect of the greenhouse effect thereby and global warming.

Keywords: solar power, car, air-conditioning, battery

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1. Introduction

The existing air conditioning system in the vehicle uses fossil fuel to operate. The amount of fuel used for air conditioning is significant. As the research goes deep into the context of the air-conditioning system of a vehicle, more problems can be found on the impact of the system. However, it is not the best way to completely remove the air-conditioning system since the hot climate needs the air-conditioning system to comfort the passengers and driver. A new kind of energy sources or renewable energy such as solar energy can be utilised as a substitute to power the air-conditioning system in a car.

2. Advantages of Solar-electric Hybrid Vehicles

Qingfeng Su et al [1] stated that electric vehicle has more advantages of no noise, no pollution, save energy and reduce carbon dioxide emissions. Solar electric vehicle can reduce greenhouse gas emissions and other pollution. All advantages of solar electric vehicle make research and application of solar electric vehicle as a hot spot of automotive industry and the trend of future cars. Solar electric vehicle is made of PV panels, battery, electric motor, vehicle controller and vehicle body. Solar electric vehicle drives are using dual-mode of PV and battery hybrid. It can be achieved as PV-driven and battery-driven independently. In good sunny conditions, the full charge endurance of solar electric vehicle can be increased about 35% substantially compared with no PV panels. Solar electric vehicle can achieve low-carbon, energy saving, environmental protection and true zero-emissions for the future of human life.

3. CO_2 Emission from Passenger Transport Sector

Sanjay kumar singh [10] stated that the problem of climatic change is one of the most serious consequences of the emission of large quantities of CO_2 and other greenhouse gases into the atmosphere. Transport in general and road transport in particular constitutes a major share in the CO_2 emissions. Vehicles using fossil fuels (diesel and gasoline) produce CO_2 emissions in quantities that depend on the carbon present in the fuel molecule. Globally, the transport sector now contributes 25% of all the CO_2 emissions released into the atmosphere. Approximately 80% of those emissions are from road transport. Although, currently, India is one of the lowest per capita emitters of CO_2, at 0.27 metric tons of carbon equivalent, energy sector's carbon intensity is high, and the country's total CO_2 emissions rank among the world's highest. In 2002, CO_2 emission in India was around 280 million metric tons of carbon equivalents which were around 4% of the world total (International Energy Annual 2002). Between 1980 and 2002, India's carbon emission increased at an astonishing rate of 5.7% per annum against the world average of 1.26 %.

4. Experiment on Fuel Economy with and without Air-conditioner at Various Speed Ranges

The experiment was conducted on two Maruthi Alto 800 cars. The experiment was conducted to find the fuel economy. The car was tested at three different traffic conditions. The car was tested at two conditions
1) Car with air-conditioning on
2) Car with air-conditioning off.
The three different traffic conditions are
1) Peak hour traffic
2) Moderate traffic
3) Highway.
The results of the two cars at three different traffic conditions are:

4.1. Experiment 1-Experimented with an Old Car Which Has Run more than 75000 km

Table 1. Mileage of old car

Traffic condition	Air-conditioner off Mileage (kmpl)	Air-conditioner on Mileage (kmpl)
Peak hour traffic	18.6	15.8
Moderate traffic	19.4	16.7
Highway	20.8	17.8

Figure 1 shows that the mileage of the car varies at three different traffic conditions. The mileage of the car is higher when the air-conditioner is turned off. The mileage is higher in the highways when compared to peak hour and moderate traffic. The average difference in the mileage is 2.83 kmpl for the old car.
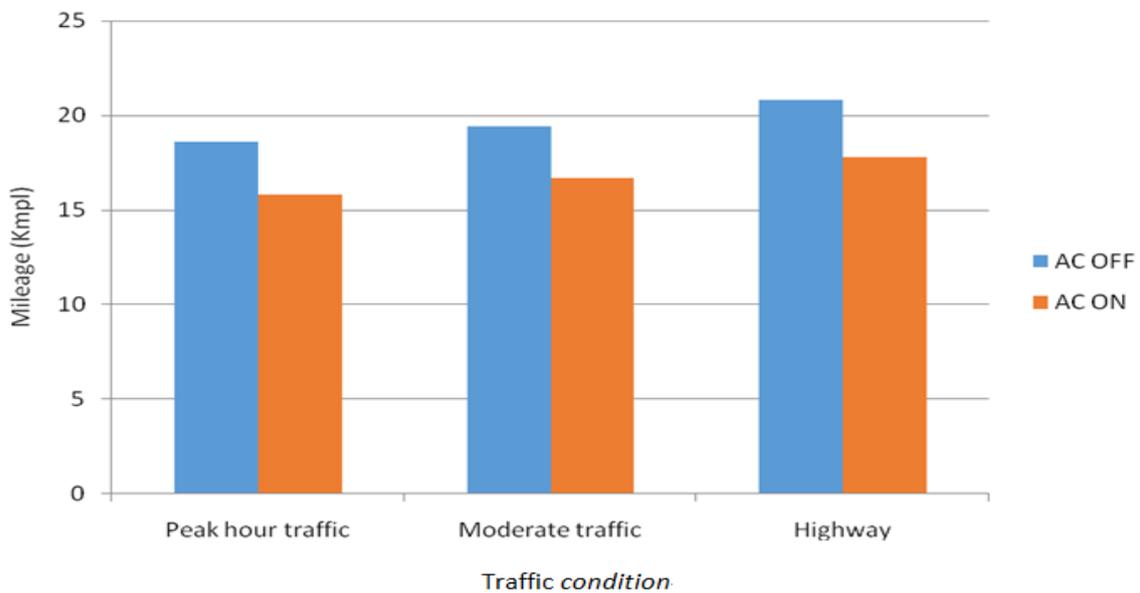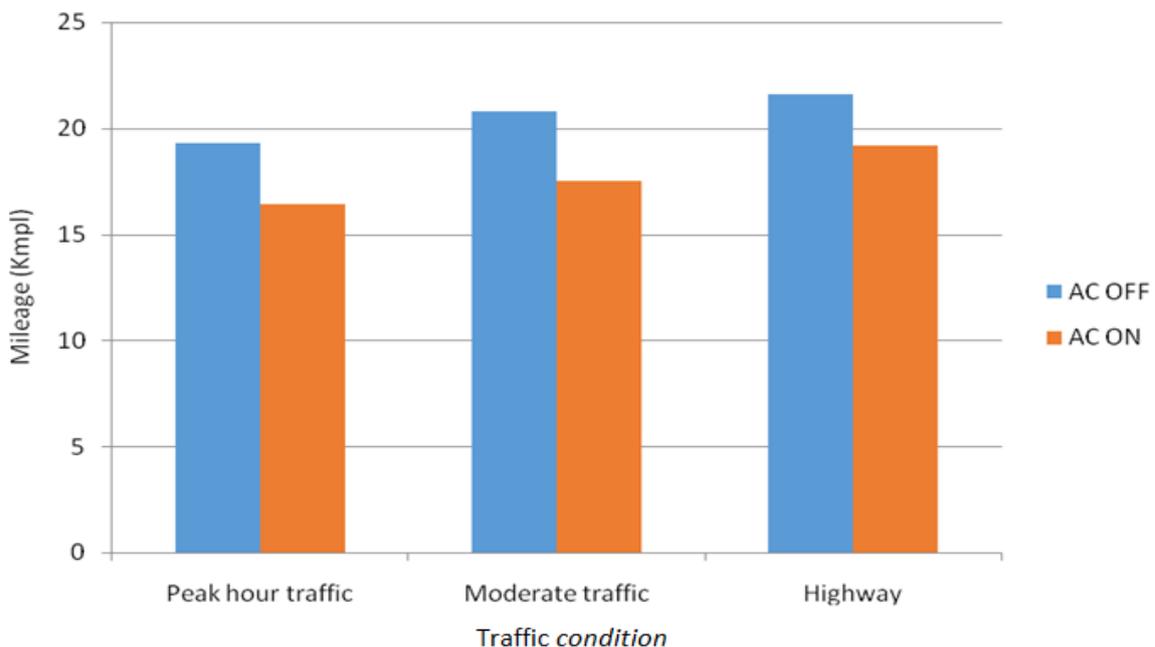

Figure 1. Mileage of old car

Figure 2. Mileage of new car

4.2. Experiment 2- Experimented with a New Car Which Has Run less than 10000 km

Table 2. Mileage of new car

Traffic condition	Air-conditioner off Mileage (kmpl)	Air-conditioner on Mileage (kmpl)
Peak hour traffic	19.3	16.4
Moderate traffic	20.8	17.5
Highway	21.6	19.2

Figure 2 shows that the mileage of the car varies at three different traffic conditions. The mileage of the car is higher when the air-conditioner is turned off. The mileage is higher in the highways when compared to peak hour and moderate traffic. The average difference in the mileage is 2.86 kmpl for the new car.

4.3. Returns

- On an average the fuel saving would be 2.8 kilometers per litre of fuel when the air-conditioner is not powered by the IC-engine.
- A family car would spend around 75 litres of fuel per month.
- They would save upto 10.5 litres of fuel per month.
- Cost of petrol is Rs. 63.20 per litre.

Table 3. Cost savings

Fuel	Cost saved
Petrol	Rs.663

It can be seen that there is a significant change in mileage when the air-conditioner is turned off. But the air-conditioner cannot be turned off as the passenger comfort is very important. The air-conditioner can be powered through renewable resources such as solar power.

5. Power calculations

- Rule 1. Average power demand should not exceed 20% of battery capacity.
- Rule 2. Peak (short-duration) demand should not exceed 40% of capacity.
- Rule 3. The battery discharge limit should be no more than 70% of its capacity. (limiting maximum discharge to 50% will measurably extend the battery life)

The compressor rating is 24 volts. The dc motor required to drive the compressor is 1hp.

- Using a 1 h.p., 24V motor, the current (I) taken at full power is: I = Power(in Watts)/Volts= 746/24 = 31 A.
- To meet rule 1, the capacity of the battery should be a minimum of: 31/0.2 = 155 A
- To meet rule 2, the capacity of our battery should be a minimum of: 31/0.4 = 77.5 A
- To meet rule 3, with a 2.5 hour cruising duration, the battery capacity should be: (31 x 2.5 hours)/0.7 = 110.71 AH

A two 150 AH, 12 V battery is connected in series to attain a 24 V battery system.

6. Solar powered air-conditioning system

The air-conditioning compressor is de-coupled from the IC-Engine by removing the timing belt connection from the crank pulley of the IC-Engine. This decouples the air-conditioning compressor from the IC- Engine. An air-conditioning unit is assembled from Maruthi Alto 800 car. The air-conditioning system is assembled using the original air-conditioning components of the car such as the compressor, condenser, evaporator, expansion valve and drier. The refrigerant which is used is R134-a. The refrigerant is loaded into its full capacity once the air-conditioning unit is assembled.

Figure 3. Assembly of air-conditioner

6.1. Power

The air-conditioning generally uses the power from the IC-Engine through timing belt. Since it is decoupled there is a need for another power source. So renewable energy resources such as solar power is opted. The compressor requires a driver to operate. A dc-motor is employed to drive the compressor. Solar panel is mounted to absorb the sun's rays as a source of energy for generating electricity. The power generated is not directly used for powering. Instead it stored in a battery setup. The solar panel is connected to the battery by the connections provided at the back of the panel. The dc motor is connected to the compressor to power the compressor. The dc motor utilizes the power from the battery. When the dc-motor is powered, it starts driving the compressor. When the air-conditioning is turned to on, the magnetic clutch is engaged with the compressor and the air-conditioning begins. The air-conditioning system is tested for its performance.

7. Testing of air-conditioning system

It is a close refrigerant loop charged with R-134a as refrigerant. The system comprises of a condenser, evaporator, compressor, expansion valve and a suitable magnetic clutch. The compressor pulley is driven by electric motor by the help of a belt-hoop system. Initially, the cooling refrigerant in the system was totally discharged prior to the tests and then recharged with the manufacturer's recommended amount of 500 g of R-134a type gas as the first charging refrigerant. The compressor was then run at this charge level of the gas for each speed of the 1000, 1500 and 2000 revolution per minute (rpm) respectively. The measurements were taken at each compressor speed after the compressor had been fully stabilized. Following this initial test, the above measurement procedure is repeated for differing amounts (300, 400 and 500 g) of the same cooling refrigerant. For computing the system performances, the following assumptions were made;

- The evaporator and the condenser pressure losses were assumed to be negligible.

- The enthalpy changes in the expansion valve were negligible.

The parameters concerning the system performances were calculated as follows:

Q_e= Cooling capacity of the evaporator
W = Compressor power
M_a = Mass of air
M_r = Mass of refrigerant
COP = Coefficient of performance

Cooling capacity of the evaporator (Q_e) was calculated by using equation (1) given below

$$Q_e = m_a \left(h_{in} - h_{out} \right). \tag{1}$$

Power (W) given to the refrigerant in the compressor was obtained by equation (2)

$$W = m_r \left(h_2 - h_1 \right). \tag{2}$$

Assuming that the heat received by the refrigerant is equal to the heat loss by the air passing through the evaporator, equation (1) can now be rewritten as follows

$$Q_e = m_a \left(h_{in} - h_{out} \right) = m_r \left(h_1 - h_4 \right). \tag{3}$$

Hence, from equation (3), the refrigerant flow rate can be expressed as

$$m_r = m_a \left(h_{in} - h_{out} \right) / \left(h_1 - h_4 \right). \tag{4}$$

The coefficient of performance (COP) can be calculated from the following equation

$$COP = Q_e / W. \tag{5}$$

The enthalpy changes can be obtained using p-h chart of R134a refrigerant.

Table 4. Effect of the compressor revolution speed on the compressor power in terms of refrigerant charge

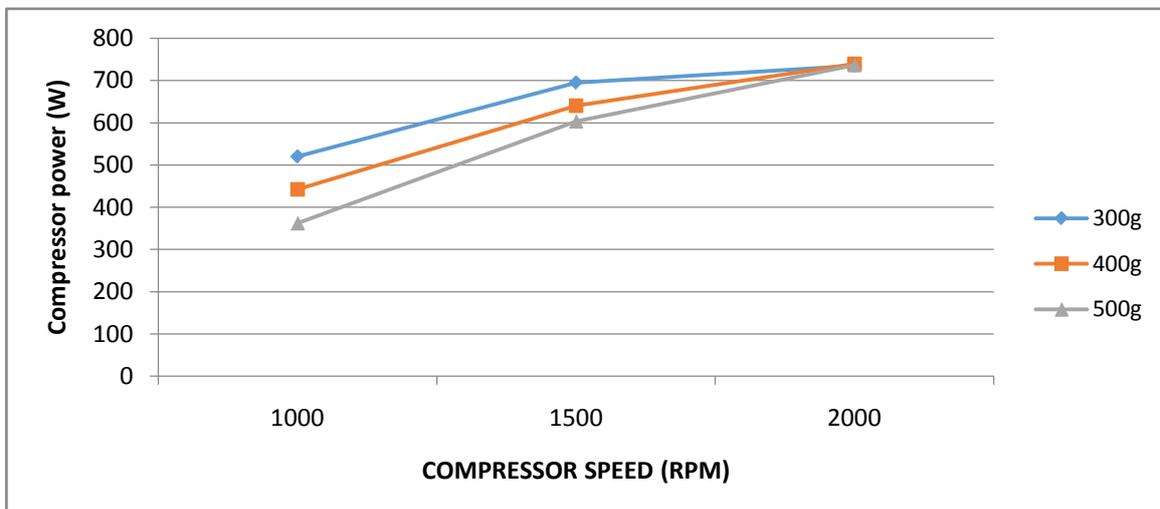| COMPRESSOR SPEED (RPM)	COMPRESSOR POWER (W) for different amounts of R134-a		
	300g	400g	500g
1000	520	442	362
1500	695	640	603
2000	735	739	736

Figure 4. Effect of the compressor revolution speed on the compressor power in terms of refrigerant charge

Power given to the compressor is almost linearly changing with the compressor revolution speed at all charging amounts of the refrigerant.

Table 5. Effect of the compressor revolution speed on the cooling capacity in terms of refrigerant charge

COMPRESSOR SPEED (RPM)	COOLING CAPACITY (kW) for different amounts of R134-a		
	300g	400g	500g
1000	1.98	2.25	1.96
1500	2.18	2.16	2.42
2000	1.93	2.35	2.34

The cooling capacity increases with increasing compressor revolution speed at all the refrigerant amounts tested. The increase in the refrigerant flow circulation within the system and the increase in the compressor revolution speed were the main causes of the observed effect. The cause of decrease in cooling capacity at lower amounts of refrigerant can be attributed to the flow of two-phase refrigerant from condenser to the expansion valve.

Table 6. Effect of the compressor revolution speed on the COP in terms of refrigerant charge

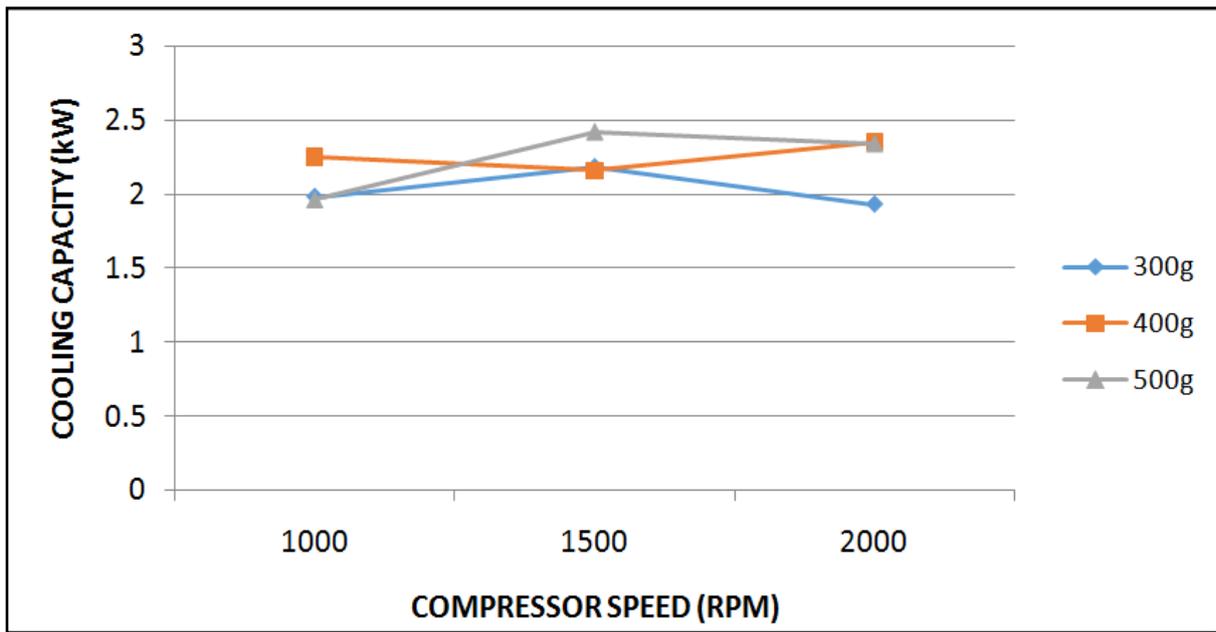| COMPRESSOR SPEED (RPM)	COEFFICIENT OF PERFORMANCE for different amounts of R134-a		
	300g	400g	500g
1000	3.82	5.1	5.44
1500	3.14	3.38	4.02
2000	2.63	3.18	3.29

Figure 5. Effect of the compressor revolution speed on the cooling capacity in terms of refrigerant charge
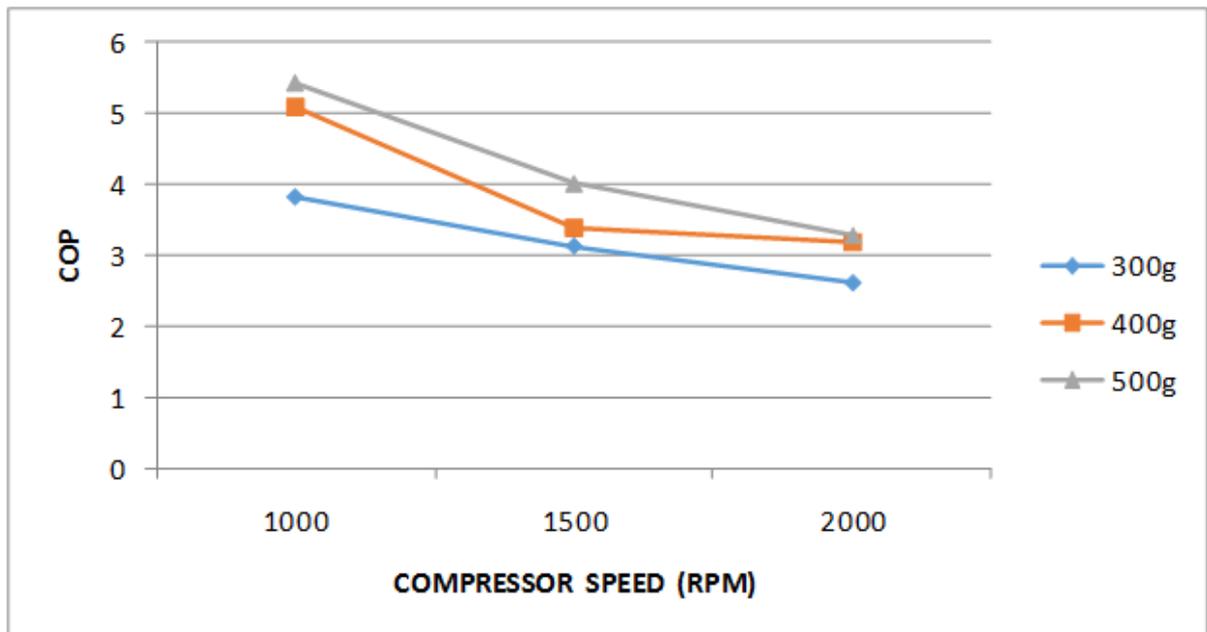

Figure 6. Effect of the compressor revolution speed on the COP in terms of refrigerant charge

COP is decreasing considerably from its maximum level in all cases with an appropriate increase in the compressor revolution speed. The reason for this may be attributed to an increase in the power level of the compressor according to an appropriate increase in the cooling capacity.

8. Results and Discussions

The result of this experiment proves that the mileage of the car increases when the air conditioning is off and the mileage difference is considerable. The average difference in the mileage is 2.83 kmpl for the old car. On an average the fuel saving would be 2.8 kilometres per litre of fuel when the air-conditioner is not powered by the IC-engine. A family car would spend around 75 litres of fuel per month. They would save upto 10.5 litres of fuel per month. Hence they can save around Rs.663 per month on fuel. But the climatic conditions require air-conditioning to comfort passengers in a car. Hence air-conditioning system can be powered through an alternate renewable energy such as solar energy.

From the test "Effect of the compressor revolution speed on the compressor power in terms of refrigerant charge", it can be seen that the compressor power increases as the speed (rpm) increases and the compressor power decreases as the amount of refrigerant charge increases. 500g refrigerant in the system working at a compressor speed of 1000 RPM consumes less power when compared to others.

From the test "Effect of the compressor revolution speed on the cooling capacity in terms of refrigerant charge", it can be seen that cooling capacity increases as the speed (rpm) increases and the cooling capacity decreases as the amount of refrigerant charge increases. The increase in the refrigerant flow circulation within the system and the increase in the compressor revolution speed were the main causes of the observed effect. The cause of decrease in cooling capacity at lower amounts of refrigerant can be attributed to the flow of two-phase refrigerant from condenser to the expansion valve.

From the test "Effect of the compressor revolution speed on the COP in terms of refrigerant charge", it can be seen that the COP increases as the amount of refrigerant charge increases and the COP decreases as the speed (rpm) increases. The reason for this may be attributed to an increase in the power level of the compressor according to an appropriate increase in the cooling capacity.

9. Conclusion

Solar powered air-conditioning is a productive product that can be used in cars and buses. The solar power in an automobile is the future of the automobile industry. They are highly feasible and can be manufactured with ease. The main advantages of a solar power air-conditioner in an automobile are that they are pollution less and are very economical. Since they cause no pollution, they are eco-friendly and are the only answer to the increasing pollution levels from automobiles in the present scenario. By using the renewable sources of energy like the solar energy, the non-renewable sources of energy can be minimised. The solar AC solves many problems related to the environment and is the best pollution free method. The solar power air-conditioner in an automobile do have some disadvantages like initial cost is high, lack of expertise, no adequate research on R&D and high cost in maintenance. These disadvantages can be easily overcome by conducting further research in this area like the problem of solar cells can be solved by using the ultra-efficient solar cells on the roof of an automobile that give about 22-23% efficiency. Furthermore, this technology can be implemented well in India because of the weather conditions. According to Indian Meteorological Department (2013), India has achieved about 32.6 to 40 Celsius on hot condition. That means, India is one of the great place for solar power application. The percentage of people using the automobile is also high. The transportation company can save the money while using the solar power. Other than that, this technology really gives lots of benefits to community, Transportation Company, government, environment and also to the country. The efficiency of the car can be increased and requires less amount of fuel. Hence, the environment will be less polluted. As this field of automobiles will be explored the problems will get solved. The solar automobiles have a huge prospective market and must be implemented in our day to day life.

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