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Parked Electric Vehicle's Cabin Temperature Management Using Photovoltaic Powered Ventilation

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Abstract

This paper presents how the electric vehicle roof integrated photovoltaic (PV) powered ventilation can be used for controlling the climate of the car. In this work, a fully-functional Renault Zoe electric car has been used to conduct experiments for PV powered ventilation. These experiments have been part of a wider research project of testing electric vehicles of the Edinburgh Napier University's Transport Research Institute. The present work illustrates performance evaluation of electric car ventilation, when roof-mounted PV modules were used to operate DC powered fans for ventilation. It was found that the motor-fan selection for removing the warm air from cabin space is of important (i.e. motor-fan operating points have to be near to the maximum power points of PV modules under varying solar radiation). In this article, experimental results are presented and analysed.

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Keywords: Photovoltaic (PV) ventilation, Electric cars, PV electro-mechanical system.

1. Introduction

The electric vehicle penetration is increasing rapidly. To reduce the power demand on the electric vehicle battery, energy efficiency should be considered. The electric car energy efficiency can be enhanced by decreasing the load of the auxiliaries of the car (e.g. ventilation, which contributes a large share percentage of energy use). The load reduction of the car auxiliaries can be helpful for electric cars as well as, fossil fuel based cars. The car auxiliaries are responsible for the consumption of larger percentage share of the overall car energy use. Car roof integrated PV modules can be used to power directly the ventilation system using DC motor-fan(s) [1-3]. It can help in reducing cabin / interior temperature of the car. Ford Motor Company has introduced C-MAX Solar Energi Concept, for sun-powered plug-in hybrid electric vehicle and Fresnel lens based PV modules can help in charging of hybrid vehicle [4]. It [4] has not considered PV modules only for car ventilation / auxiliary load. A Renault Zoe electric car has

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been used to conduct experiments for PV powered ventilation [1]. This paper examines a simple technique for ventilation in vehicles using PV powered motor-fan, when the car is parked in an open space directly open to the sun. When a vehicle is parked in the open space under clear sunshine, the car cabin temperature rises steeply and can reach up to 60^{0}C. It was observed during the experiment at the Napier Edinburgh University. PV arrays are directly used for powering water pumping and propeller systems through DC motor-centrifugal pump / load [5-11]. There is a possibility for use of car roof mounted PV array for powering directly coupled PV powered DC moto-fan systems for car ventilation [1]. This work is examining role of directly PV powered DC motor-fan system for reducing the car cabin temperature and increasing the energy efficiency of the electric car.

Fig 1: Car used for the carrying out the experiment

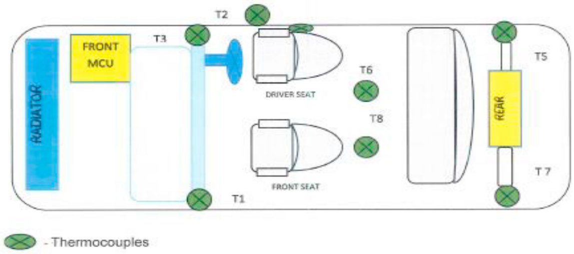

Fig 2. The thermocouples positions in the car

2. Experimental Setup

For the PV powered ventilation system experiments, the Renault Zoe electric car was used, and it was parked at Edinburgh Napier University’s Merchistion campus (UK).

Thermocouples were placed inside the car to quantity temperatures inside the cabin. A schematic diagram of the thermocouples placed in this car is shown in Fig.2 [1]. Thermocouple locations are given in Table 1

Table 1: Thermocouple locations in the car [1]

Thermocouples	Placement	Position
T1	Front Side	From left edge –23 cm Above the vehicle floor - 80 cm
T3	Front Side	From the right edge - 24 cm Above the vehicle floor - 80 cm
T6	Vehicle Roof	From the right edge - 16 cm Above the vehicle floor -102 cm
T8	Vehicle Floor	From the left edge - 34 cm Above the vehicle floor - 120 cm
T5	Backside	From the right edge - 16 cm Above the vehicle floor -102 cm
T7	Backside	From the left edge - 33 cm Above the vehicle floor -102 cm
T2	Outside	Above the vehicle floor - 98 cm

The PV module and other instrumentation details are provided in Table 2:

Table 2: PV module and instrumentation of the experiment

Equipment	Rating	Description
PV Module	80 W_p	V_{mp} of 17.6 V.
Data Logger		Squirrel 2020 series data logger, having internal memory of 128 Mb
Pyranometer		Kipp and Zonen CM11 pyranometer having sensitivity of 5.28 X 10^{-6}V/ Wm^{-2}
Fans	10 Watt	Rotating speed - 3650 rpm at 12 V and 830 mA
	12 Watt	Rotating speed - 5400 rpm at 12 V and 1A
	5 Watt	Rotating speed - 2900 rpm at 12 V and 440mA

3. Data Measurements

The measurements were recorded for 6 days. The measurement details [1] are described as:

- Day 1 to 3: The PV panels and pyranometer were tilted from horizontal at 23^0. The PV output was used directly to power fans of 10 W and 12 W. The fans were located on the rear side of the car and the windows on the front were released 1.3 cm once the PV powered fans were operating.
- Day 4 and 5: The PV panels and pyranometer were horizontal. The PV output was used to power four fans (2 on backside and 2 on front side) each of 5.3 W.
- Day 6: The car was fully closed and ventilation fans were not used. The car cabin temperature recorded and observed it varies according solar radiations.

The measurements for each day are analyzed. Some analysis is also presented in our earlier paper [1].

3.1 Day 1 (09-07-2014)

A. Solar Radiation

The solar radiation measurements are given in Fig. 3.

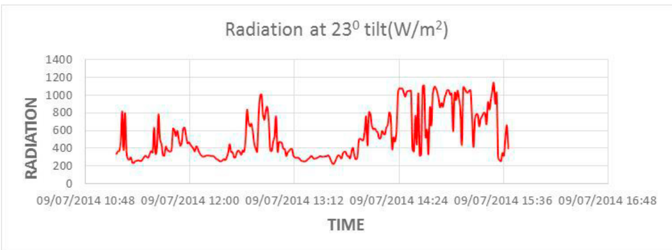

Fig 3: Solar radiation at Aspect of 53^0 West of South and tilt of 23^0C [1]

B. Temperature measurements:

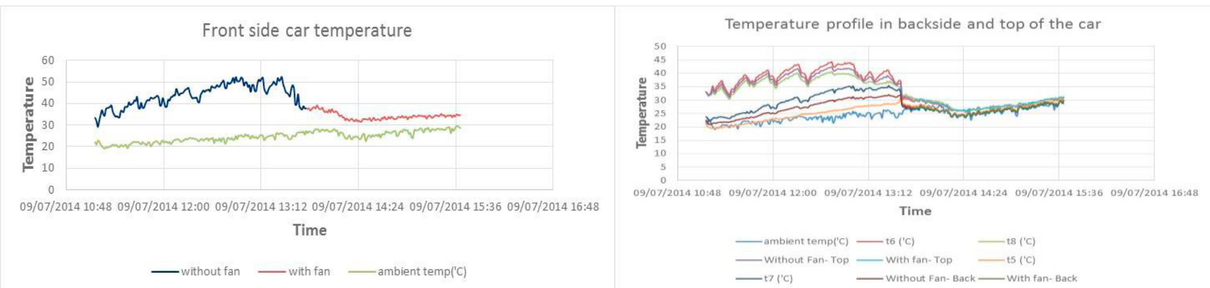

Fig 4. Temperature profile in front back and top side of the car (with / without fan) [1]

Temperature profile in front side backside and top of the car of the car (with / without fan) is given in Fig.4. Maximum temperature inside the car cabin at the front was increased to 52^0 C. After turning on the PV powered fan, the cabin temperature started decreasing and average temperature was 33^0 C. Similarly, it is observed that the top side average temperature was 43^0C and car backside maximum temperature was 35^0C. When the PV powered fan was turned on the temperature dropped to 25^0C.

3.2 Day 2 (10-07-2014)

A. Solar radiation:

The solar radiation measurement on this day is given in Fig. 5

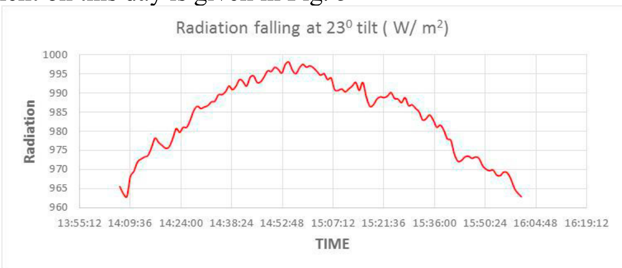

Fig 5: Solar radiation at aspect of 53^0 West of South and tilt of 23^0C [1]

B: Temperature measurements:

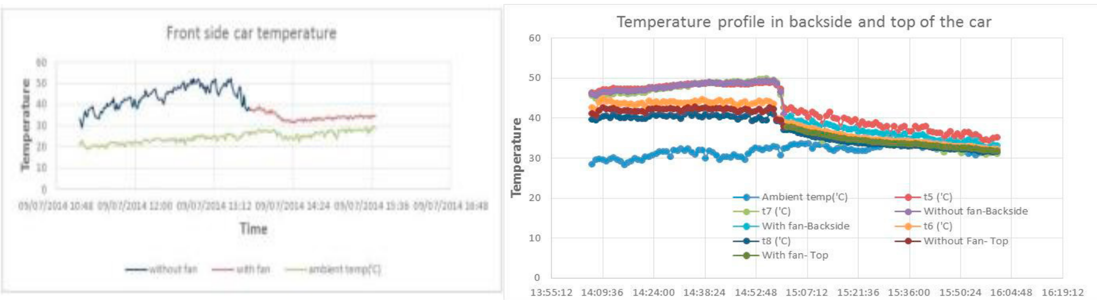

Fig 6: Temperature profile in front, back and topside of the car (without and with fan) [1]

It can be observed that the car cabin temperature in the top was around 40^0 C and backside temperature was 50^0C (Fig.6). After powering the ventilation fan from PV, the temperature dropped to 32^0C, nearer to ambient temperature.

3.3 Day 3: (11-07-2014)

A. Solar radiation

The solar radiation measurement on this day is given in Fig. 7.

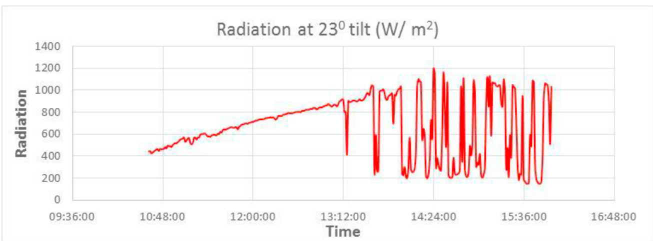

Fig 7: Solar radiation at aspect of 53^0 West of South and tilt of 23^0C [1].

B: Temperature measurements:

Car cabin temperature profile in front (without- and with fan) is given Fig. 8. The cabin temperature was increased to 57^0C and after powering ventilation fans from PV, it dropped to 40^0 C. Car cabin temperature profile at the back and top (without and with fan) is given in Fig. 10. The t6 thermocouple (top side) recorded 49^0C and average temperature was 45^0C. Similarly the other thermocouple t8 recorded 42^0C. After PV powering the ventilation fan, the car cabin temperature decreased near to ambient temperature of around 30^0C.

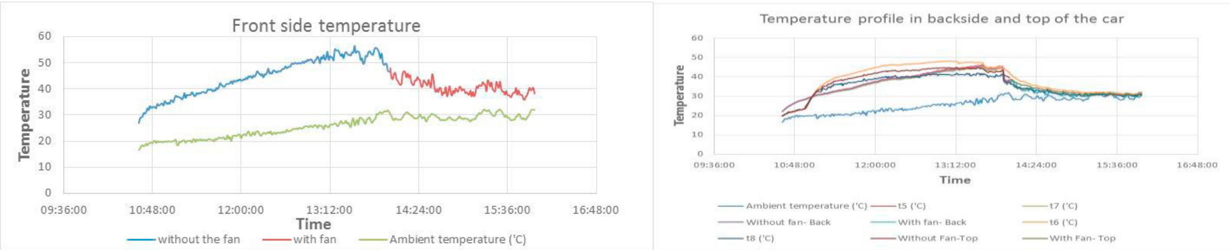

Fig 8. Temperature profile in front, top and back of the car (without- and with fan) [1].

3.4 Day 4: (17-07-2014)

A. Solar radiation:

The solar radiation measurement on this day is given in Fig. 9.

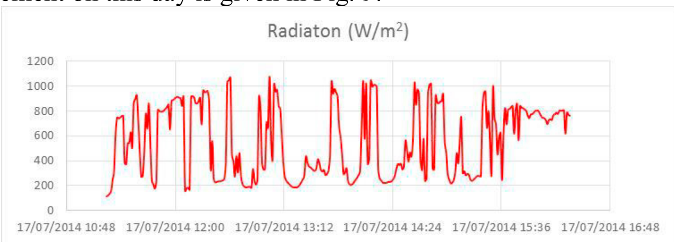

Fig 9: Solar radiation on horizontal surface [1]

B. Temperature measurements:

Temperature profile in front of the car (without and with fan) is given in Fig. 10. In this test, four low-starting-torque fans each of 5.3W were used. The back and top side car cabin temperature variations with thermocouples are given in Fig.10. After powering the ventilation fans from PV, the car cabin temperature dropped near to ambient.

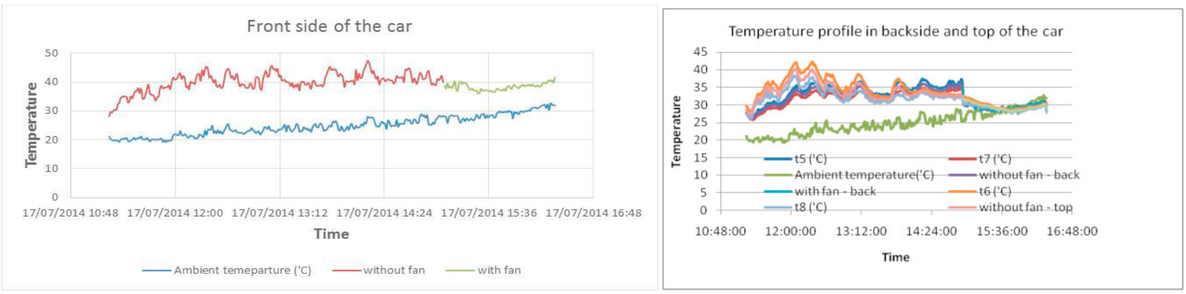

Fig 10: Temperature profile in front back and topside of the car (without and with fan) [1]

3.5 Day 5: (18-07-2014)

A. Solar radiation.

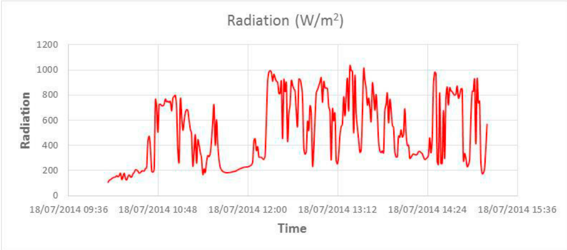

Fig 11: Solar radiation on horizontal surface [1]

The solar radiation measurement on this day is given in Fig. 11.

B. Temperature measurements:

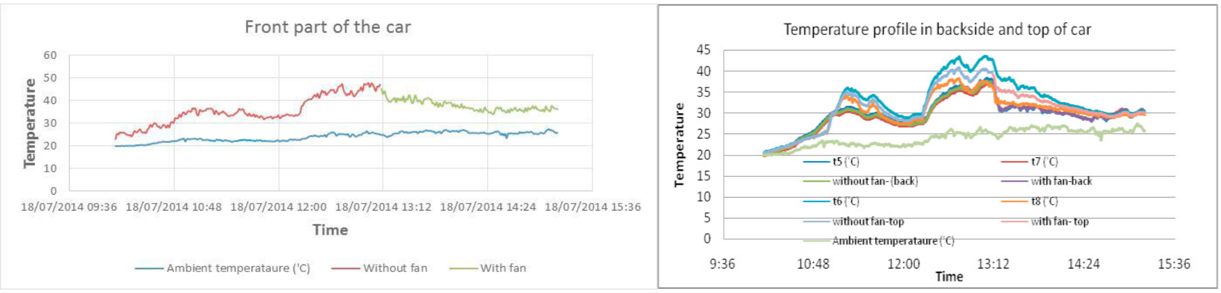

Fig 12: Temperature profile in front, back and topside of the car (without and with fan) [1]

Car cabin temperature [1] in front and back and side (without and with PV powered ventilation fans) is given in Fig. 12 respectively.

3.6 Day 6: Date (20/07/2014-21/07/2014)

During this time-period, only the car cabin temperature variations were measured (Fig.13). The idea behind carrying out this test was to analyse at the temperature profile inside the car cabin during a 24-hour time period.

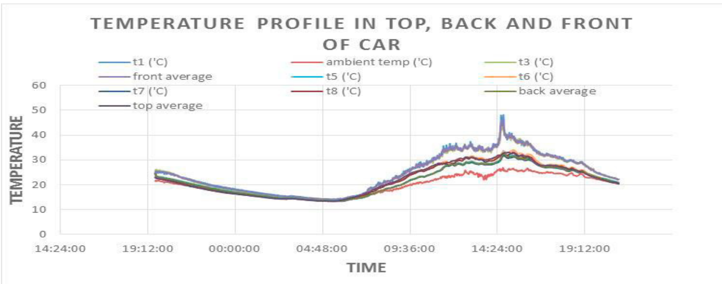

Fig 13: Car cabin ttemperature profile [1]

The top-side temperature was increased up to 48^{0}C due to thermal stratification. Similarly, temperatures had started decreasing after 4 PM and at around 8PM the cabin temperature was close to the ambient temperature. Some results are also described in detail in our previous work [1].

4. Conclusion

The experimental results have shown that vehicle roof integrated PV modules can be used for powering car ventilation system and it can help in reducing the cabin temperature especially during summer months. It can help in reducing the vehicle cabin temperature near to ambient temperature level. The operating speed of the fans depends on the incident solar radiation and motor-fan parameters. Similarly, motor-fan starting torque, rotational speed and volumetric flow rate are dependent on the PV array output. It has been found that the selection of fan and DC motor for extracting the warm air from cabin space is of crucial importance. The operational points of combination of DC electric motor and fan should be near to PV array's maximum operating points. Results from this work will be helpful for designing electric vehicle ventilation system when powered by vehicle roof integrated PV modules.

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