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EFFECT OF SOLAR VENTILATION ON AIR CONDITIONING SYSTEM PERFORMANCE OF THE CAR PARKED UNDER SUN LIGHT

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ABSTRACT

Summer ambient temperatures in Sultanate of Oman are well known to be higher as commonly seen in other GCC countries. During summer, cars parked directly under the sun with window glass raised up, experience a very high temperature rise inside its cabin. Current research paper reports the experimental studies carried out on a parked car installed with an indigenously designed and developed cabin ventilation system powered with Solar PV energy. The experiment was carried on chosen vehicle parked at a unique direction and location exposed to day long sunlight at Muscat for considerable period of time. The experimental investigation showed that the vehicle cabin temperature was lower when ventilation system was turned on. Investigation showed that, with the ventilation system, the time taken to cool down vehicle cabin air temperature to the acceptable limit was significantly lower. With developed ventilation system the car cabin temperature reached to the comfort level much quicker, typically lesser than the half of the time compared to those values tested without ventilation system. Thus indicating, the power saving potential of the developed system as the desired level of thermal comfort can be achieved within the shorter period of time. The reduction in time taken to cool down the cabin temperature to the acceptable limits has direct two fold effects; firstly, the fuel consumption for cooling purpose is reduced and secondly increased thermal comfort level inside the cars cabin. However, the temperature drop pattern was not similar all around the cabin, due to the varied level of cabin sunlight exposure. Temperature drop at the front end of the car was lower than in middle and rear of the car. It was noted that when the ventilation system was turned on, the temperature inside the car was nearly 10 ºC lesser compared to cabin temperature without ventilation system.

Keywords: solar photovoltaic ventilation, temperature zones, air conditioning system performance.

INTRODUCTION

According to a study on Renewable Energy Resources in Oman carried out by Authority for Electricity Regulation, Oman [1] the average solar global insolation in the country varies from 4.5 to 6.1 kWh/m^2 per day. Further this quantum of energy is available for the most of the time in a year. Thus, the quantum of solar energy density in Sultanate of Oman may be considered at par with other countries which are accounted as highest in the world. High solar energy density is available in most part of the Sultanate. With yearly variation in average amounts to about 4 kWh/m^2 per day for January to about 6.5 kWh/m^2 per day for May in which the solar global insolation is highest [1]. When these packets of radiation energy are absorbed by the vehicles which are parked in open space will experience an unpleasant rise in its cabin air temperature. Especially during summer, the heat generated in the vehicle cabin will increase the interior temperature up to 45ºC, and causes health risk and damage to the vehicle cabin components [2] [3].

Countries which are known for their scorching hot summer, like most countries in middle east, it is generally seen that, vehicles which are parked under direct sunlight especially during hot summer day, experience drastic rise in cabin temperature, and more often it becomes unbearable to hold or touch the steering wheel and dashboards[4]. Further the high temperature inside the vehicle will cause a huge amount of thermal discomfort to the drivers and passengers during the first few minutes after entering in to the vehicles. As a general practice to obviate this harmful thermal discomfort, drivers as soon they turn on the ignition switch, they will also turn on the vehicles air-conditioning (AC) system and set it to run high. But this general practice has a tremendous implication on the vehicles air-conditioning system due to increased thermal load on the AC system, which eventually demand higher fuel consumption.

Hence it is very important to minimize the unwanted temperature rise inside the vehicles cabin to improve the thermal comforts inside the cabin of the cars parked under sun. To minimize the thermal discomforts, it's important to carry out a continuous positive air exchange across the cars cabin without using vehicles stored energy and also without causing any threat to the vehicles security.

LITERATURE REVIEW

The studies carried out by Basar *et al.* [5], at Malaysia indicate that, the vehicles parked under the direct sunlight showed temperature rise inside the cabin nearing to 60°C. Their study indicated that the higher cabin temperature has made driver and passenger to feel more uncomfortable while entering the vehicle, especially for first 10 to 15 minutes. Moreover, the vehicles cabin construction elements, especially fabrics would face early aging problem and may also cause damage to the goods stored inside the cars cabin. According to the shocking findings of Saidur *et al*. [6], every year many children die of (hyperthermia) heatstroke after being left unattended in vehicles in the USA. It shocking to note that the average number of children died of heat stroke was 29 persons per year in the year between 1998 to 2000. While in 2003 alone, this number increased to 42 and 35 persons in 2004. Annually, hundreds of children experience varying degrees of heat illness from being left in vehicles which are parked under the sun. Studies of Saidur *et al*. [6] Indicate that, cars need an auxiliary ventilation system to increase the air flow rate and decrease temperature inside the cars cabinet, their experimental results show a reduced temperature inside the vehicle compared to the non-ventilated cabin.

At department of Geosciences of San Francisco State University, USA, Jan Null [7] carried out studies on the unnecessary temperature rise in enclosed vehicles. The study was carried out with reference to the accident of children being left unattended in the closed vehicles. Their main aim of the experimental investigation was to quantify vehicle cabin temperatures and to note the temperature changes with time under a variety of meteorological circumstances. Jan Null [7] carried out experimental investigation on two vehicles, which were parked under the heat of the sun with temperature sensors mounted to measure the temperatures at various points. The first vehicle was parked with the window fully closed and the other with window “cracked” i.e. open approximately 3.8 cm. The study revealed that temperature rise in the vehicle cabin was very rapid in short span of time in a vehicle with windows closed. While, in the vehicle with ‘cracked’ window; the temperature rise was little slower for a given time. But interestingly, results concluded that both vehicles reached dangerous temperature level after long hours of parking, even though the vehicle windows are ‘cracked’. Hence it may still be able to cause accident if there are children left inside unattended. From Jan Null [7], studies, it can be understood that, with partial opening of windows, only minor mitigation is achieved, however, opening the windows for small gap, may invite threat to the cars safety aspect.

Dadour, *et al.*[3], reports a similar experimental studies carried out in Australia, which show a typically 20°C hotter inside a parked vehicle compared outside ambient temperature on a hot summer day, in such condition children or pets left in such a parked car for periods of the order of 30 minutes suffer heat stress and a number of deaths are reported in Australia each year as a result [3]. In another study carried out by Russell Manning et.al [8] shows that the steering wheel temperature rises above the cabin temperature during the parked condition. It was reported that steering wheel was hotter than the inside cabin by 7.5^0C.

During hot sunny days, if the vehicle is to be moved after parking for long hours, in general passengers are hesitant to start immediately due to prevailing thermal discomfort condition inside the vehicle itself. More often it is observed that, the passengers and drivers turn on the car’s ignition and AC system to high and roll down the window glass and prefer to wait for a substantial period of time before getting into the vehicle. This will allow cabin to cool down the interior condition, which will results in higher fuel consumption [9]. Few studies have been reported earlier on the issues and matters concerned with elevated temperatures in the parked car and few of the findings are well reported by Grundstein *et al.* [10] and McLaren *et al*. [11].

In recent past, there have been few add on artificial ventilation gadgets in the market sold as accessories for cars, which help to minimize temperature buildup inside the cars cabin under parked condition. Few of the artificial ventilations systems were driven by the vehicle power source and few refined ventilation systems driven by a small solar PV. John et al [12] reports once such ventilation system driven through a small solar PV panel, wherein ventilation system helps to reduce the temperature inside the car up to 20°C. The ventilations systems developed by John et al., [12] constituted a set of fans and to make sure that the fan gets continuously power supply they have installed the solar panel on the moon-roof. However, the car and ventilations system were observed to be unsafe, due to possibilities of theft as the moon-roof to be kept complete open. On the other hand, when it rains, the water enters in to the car through the opening in the moon-roof.

From the above discussion, parking the vehicle under a shade is definitely an attractive option to obtain better thermal comforts inside the cars cabin. Every passing year, Sultanate of Oman is witnessing increased numbers of new private passenger vehicles hitting the roads of Oman, further dependency on the passenger vehicles due to thinly available public transport has resulted in higher vehicle density. Invariably, the high density of private passenger vehicles has resulted in paucity of parking space and demand for additional parking spaces are getting more significant, especially at the government offices, universities, colleges and shopping area. Unfortunately the available shaded parking space are no match for the existing number of vehicles, hence the alternative choice for those who are unable to park under shade is to park in an open parking space and thus inviting the thermal discomfort problems in parked vehicles. Hence, an attempt was made by the authors to design and develop a simple standalone solar driven ventilation system to provide necessary air exchange across the cars cabin. In this research paper, an investigation on vehicles AC cooling performance in order to raise the cabin thermal comfort of the cars parked under the hot sun is studied and reported.

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MATERIALS AND METHODS

Ventilation system development

A simple ventilation system was developed and installed in a chosen test vehicle with necessary instrumentation which supplied fresh air from outdoors into the car cabin and purging the hot accumulated air from vehicle cabin. In order to evaluate the air conditioning system performance inside a long parked vehicle, a simple proof of concept of solar powered cabin ventilation system was developed and studied at the Caledonian College of Engineering Oman campus. This paper reports the experimental findings of the simple real time AC tests conducted with developed ventilation system in a chosen car and results are analyzed with reference to the readings obtained during testing.

In general, purpose of ventilation system is to remove the air or smell unwanted in any place as well as maintain conditions of temperature or smell which are compatible with human habitation and industrial operations. Experimental methodology adopted in the current study can be divided into two parts. The first part of the study included, developing and installing the temperature measurement devices inside the cabin of the chosen car and record the cabin temperatures rise without ventilation system. In the second part of the study, a simple standalone solar P.V ventilation system was to designed, fabricated installed and experimental studies were carried out to investigate cabin air temperature rise with developed the solar P.V ventilator. The system concept diagram is shown in the Figure-1.

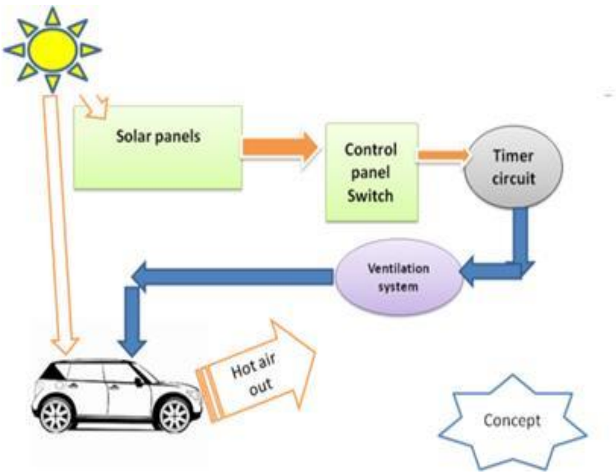
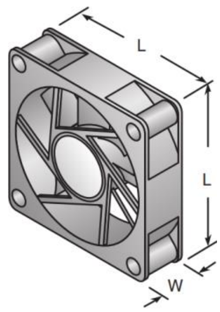


Figure-1. Concept diagram of the setup.

Following components and equipment were used in designing and fabrication of a simple standalone Solar PV ventilation system, viz. Solar panel, Ventilation Fans, Timer Circuit, Switches, Pipes, Multimeter with temperature measurement capacity and Thermocouples. The ventilation system was designed and developed, to take hot air from inside the car to outside so that it reduces the temperature inside the car. It was a challenge to install a ventilation system inside the car as it should not obstruct the cars utility. Through investigation was done to identify a suitable location inside the cars cabin to fix the ventilation fan and other circuitry without causing any disturbance to the occupants while seated inside the car. After several discussions with local garage mechanics, space behind the back seat was found to be ideal to fix the developed ventilation system. Figure-2 shows the schematic diagram of the ventilation system installed in the car. Figure-3 shows various images of ventilation system installed on the car rear side. Solar PV panels where installed at the just below the rear wind shield so that it overlook every time to open sky for receiving solar energy (refer to Figure-4). To supply fresh air inside the car cabin, another set of fresh air ventilation pipes were installed and set of fans drove the air across the cars cabin using a preset timer. The technical specification of the Solar PV panel and ventilation fan is shown in the Table-1.

Table-1. Technical specification of solar PV panel and ventilator fan.

Solar panel (1 No.)	Rated Power (P_{max}) :10W , Current at P_{max} (I_{mp}) :0.52A , Voltage at P_{max} (V_{mp}) :18.72V(DC) , Nominal Operating Cell Temperature: 45^0C , Dimension: 335x235x20mm , Maximum Series Fuse Rating :4A.
Ventilator fans (3 No's)	Model AD0612HB-D71GL, Current : 0.13A, Voltage :12V (DC), Power Rating: 1.56 W, Rated Airflow: 16.6 CFM, Fan Speed: 4500 RPM , Frame Dimensions : (L)60 mm x (L)60 mm x (W)15 mm. 

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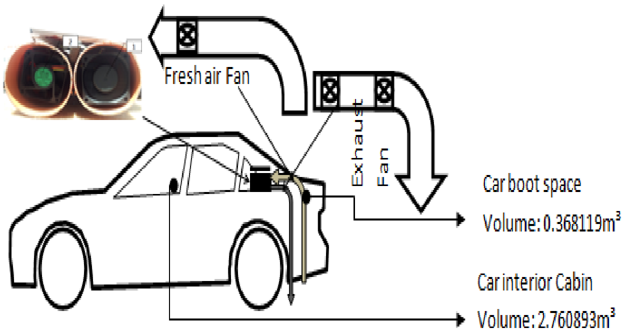

Figure-2. Ventilator location inside the car.

Figure-2. Photographs of ventilation pipes and fans.

Figure-3. Photograph of solar panel mounted on rear side along with ventilation pipes and fans.

To measure the temperature inside the car cabin at various points, a simple set of thermocouples were used. Palm sizes Digital Multimeter UNT-T make which had 1^{0}C accuracy and with temperatures range from -40 ^{0}C to 150 ^{0}C is used to readout the thermocouples output. The Figure-6 shows the multimeter with 6 thermocouples and a sector switch which was used for the experimental investigation. 6 thermocouples were attached to selection switch to measure readings from mutlimeter as shown in Figure-5. Mounting location of 6 thermocouples inside the cars cabin is very important so that it aids to locate different temperature zones inside the cabin. As temperatures need to be continuously monitored and recorded daily basis, thermocouples were mounted such that it posed no threat or obstructions while driving. Each thermocouple was hung vertically from the roof top at distance of approximately 60 mm from the roof top. Identified locations inside the car cabin, where so chosen that six different zones were identified and thermocouples are wired as shown in Figure-6. Figure-5 shows the 6 locations at which the thermocouples were installed inside the car cabin. Along with this this setup, outside temperatures during the experimental investigation was also measured.

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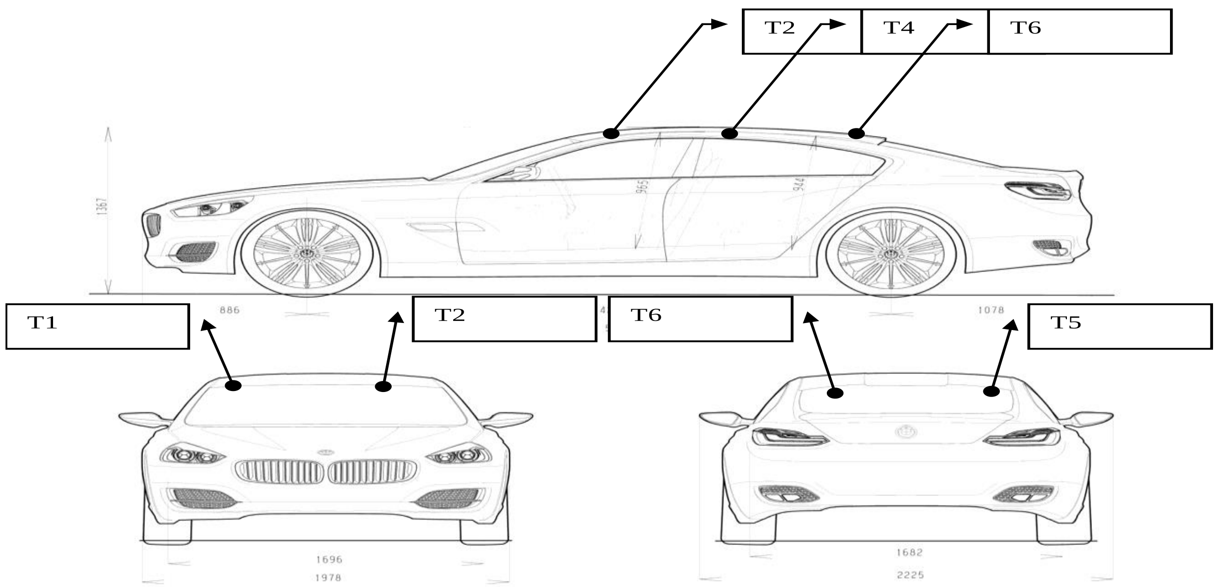
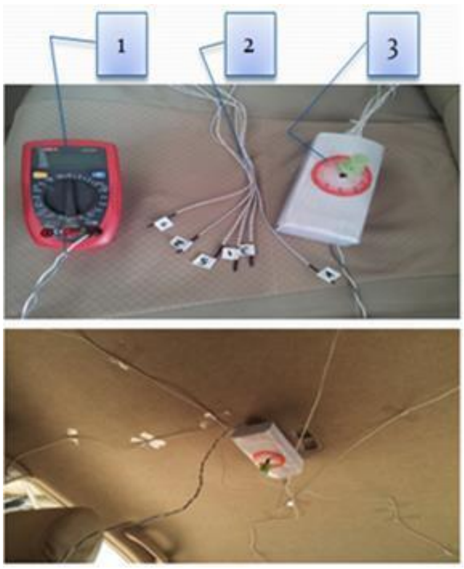


Figure-4. Location of tthermocoupless mounted inside the car [13] (Line diagram Courtesy: http://www.autoblog.com).



Legends	1	2	3
	Multimeter	*Thermocouples*	*Selector switch*

Figure-5. Temperature measuring equipment.

RESULTS AND DISCUSSIONS

a) Theoretical air exchange requirements

As an ideal condition, an effective fan should capable of replacing the entire volume of air 8 times per hour (8 air changes per hour). Thus CFM of air required for ventilation = Volume of cabin/ 7.5 =13 CFM. In order to drive the suction fan and blower fan in tandem, a timer circuits was designed and developed such that the suction fans was fresh air fan was driven in tandem in a cycle of 3 minutes as depicted in the Figure-7.

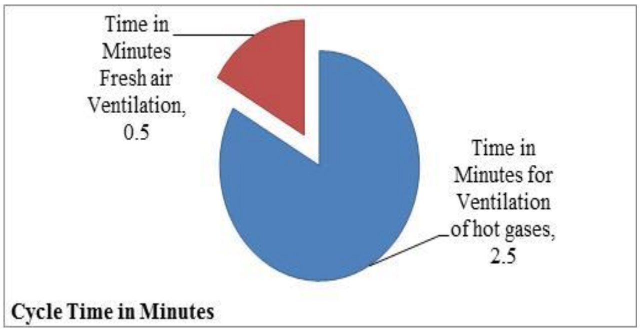


Figure-6. Time period in minutes for ventilation circuit.

With the designed circuit timer for a cycle time of 3 minutes, and with the volume of air to be exchanged and the static pressure of the system to be cooled are known, it is possible to specify a fan. The governing principle in fan selection is that any given fan can only deliver one flow at one pressure in a given system. Since it is difficulty to draw the hot air in to the suction pipe and then push it down to through vent hole situated at the boot space. Two fans in series are used so as to operate in a push-pull arrangement for purging the hot air from the cabin space. By staging two fans in series, the static pressure capability at a given airflow is fairly being increased, but again, cannot be doubled. The airflow required to dissipate the heat generated can be approximated with fan specification. Amount of heat to be dissipated can be estimated if both specific heat and the density of the air are known, then the basic heat transfer equation (1) is:

$$Q = m \times C_p \times \Delta T \qquad (1)$$

By incorporating conversion factors, the heat dissipation equation is arrived considering the fan specification in CFM, and then above equation can be rearranged as in equation (2):

$$Q = CFM \times 0.00047194 \times \rho \times C_p \times \Delta T \qquad (2)$$

Where,
Q = amount of heat transferred**,** Watts
M = mass flow rate of the moving air, kg/s
$\mathbf{C_p}$ = specific heat of air (J/kg.K, for dry air at 40^0C , 1004 J/kgK)
ΔT = air temperature difference between cabin and outside, K. Theoretical heat transferred from an ventilation fan with the assumption that temperature difference between inside and outside is on an average is 20 ^{0}C.

This yields a rough estimate of the heat dissipation for the chosen airflow fans at sea level. For the cycle time of 3 minutes, the amount of air exchanged can be calculated as below.

The Amount of hot air drained out of car cabin in a cycle = Air flow rate of exhaust fan X venting time in a cycle

Amount of fresh air drawn in to the car cabin in cycle = Air flow rate of fresh air fan X fresh air intake time in a cycle. Thus the air exchanged and heat transferred for a cycle time is shown in the Table-2.

Table-2. Air exchange and heat transferred in a cycle of operation.

Cycle running time	Minutes	Amount of air exchange	Heat transferred
Venting time in a cycle	2.5	1.1725 m^3	25.96KJ (Heat purged away)
Fresh air intake time in a cycle	0.5	0.2345 m^3	- 5.19KJ(Cooling through fresh air)

Based on the above chosen cycle time, an electrical circuitry to drive the ventilation system was developed in-house and it is depicted in the Figure-8.

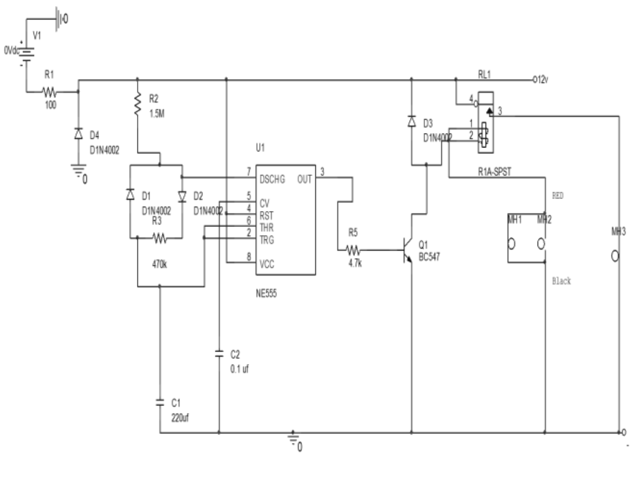


Figure-7. Circuit diagram of the developed ventilation system.

b) AC performance test results

With the developed indigenous ventilation system, host of experimentation was carried out to establish the base line reference temperature and identify the different temperature zones inside car cabin. From the experimentation, it was understood that car cabin can be classified in to three zones, viz. front, middle and rear zones. Cabin temperature readings without PV ventilation was carried out for continuous 4 days of the week in the summer month May 2013, and the average temperature of the car cabin at front, middle and rear zone is recorded and depicted in the Figure-9.

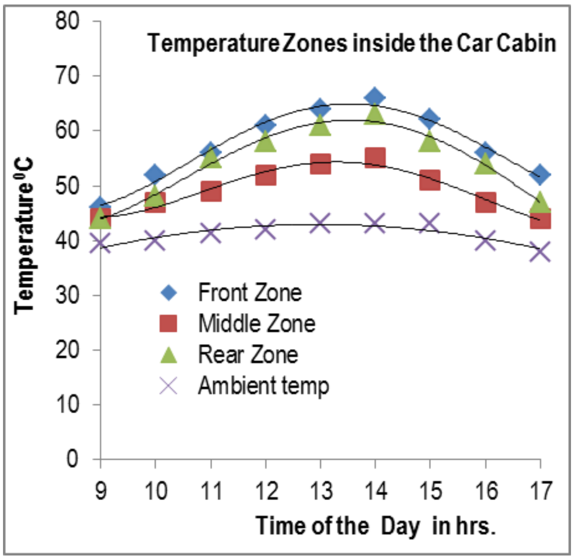


Figure-8. Average temperatures inside the parked car cabin without ventilation system.

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From Figure-9 it is evident that there is exits a greenhouse effect inside the parked car cabin, if it is parked under the sun. Due to this effect, the temperature raises excessively at the car cabin front zone and rear zone. The temperature rise at the front and rear zone is attributed to the front and rear glass windshield aperture area, which allow large quantum of sun rays entering the car. The glass aperture area of front and rear windshields exposed to sun's rays are considerably higher compared to the window glass area in the mid-section of the car, hence the temperature at the middle zone of the car was recorded lower than other zones. It was observed that the maximum temperature inside the car cabin was consistently hovering around 65^{0}C at the front zone while the average ambient temperature outside the car was 43^{0}C during 1 PM. From the Figure-9 it is evident that temperature inside the car cabin is typically 20^{0}C to 23^{0}C higher than the ambient temperature and this situation for any given day is not favoring air conditioning systems available in the car. The excess car cabin temperature puts on lots thermal load on the car air conditioning system. Further, looking at the temperature profile inside the car cabin, it is needless to say that it is very harmful to the humans and the temperature is way beyond the human thermal comfort zone.

After establishing the baseline temperatures of car cabin in the first part of experiment, further experiments was performed with PV driven ventilation system and studies were carried out to see its impact on the cooling performance of the car air conditioning systems. In order to test the effectiveness of the developed ventilation system the car air conditioner test was performed on selected two consecutive days in the May 2013. The air conditioning performance test was conducted at 12 noon with the car starting with existing temperature and turning on the engine with air-conditioning setup for full cooling mode. The AC control switch was turned to a set position and thermostat knob was turned to maximum position for maximum cooling performance as shown in the Figure-10. To study effect of solar ventilation on air conditioning system of the car parked under the sun, the test was conducted for two consecutive days. At day one, the air conditioning system was tested with ventilation system turned on and on day two, the test was conducted without ventilation system. In Figures 11, 12 and 13 show the AC testing results with and without ventilation system the car at 12 noon which emphasizes on time taken to cool down the car cabin temperature for first 14minutes of the test.

Figure-9. AC control switch positions.

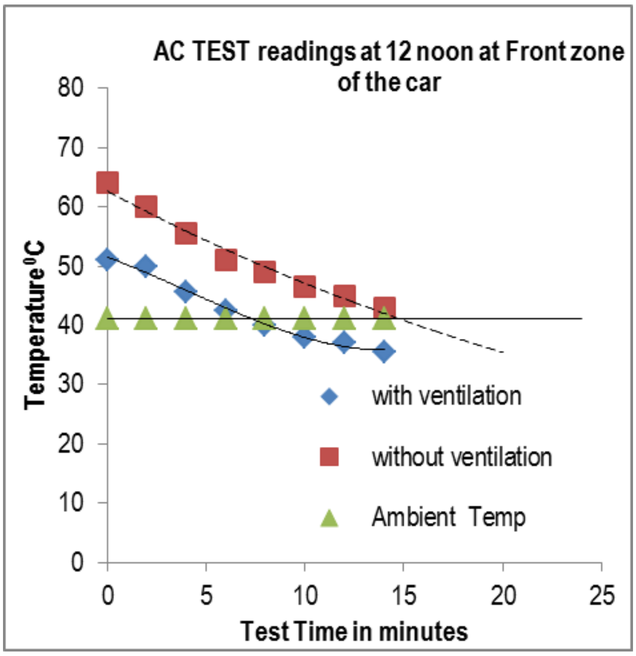

Figure-10. AC test readings at front zone of the car.

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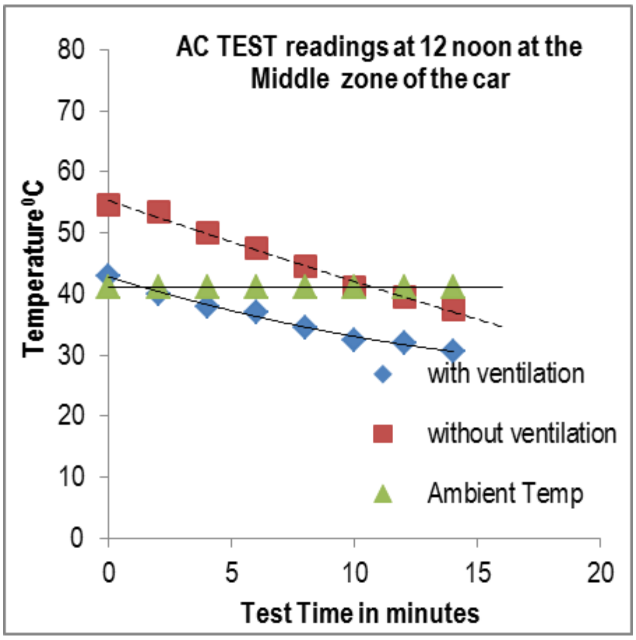

Figure-11. AC test readings at middle zone of the car

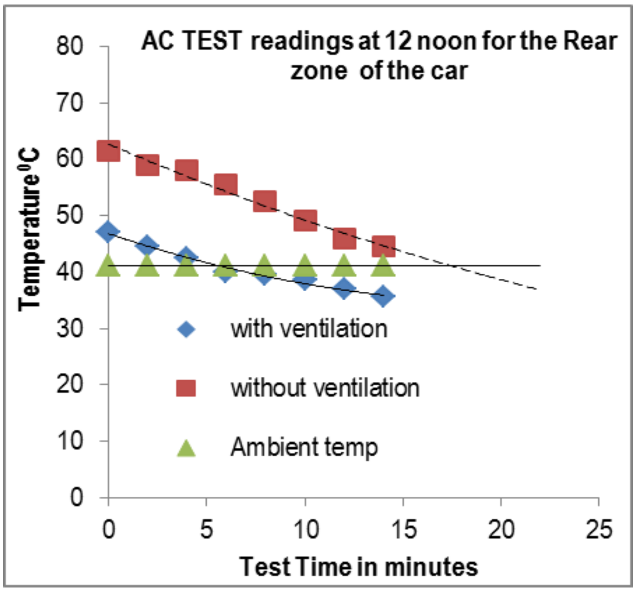

Figure-12. AC test readings at rear zone of the car.

Air condition systems in the car when turned on is expected to cool down the temperature of the car cabin, faster it cools down the air, more is the effectiveness of the air condition system. Car air conditioning system will experience higher thermal load if the temperature inside the car cabin is higher than the normal temperature when cars are parked under the sun light. In such cases, AC systems typically take longer period of time to cool down car cabin air temperature consequently demanding more fuel cost for cooling. It was observed in Figures 11, 12 and 13 that the car cabin temperature was found decreasing with time and drop in temperature is more rapid when car PV ventilation system was turned on. As seen in the Figure-11, the air temperature at the front zone of the car cabin decreased rapidly with time, interestingly the car cabin temperature reached the ambient temperature at the end of 15th minute of test when the car ventilation system was turned off. While, with PV ventilation system turned on, for the similar condition, cabin air temperature reached the ambient temperature at the end of 6.5 minute. This experimental study clear demonstrates the temperature-cooling time relationship, and the impact of solar ventilation system on cooling performances of car air conditioning system.

The situation at the rear zone of the car cabin was no different than the front zone, it was observed that the temperature dropped with time and typically it reached the ambient temperature at the end of 17th minutes of test when the car ventilation system was turned off. While, with ventilation system turned on, for the similar condition, cabin air temperature reached the ambient temperature at the end of 6th minutes as shown in the Figure-13. As the car air conditioning dispensing unit is at the front dashboard, rate at which temperature drops at rear zone of the cabin was observed to be slower than the front zone. Should there be an air dispensing unit at the rear zone, then the rate of temperature drop would be of similar that of front zone.

Temperature-time profile for the middle zone of the car was very much distinct as depicted in the Figure-12. At the 10th minute of AC of test, temperature inside the car cabin reached ambient temperature when ventilation was turned off. But, with ventilation system turned on, cabin air temperature reached the ambient temperature by the end of 2nd minute of the AC test. The above AC test run suggest that with the solar driven ventilation system, the air condition systems performance is effective as lower temperature can be felt with short span of time. This undeniably helps in lowering thermal load on the car AC and therefore drivers and passengers will feel comfortable to enter inside the parked car.

CONCLUSIONS

Simple solar PV driven ventilation system was developed and tested for its effectiveness inside the car. From the experimental investigation it was found that the temperature inside the car cabin when parked under the sun was extremely higher with maximum temperature reaching 66^{0}C during noon time. It was observed that when the ventilation system was functional the air temperature inside the car reduced and reached maximum of 56^{0}C. From the above experimental investigation, it can be concluded that solar PV driven ventilation system is a very effective approach to minimize the temperature build-up inside the car cabin when it is parked under the sun. Further the experiments done with vehicle air conditioning system suggested, cabin experience quicker cooling and there by bringing in the thermal comfort inside the car cabin in short span of time when ventilation system was operational. With the ventilation system operational, the thermal load on the car AC is lower and therefore aid in achieving higher fuel economy. With solar driven ventilation system the car cabin temperature reached to the comfort level much quicker, typically lesser than the half of the time compared to those values tested without ventilation system. Thus with the developed solar powered ventilation system, cabin air temperature of the car can be reduced drastically. Further, the ventilation system will also help in improvising the functional aspect of the air conditioning system..

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