CABIN HEAT REMOVAL FROM PARKED CARS

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Abstract:*The paper presents a solution for designing an intelligent and modular solar energy system for heat removal from parked car cabins. We propose a ventilation system composed of two pairs of cross flow fans, one placed under the car roof cabin between the steel plate and the indoor insulation and the second under the rear shelf of the back seats. The cabin was exposed to the sun radiation (600-800 W/m^2) with no wind. Indoor temperature and humidity were measured with no ventilation. The data was used to design the cross flow fans. The air flow rate needed for an efficient ventilation was calculated at 0.02 m^3/s, a value compatible with other results in the literature.*

Keywords*: car ventilation, solar energy, cross flow fan*

1. Introduction

The increase of the air temperature inside car cabins, especially when parked under intense solar radiation, has some negative impact such as: low thermal comfort and some health risk for the passengers, increased fuel consumption when restarting the air conditioning for reducing the indoor temperature and lowering the quality of the cabin materials like plastics, foams or artificial leather, rubber, synthetic fiber etc.

Concerning the health risk for the passengers, research was performed in order to highlight the risk of human exposure to volatile organic compounds (VOC) especially in the case of new cars [1]. Even if some studies state that "the smell of the new car"wears off in a matter of weeks or months [2], the process of VOC elimination, also responsible for the indoor air quality, is not confirmed. For example, the toluene and xylene concentration inside cars declines from 200 to 60 $\mu g/m^3$ and from 250 to 30 $\mu g/m^3$ respectively in 20 days but these VOCremain present [3]. Also, research shows that for some VOC the concentration varies in time and is dependent on indoor temperature, humidity, ventilation efficiency, age of the car (where poor sealing allows exhaust gases to enter the cabin)and other conditions such asclimate etc. In close relation with the above, we know that in an automobile of 1000 kg weight, about 100 kg consists of plastics –50% of the total internal components including safety subsystems, doors and seat assemblies. Also, 13 types of polymers are used in an automobile - 66% of these are polypropylene (32%), polyurethane (17%) and PVC (16%) [4]. Statistics estimate that people spend about 7% of their day commuting between home and workplace [5], or even more if vehicle's cabinis in fact their workplace(the case of professional drivers). Hence automobile drivers are exposed to organic hydrocarbons. Concentrations reported in the passenger cabins are about 13 to 560 $\mu g/m^3$ for benzene, 33 to 258 $\mu g/m^3$ for toluene, 20 to 250 $\mu g/m^3$ for xylene and 3 to 23 $\mu g/m^3$ for trimethylbenzene [3]. The accepted values for the environment are 2–150 $\mu g/m^3$ for toluene and 5–20 $\mu g/m^3$ for benzene (European Chemicals Bureau, 2003 a,b; World Health Organization, 2000). For new cars, studies [6-7] report average concentrations values of 11.8 $\mu g/m^3$, 82,7$\mu g/m^3$, 21,2 $\mu g/m^3$ and 89,5 $\mu g/m^3$ for BTX - benzene, toluene, o-xylene and m,p-xylene respectively. In used cars, BTX concentration values are higher and relevant deterioration of data was reported for more than 11.000 km.

Concerning the passenger thermal comfort, some research was performed in order to evaluate the interaction between the human body and indoor cabin conditions. For this, a "human body defragmentation"in 16 static elements was proposed [9] for which mass and heat exchange was measured between these elements and cabin components. It was reported that nonuniform air and temperature distribution are the cause for local high discomfort for passengers. Other studies propose intelligent ventilation of the cabin when the car is parked [10]. For some case studies windshields are consideredas the main gate for solar radiation access and for this hypothesis some extreme heat surfaces were identified in order to be first/intensely ventilated. Still, existing studies do not provide clear results regarding efficient solutions for cabin ventilation, since experimental results are not convergent with theoretical models [11].

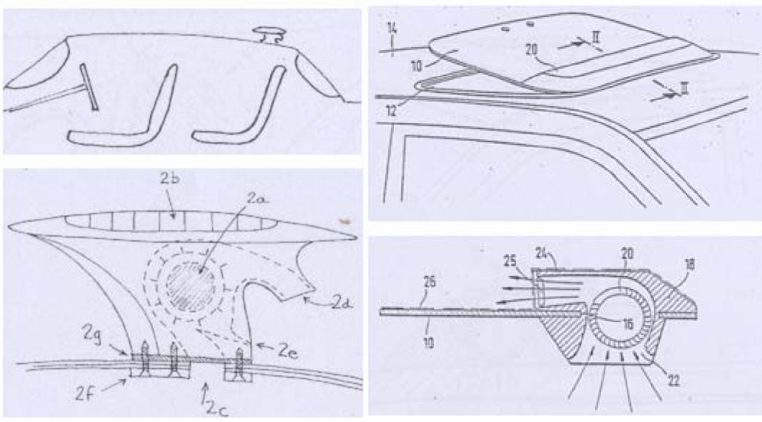
Concerning the fuel consumption it is known that when restarting the air conditioning system over a parked period under high solar radiation, the car engine will request more fuel than under normal conditions (related to rated engine temperature). Hence high engine fuel consumption will be registered untilindoor conditions becomesuitable for passenger comfort. The above reasons constitute a good motivation for studying an efficient ventilation system also for reducing house effect in the cabin.

According to the above assumptions, we propose an original solution for cabin heat removal from parked cars by using an intelligent solar modulated system equipped with crossflow fans.

2. The ventilation system

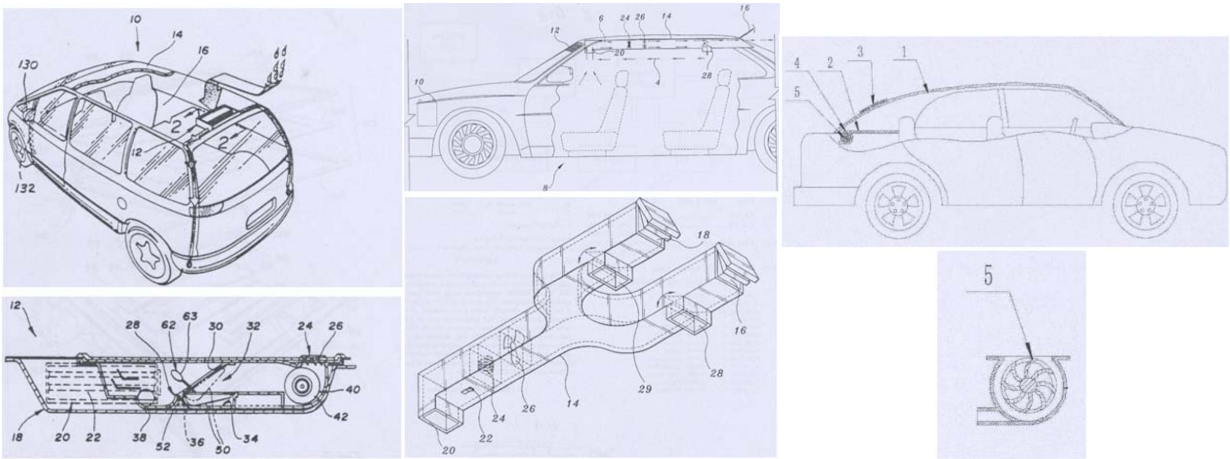
For the ventilation of passenger cabins some solutions propose independent units with simple structuresuch as lateral windows fans [12-14] or roof window fans [15] powered by solar photovoltaic panels. Another solution is given by considering complex ventilation systems included in the ventilation structure of the cabin. For example some systems are placed on the roof of the car [16-17] in the exterior as shown in figure nr. 1 a, b or inside the car [7-9] as shown in figure nr. 2 a,b,c; the case "c"pictures a ventilation through the car trunk.

The solutions for ventilation systems are only to some extent compatible with theoretical results as presented in the first chapter. This is because most of the ventilation solutions are focused just on exhausting the heat air form the car cabin neglecting the indoor region where temperature is rising excessively–for example the front shelf. On the other hand, theoretical studies depend on some special border conditions in order to provide numerical solutions –for example the sun azimuth. Due to such a hypothesis, some theoretical results are not suitable to be used for selecting practical solutions –for example some studies consider the high temperature region to be on front shelf, other results consider this region as between the front and back seats.



a. b.

Fig. 1 External vehicle ventilation units
a. Top window cabin unit [16]; b. Air extraction unit [17]

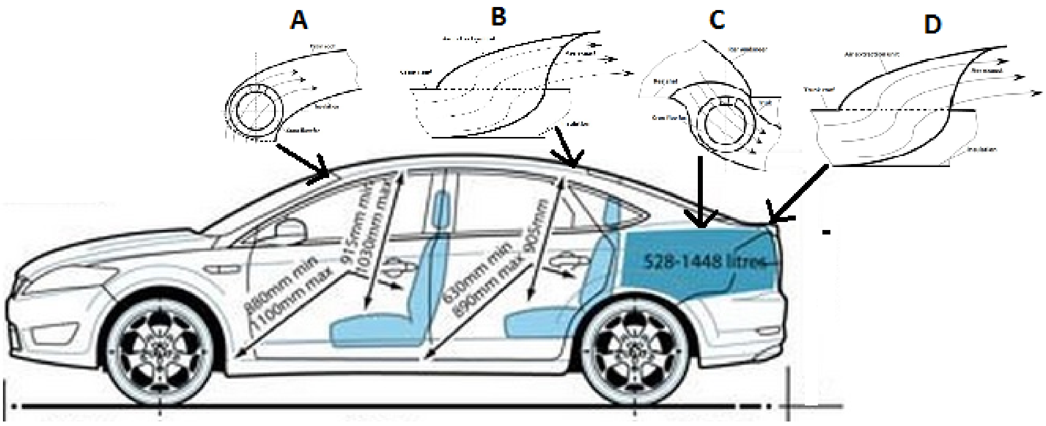


a. b. c.

Fig. 2 Internal vehicle ventilation systems
a.b. Top cabin system [18-20]; c. Trunk system [21]

According to these conclusions one has to decide the optimum position and size of the fans and to design the ventilation system in terms of electrical and operating demands.

The present paper presents a solution to these problems by considering that the best method to remove the car cabin heat is to avoid, as much as possible, the rise of the indoor temperature. Hence one propose a modular ventilation system. Two cross flow fans are to be positioned on the top front of the cabin–under the car roof cabin between the steel plate and the indoor insulation - and the other two under the rear shelf of the back seats. The main idea is to avoid temperature rise by ventilating the car roof - which is the highest surface exposed to the sun –and at the same time to remove the indoor heat through the rear of the cabin using the trunk in the same conditions as before. The positions of the fans and the system are presented in figure nr. 3. A Ford Mondeo cabin was considered for the preliminary experimental research i.e. monitoring the indoor parameters –temperature and humidity–and outdoor parameters –air temperature and external car roof temperature.



a.

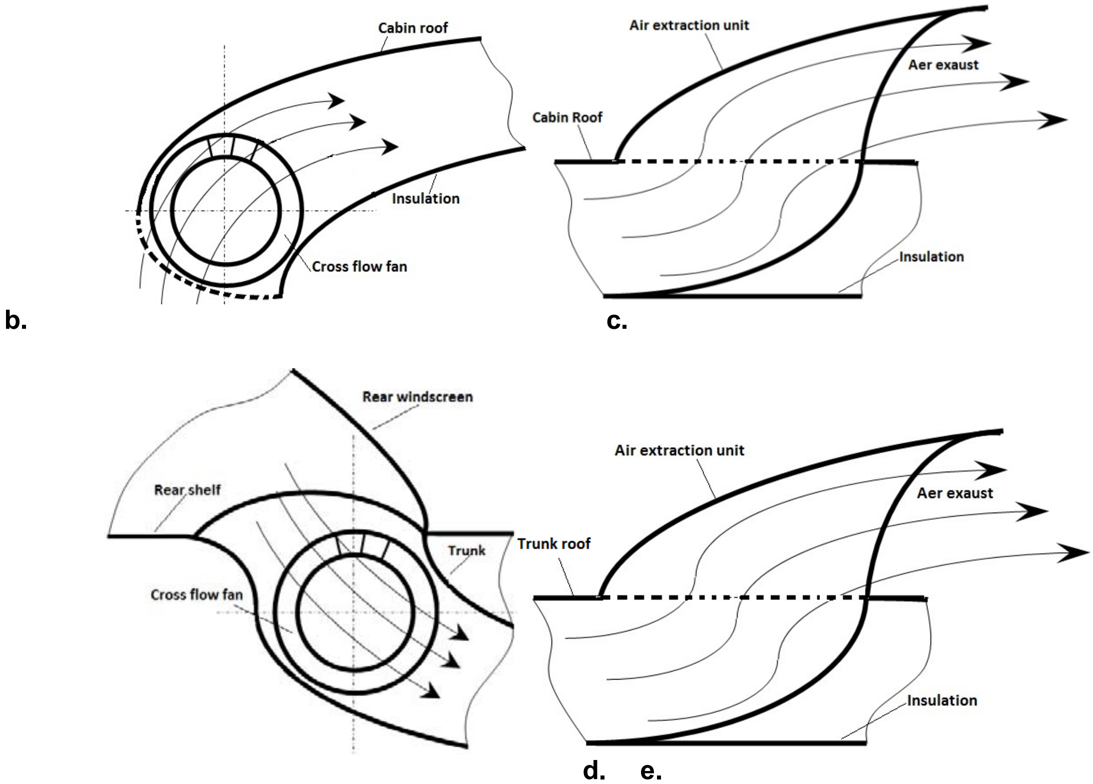


Fig. 3 The proposed ventilation system

a. Structure of the ventilation system; b. Front cross flow fan (A); c. Roof cabin extraction unit (B);d.Rear cross flow fan (C); e. The trunk extraction unit (D)

3. Experimental research

The cabin was exposed to the sun radiation –600-800 W/m^2- with no wind. Indoor temperature and humidity were measured with no ventilation. In the cabin, the temperature and humidity were measured at the level of the driver; the outdoor thermometer for measuring the temperature of the steel roof was positioned at 5mm distance from it. The measurements had a 15 min frequency. Table nr. 1 shows the results. The data corresponds to the values of the indoor temperature provided by the literature –(60-65) ^{0}C –which is reached in about 70 min. after the moment of parking the vehicle. The gap between indoor, outdoor and roof steel temperature is presented in figure nr. 4.

Table 1.

Temperature and humidity inside the car cabin

Time	T_{out} [^{0}C]	T_{in} [^{0}C]	T_{steel} [^{0}C]	u_{rel} [%]	H [W/m^2]
12^{30}	40.0	32.8	40.0	35.0	728
12^{45}	40.2	34.9	46.6	31.3	738
13^{00}	40.6	45.2	66.0	22.4	746
13^{15}	40.8	51.5	66.0	18.1	788
13^{30}	40.9	56.5	61.0	15.5	785

13^{45}	41.5	59.1	62.5	14.6	790
14^{00}	42.7	61.0	64.3	14.1	780
14^{15}	42.7	61.0	62.7	13.8	752
14^{30}	43.4	64.3	63.6	13.6	747
14^{45}	43.6	64.8	64.6	13.4	727
15^{00}	45.1	65.6	66.3	13.4	714
15^{15}	45.8	65.9	66.3	13.4	704
15^{30}	46.7	65.8	66.3	14.0	688

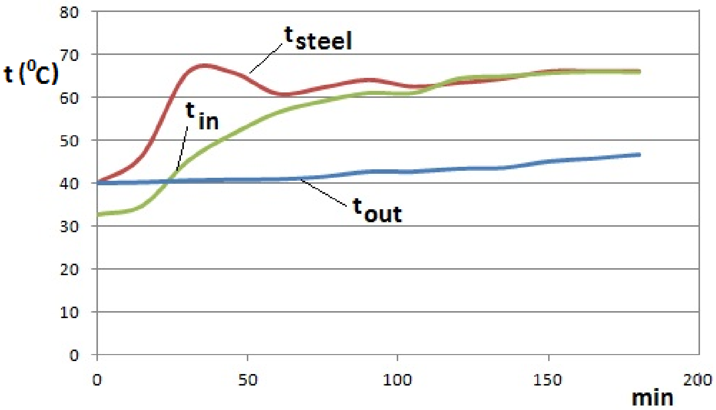


Fig.4 The gap between t_{indoor} , $t_{outdoor}$ and t_{steel}

It can be observed that after 60 minutes the gap is 4.5 ^{0}C and after 90 minutes the gap remains constant at about 2-3 ^{0}C. It is also clear that the ventilation system must start after about 25 min after parking the car.

In order to design the cross flow fan it is necessary to evaluate the air velocity in the channel (see figure 3.b). Using the average values of the data presented in table nr. 1 we consider that all the heat transferred from the roof to the channel is removed through section B. As the physical model is similar with that of plane solar heat collectors one can use the same mathematical approach: the roof channel describes a plain solar heat collector with internal flow. The dimensions are L x l x b = (1,3 x 1 x 0,03) m, where "b"is the diameter of the fan rotor and has to meet the ventilation requirements. If the efficiency of the installation is$|_c$ = 0,5, assuming a good evacuation of the heat, velocity value and the air flow through section B can be calculated. Using the classical formula for the heat flux:

Q = ©$_{air}$ xc_{pair} l x b x v x (t_{in} - t_{out}) 1

and: $|_c$ = Q/ (L x l x H), 2

we obtain the value for air velocity "v". For the present case study, if average values are H = 750 W/m^{2}and (t_{in} - t_{out}) = 20^0 C, the velocity average value is v = 0,65 m/s and the air flow rate is 0,02 m^3/s. The obtained values are compatible with recent theoretical research [21] where the authors obtained an air flow rate of 0,023 m^3/s for the case of heat removing from a car cabin by using a numerical method (thesestudies were performed between the same time of the day). As the results are similar both for the roof channel (experimental) and cabin (theoretical from the literature) we propose the same dimensions for the rear cross flow fans of the cabin.

Figure nr. 5 shows an example of an available the cross flow fans. The technical solution for the case study consists in two pairs of fans with a single motor for each pair.

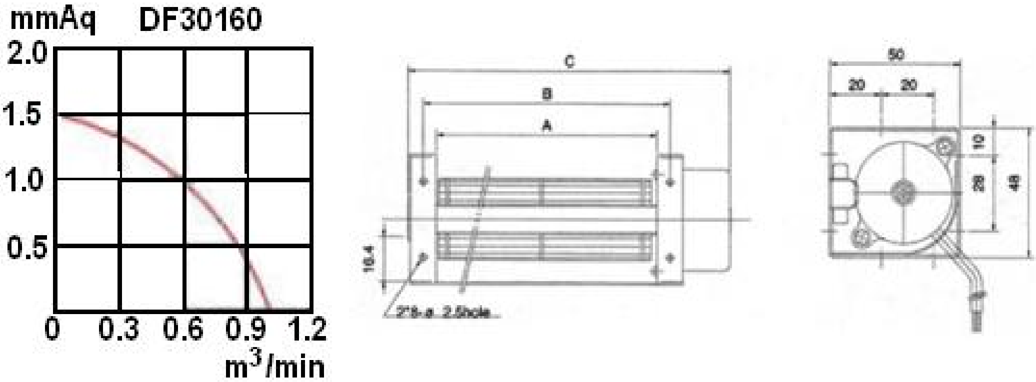


Fig. 5 Cross flow fan
(d_{rotor}=30 mm; A=160 mm; B=170 mm; C = 194 mm; Rated voltage =12 V; Rated current = 0,2 A; Speed =3,200 RPM; Max. Pressure = 1.5 nnH_2O; Air Flow = 0.8 m^2/min; Noise = 37 dB; Weight = 230 g)

The fans are selected for parallel operation, doubling the available flow rate. If longer rotors (A) are used, more air flow can be obtained. The two ventilation modules are powered by solar photovoltaic cells positioned on the roof of the auto vehicle and assisted by an automation system –as presented in figure nr. 6 -providing variable rotating speed for the fans according with the indoor temperature and the external temperature of the steel roof –related with the solar radiation.

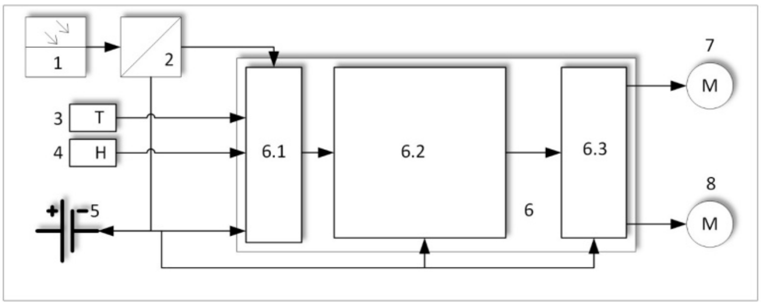


Fig. nr. 6 Automation system

1. Photovoltaic cells; 2. DC to DC Converter – Switched Mode; 3.Temperaturesensors; 4.Humidity sensors; 5.Car Battery; 6.Automation Unit; 6.1.Measurement Unit; 6.2.Microcontroller Unit; 6.3.SMPS (Switched Mode Power Supply) Variable Speed Fan Motor Driver; 7. Fan Motor 1; 8. Fan Motor 2.

As the humidity is decreasing in the cabin car during the parked period, a method for improving the passenger comfort after restarting air conditioning is needed. Further research will be focused on controlling humidity vs. temperature in the cabin car.

The presented system has low economic impact on vehicle price. From an economic point of view, the cost of the system is approx. 250 Euro since the double cross flow fans cost is 100 Euro.

Conclusions

The paper presents a solution for designing an intelligent and modular solar energy system for heat removal from parked car cabins. We propose a ventilation system composed of two pairs of cross flow fans, one placed under the car roof cabin between the steel plate and the indoor insulation and the second under the rear shelf of the back seats. The cabin was exposed to the sun radiation with no wind. Indoor temperature and humidity were measured with no ventilation. For a 750 W/m^2 average solar radiation the air flow rate needed for an efficient ventilation was calculated at 0,02 m^3/s, a value compatible with other results in the literature.From an economic point of view, the cost of the system is approx. 250 Euro since the double cross flow fans cost is 100 Euro. Further research will be focused on controlling humidity vs. temperature in the cabin car.

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