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In-Cabin Vehicle Initial Temperature Control: A Review

A. H. Zulkifli[a], *H. Nasution*[b,*], *A. A. Dahlan*[c] *and A. Abdul Aziz*[d]

Automotive Development Center, Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[a] *ahaziqahzulkifli@gmail.com,* [b,*] *henry@utm.my,* [c] *afiqaimandahlan@yahoo.com,* [d] *azhar@fkm.utm.my*

Abstract – *This paper presents a literature review of in-cabin ventilation for park vehicle. Various ways to decrease peak temperature inside vehicle cabin is presented. The present study can also provide an idea to the best possible solution for cooling load reduction to improve fuel economy and increase thermal comfort for passengers.*

Keywords: In-cabin ventilation, Heat reduction, Thermal comfort, Vehicle, Control device

1.0 INTRODUCTION

Air-conditioning (AC) systems significantly increase the fuel consumption of a vehicle by increasing load to the engine. When operating, AC system is the main auxiliary load for the vehicle engine [1]. It increases NOx emissions from 15 to 100% [2]. Lambert and Jones found out that around 12-17% increment of the fuel consumption of a vehicle is for compressor of the vehicle AC system [2, 3]. In hybrid and electric vehicles, the AC system is the second most energy-consuming systems with 40% energy usage of the whole system after the electric motor [4]. By decreasing cooling load of the vehicle AC system will lead to the smaller AC system, thus decreases the overall vehicle fuel consumption.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defined thermal comfort as the condition of the mind in which satisfaction is expressed with thermal environment [5]. Hensen defined thermal comfort as a state in which there are no driving impulses to correct the environment by the behaviour [6]. Thermal comfort is very important as it affects the passengers inside vehicle cabin as they enter the vehicle.

Vehicle air conditioning is usually oversize to cool down the vehicle faster especially as the passengers just enter the vehicle. The aim is to minimize the discomfort of the passengers for initial cooling time to just a few minutes. The evaporator, compressor, condenser and blower capacity is increased to be obtained faster cabin cooling time.

Cooling load in a vehicle is affected by many parameters such as dimensions and thermal properties of the vehicle and surrounding environmental conditions. To decrease the cooling load of the vehicle AC system, lower the initial cabin temperature is one of the approaches.

When a vehicle parked under direct sunlight, the temperature inside vehicle cabin can increase up to 80 ^{o}C [4, 7-11]. This makes the first five minutes for passengers is not thermally comfortable [12-15]. The need for decreasing the in-cabin vehicle initial temperature is crucial to decrease fuel usage and increase passenger thermal comfort [16, 17].

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2.0 LITERATURE REVIEW

Recently, the emphasis on controlling in-cabin vehicle initial temperature is increasing and becoming one of the competitive technologies and main features in the vehicle design and aftermarket. Several researchers have analyzed the in-cabin vehicle initial temperature from different perspectives; solar-reflective glazing, exhaust cabin ventilation, chromogenic windows, evaporative ventilation cooling, sunshade and window tint. Also, some researchers investigated the use usage of thermal imagery via infrared sensor to visualize and help in predicting the in-cabin surface's temperature. Some of these studies have also integrated some methods to provide the data of in-cabin temperature.

2.1 Solar-Reflective Glazing

The usage of tint solar panel on the vehicle window is vastly available either from the factory or in the aftermarket. The price is reasonable and cheap enough to be considered as a technique to decrease temperature inside vehicle cabin. Some researchers have studied for the effect of solar tint to the cooling load and the response to the environment temperature.

Jaksic and Salahifar [18] study the feasibility of electrochromic windows in vehicles to decrease the transmittance of glass. They managed to reduce up to 2.5 times better results than the existing glass types. Reducing glass transmittance results in the lower cabin soak temperature [19]. The durability study of the electrochromic windows to lengthen the life cycle is study and the maximum available in commercial is only five years [20, 21].

Manning et al. [22] have studied the effectiveness of window tinting at three different type that is T35 and T20, which 'T' refers to film's light transmittance factor. The three windows are bonded into polystyrene boxes to provide insulation and airtight seal. They found that the temperature for window with no tint rises the fastest and has highest temperature peak compared with other two windows but with advantages of faster cooling rate. Windows with tint on the other has lower temperature peak by 5°C and lower heating rate, but in the expense of lower cooling rate. This is because the tint slows down the heat exchange between the environment and vehicle cabin. Considering the test is done by only a small margin and windshield of the vehicle which is the highest heating rate cannot be tinted by regulation to avoid disturbing driver's vision, the impact to the peak temperature inside vehicle cabin would be very small.

50-70% of thermal energy is transferred into the passenger compartment through the convection and ration process [23, 24]. Reflecting the solar radiation is a crucial thing to make significant reductions in thermal loads. Lower thermal load offers a reduction in the capacity of the AC system.

Study by Parrino et al. [25] found that the most effective way to reduce initial vehicle temperature is by applying appropriate shielding of the windscreen when parked in the sun. The temperature can increase up to 40ºC in just 5 minutes, making pre-cooling of the vehicle cabin to be insignificant.

Modelling results show that it is much more effective to reduce initial vehicle cabin temperature by preventing the solar radiation from entering to ventilate the vehicle with ambient temperature.

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Rugh et al. [26] put the non-metallic solar-reflective film that was soaked and put on two minivans and two sport-utility vehicles. The temperature reduction of 1.8°C in maximum breath temperature and 3.4°C reduction in instrument panel transmission was obtained. Although the result is not impressive, the advantage of non-metallic construction is it does not attenuate electromagnetic transmission/reception from cell phones or other devices.

Vehicle with solar reflective glazing by Sungate offers better lower maximum breath temperature by 2.7°C while the instrument panel was lower by 7.6°C [27, 28]. It reduces the solar radiation up to 160 W from entering the vehicle, thus the temperature inside vehicle does not increase at a sudden speed. The peak temperature is lower by 10°C from the peak temperature.

Levinson et al. [29] study about the solar reflective car shells and conclude that the white or silver shell could increase fuel economy by 2% instead of using black shell. The study is done by simulation and following the SC 03 driving cycle. Refrigeration capacity required to cool down the cabin to 25ºC from the soak temperature for white shell is 13% less than black shell.

Hoke and Greiner [30] study through simulation and conclude that the usage of darker paint has the higher baseline absorptive ratio. The reduction of 0.08 absorptive ratio is obtained with the black pigment is reduced or removes from the paint. Decrease of initial vehicle temperature inside vehicle cabin obtained is 2°C.

Window is the main components that cause the light radiation to enter a vehicle. A smart windows system works by changing their optical properties depending on the environment, many of them still in development stage. There are many types of mechanisms that control the optical properties and can be categorized as electrochromics, liquid crystals, thermochromics and photochromic, which all of them represents the chromogenic materials.

Nagai et al. [20] had presented the durability of an all-solid-state electrochromic window by analyzing and graphing optical data. The main advantages of electrochromic windows are environmental stability and possibility for large area applications with visible transmittance control between 72.6 to 17.6% and over 100,000 live cycles at 60ºC. The test done through the accelerated weather testing machines showed that the electrochromic glass has an estimated life of five years for outdoor applications and would be suitable for vehicle applications.

2.2 Cabin Ventilation

Cabin ventilation system to decrease the built temperature inside vehicle cabin during park has been extensively studied by many researchers around the globe. Heat transfer to outside of the vehicle is considered as the best method as it gives the best performance of heat dissipation in expense of energy usage. Some researchers have studied about the possibility of cabin ventilation in reducing the temperature inside vehicle cabin.

Huang et al. [31] found out that the best air exhausting performance is at the air inlet near to the steering wheel as it can rapidly exhaust hot air under preset pressure difference of -10Pa at the air inlet. The exhaust of hot air from the steering wheel helps to reduce the overall temperature of the vehicle cabin as the highest source of heat is from the windshield. He managed to reduce the temperature down to just 42°C.

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Rugh et al. [28] found out that the air must be exhausted outside of the vehicle as it is more effective and offers higher temperature reduction. The air ventilation is put on the roof, which is not the best place to ventilate air as the highest temperature coming from the windshield. The temperature reduction obtained is up to 8°C.

Farrington et al. [4] provide ventilation during peak solar gain hours using small fans. It consumes about 1 W per 50 cfm. Partially open window provides an infiltration level of 20 cfm. He also concludes that it is more effective to remove the hot boundary layers than bulk ventilates the entire vehicle cabin.

Saidur et al. [9] ventilate the hot air to outside through the window. He managed to get 51°C of indoor air temperature with the usage of solar power with 110.5 cfm air flow rate. The downside of this way is that the user requires placing the ventilator on the window each time. This is not friendly user and also time consuming.

Jasni et al. [7] conclude his research with air ventilation at windows, the ambient air inside vehicle cabin can be reduced up to 5.8%. The method, however, did not manage to reduce the interior surfaces' temperatures. This method is also considered as impractical as the method used is the same as in Ref. [9].

2.3 Ventilation with Evaporative Cooling

Study by Latiff et al. [8] managed to lower the cabin temperature down to just 40 to 50°C by applying water mist and ventilation together. The temperature is controlled automatically by microcontroller and activated at a certain temperature. Speed of the blower is varied to study the response of temperature inside vehicle cabin. The study, however, did not measure the power consumption of the system as it is solely powered by the car battery. The excessive usage of electric source from the car battery could lead to dead battery or shorter battery life.

Basar et al. [32] are the best system in controlling the initial cabin temperature as they managed to maintain the temperature inside vehicle cabin at room temperature. They proposed a portable ventilation system together with wet cloth for evaporative cooling, which powered by rechargeable 12V battery and Peltier cell to cool down the cabin. This system, however, requires the users to refill water each time before applying it. Furthermore, the peltier cell produced as low as milliampere (mA) which is not enough to power the blower system.

2.4 Sunshade

Manning et al. [22] showed that sunshade application to a vehicle is insignificant for the first one hour with only 1.4°C differences and 4.7°C cooler after 5 hours of soaking period. However, Al-Kayiem et al. [16] differs with Manning that the usage of sunshade was found to be 25°C lower than other vehicles without any shades.

Jasni et al. [7] proved that the application of sunshade can decrease dashboard and steering wheel temperature by 18°C. The sunshade managed to avoid direct sunlight through the windshield, but it does not have significant effect on vehicle cabin ambient air.

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3.0 IMPACT OF IN-VEHICLE INITIAL TEMPERATURE CONTROL DEVICES ON COOLING LOAD REDUCTION

A number of studies had focused on estimating the impact of in-vehicle initial temperature control devices on cooling load reduction from different vehicles. Table 1 presents the temperature reduction from different techniques from different studies to compare the capability and feasibility of different technologies.

Table 1: Choices of technology to reduce initial vehicle cabin temperature

In-Cabin Cooling Park Ventilation	Function	Advantages	Disadvantages	Temperature reduction (°C)	Technology status	Helps in reducing cooling load during AC operation	Refs.
Solar-reflective glazing	Reduce solar radiation from entering vehicle cabin	Suitable for any vehicles	Aesthetic value	2-5	Commercial	Yes	[4,26,27,28,29,30]
Exhaust Cabin ventilation	Exhaust hot air from vehicle cabin to the environment	Suitable for any vehicles	Power consumption depends on vehicle battery/solar and no aesthetic value	20-40	Commercial	No	[4,9,19,28,31,33]
Chromogenic windows	Reduce solar radiation from entering vehicle cabin	Suitable for any vehicles	High initial cost	10-20	At or near commercial	Yes	[18,20,21,23,34]
Sunshade	Reduce solar radiation through the windshield	Suitable for any vehicles	Not user friendly, depends on vehicle angle to the sunlight	5-10	Commercial	No	[7,16,22]
Window open	Transfer hot air inside vehicle to the environment naturally	Suitable for any vehicles	Risks for vehicle security, not weather proof.	5-10	Not commercial	No	[22]
Evaporative cooling	Dissipate water mist to cool down temperature	Suitable for any vehicles	Power consumption depends on vehicle battery/solar and not user friendly	20-40	At or near commercial	No	[8,31]
Window tint	Reduce solar radiation entering the vehicle	Suitable for any vehicles	Good solar tint is expensive	5-10	Commercial	Yes	[7,22]

From those above-mentioned studies, it is possible to compare and understand the capability of fuel decrease by reducing the cooling load inside vehicle cabin. In most studies, air ventilation shows the best performance in reducing the temperature inside vehicle cabin during parking. In practice, ventilation with evaporative cooling results in 20-40°C of vehicle initial temperature. This is followed by ventilation, chromogenic windows down, windows tint, sunshade and solar reflective glazing.

4.0 CONCLUSSION

This paper presents a comprehensive review on in-cabin cooling ventilation for vehicle during park. It has been seen that each approaches has its potentials and limits or practicality. There are various factors that influence cooling load reduction options, and these factors can be used to select the technique that has low-cost and did not affect the aesthetic value of the vehicle. Determining the effectiveness of these technologies is crucial as an unsatisfactory performance cannot gain market approval. This study was conducted to review available literature to determine the efficiency, advantages and disadvantages of various technologies and their impact on the reduction of cooling load inside vehicle to decrease fuel consumption and size

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of the vehicle AC system. The present study can also provide an idea to the best possible solution for cooling load reduction to improve fuel economy and increase thermal comfort for passengers.

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