Experimental Comparison Study of the Passive Methods in Reducing Car Cabin Interior Temperature

M.A. Jasni and F.M. Nasir

***Abstract*—**The objective of this paper is to determine the most technically feasible passive method in reducing the car interior temperature. Three methods were experimentally studied; using sunshades, ventilators and window tints. A 1.5 national sedan car was used in this study where it was exposed to direct sunlight for a period of 5 hours for four different cases. The temperatures measured by thermocouples strategically located within the car were obtained and analyzed. It is observed that the maximum temperature occurred at the dashboard for all cases. The usage of ventilators is found to reduce the average maximum temperature for the ambient air inside the car by as much as 3.3^{o}C. Although their performance is more or less similar with that for the window tints, their application is impractical. All in all, it can be concluded that the window tints is the best method in reducing the interior temperature.

***Keywords*—**Automotive; Heat Transfer; Temperature; Thermal Comfort.

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I. Introduction

WHEN a vehicle is parked under direct sunlight, the heat generated in the vehicle cabin will increase the interior temperature up to 80ºC [1]. The thermal accumulation in a vehicle cabin will cause an uncomfortable sensation to the driver during the first 10 minutes after entering a prolonged soaked vehicle [2]. To decrease the temperature built up during the soaking period, drivers have to run the air conditioner at high speed, which ensures the necessary cooling to desired temperature [3]. The decrease in the internal temperature by running the air conditioner is higher (50%) comparing to cases where air conditioner is turned off, reflecting the big influence of the air conditioning system (A/C) to obtain good thermal comfort [4]. The increasing thermal load of the A/C system subsequently increases the fuel consumption of the vehicle as well as increased CO_2 emissions [5].

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The effects of accumulated heat and the raise in cabin temperature could be decreased by several alternatives, such as by installing solar-powered air ventilators, sunshade application during soaking, and also the installation of solar reflective films or window tints.

Solar-powered air ventilators in theory will remove hot air in the cabin, and replace them with cooler fresh air, thus decreasing the interior temperature. Rugh et al [6] compared the effect of ventilation with, air pulled in through the HVAC heater/defroster ducts, air being pulled out of the vehicle and without any ventilation. Their study showed that ventilation reduces maximum temperature at the windshield and the dashboard by as much as 2.3^{o}C and 8.3^{o}C respectively. Their results also indicate that the cabin ambient air temperature can be reduced by up to 8.3^{o}C by using the ventilator. In a study by Flores et al. [7], their improved ventilator was able to reduce the peak temperature of the ambient cabin air by 7.4^{o}C.

Solar reflective films are normally applied to the interior of flat glass windows to reduce the amount of infrared, visible light, and ultraviolet (UV) radiation entering windows. Low-emissivity coating reduce the amount of visible and ultraviolet radiation entering a window, and are often applied to reduce fading of the contents of a room. In a study conducted by Rugh et al [9]-[10], the car maximum ambient temperature can be reduced in the range of 1.8 to 4.6^{o}C by using the solar reflective films. The results are dependent on the type of cars used and the type (or brand) of the solar films. Their study also showed that the maximum temperature at the dashboard and the windshields can be reduced by as much as 6.3^{o}C and 9.5^{o}C, respectively, if solar films were employed.

Some vehicles include or are retrofitted with sun blinds for rear and rear side windows. These blinds are used to protect the vehicle and the passengers from direct sunlight. Car shades are another common way to protect the vehicle. The shades for the rear and front windows are designed to be unfolded and sit against the window. Sunshades reduce or block the sunlight from entering the vehicle through the glazing. Since most of the heat load during the soaking period comes from the transmission and absorbance of the solar radiation through the glazing, they should be very effective to block the sun radiation at the glazing.

Manning et al. [4] studied the effect of sunshade application on the temperature rise in a Holden Epica sedan. From the study it was shown that the effect of the sunshade was insignificant for the first one hour, with only 1.4ºC differences. The maximum car-to-car variation throughout the test was recorded only after 5 hours of soaking period with the vehicle with sunshades 4.7ºC cooler. In another study by Al-Kayiem et al [1], the effect of sunshades application to the interior windshield on the temperature was significant, as the maximum dashboard temperature of the soaked vehicle with the sunshade was found to be 25^{o}C lower than the other vehicle without any shades.

The solar-powered auto air ventilator’s performance was never proven to be efficient, because of its low flow rate and low-powered fan. Besides, its application is not suitable for window-tinted cars, because tints will decrease solar energy absorption of the solar panel. The sunshades application on the other hand is quite impractical. The driver must manually unfold and install the sunshades to the windscreen and the side windows for each application. This is time-consuming and cumbersome to the driver.

Therefore, the objective of this study is to investigates and compare the performance of each of these passive methods in order to determine the most effective method in reducing the car interior temperature, both technically and economically.

II. Experimental Set Up

A. Vehicle Selection

The vehicle chosen in this study is 1500 cc, nationally made sedan car.

B.Test Area

The test area was the car park of a private residential area at Jitra, Kedah, Malaysia (Latitude. 6.3°, Longitude. 100.4°). The test vehicle was oriented East-West (facing approximately 280° N), to ensure maximum sun load on the front windscreen and on rear window.

C.Test period and time

The tests were performed on 20 different days with possibly minimum clouds, from September until mid October 2011. The time interval selected for the tests is from 10:00 AM to 3:00 PM, as the sun load within this period is at the highest.

D.Test equipment and measurements

The vehicle was fitted with type-K thermocouples at several positions in the vehicle, which includes the dashboard, the steering wheel, the front and rear ambient. The thermocouples were then connected to a data-logger module.

III. Experimental Procedure

Initially, the test vehicle was parked under a shaded parking space. At approximately 9:50 am, the test vehicle was driven away to the test area and parked under direct sunlight. The thermocouples connected to the data acquisition module were then connected to a portable notebook for data recording. At approximately 10:00 am, the data acquisition started and it stopped at about 3:15 pm. This procedure was repeated five times for four different cases, which are:

A. Base Case

Bare test vehicle without any temperature-reducing methods applied.

B. Case 1

The test vehicle was fitted with sunshades at every window. For the front windshield, a nylon shade was applied, with dimensions of 1180mm x 490mm covering most of the front windshield area. For the front and rear side windows, black nylon mesh shades with dimension 440 mm x 360 mm were fitted. At the rear window, two silver 490mm x 590 mm nylon mesh shades were used.

C. Case 2

The test vehicle was fitted with solar-powered ventilators at every side window. The specifications of the existing ventilators are described in Table 1. Since the built-in solar panel of the ventilator is in vertical position, the solar energy gain by the panel is far from maximum, resulting in low fan speed. Hence the solar powered ventilators were improved by using a larger 5W-solar panel, located horizontally above the exterior roof of the test vehicle, maximizing possible solar energy gain by the panel, yielding a higher fan speed.

TABLE 1
Existing ventilator specifications

Components	Capacity
Solar panel	1W per panel
Brushless DC motor	5V/200mA
Flow rate	20cfm

D. Case 3

The test vehicle was fitted with solar reflective films (tints) on every window. The type of tints used was the dyed tints. The infrared rejection of the tint film applied to the front windshield is 85% and all of the side windows and also the rear window were installed with tint films with 65% infrared rejection.

IV. Results and Discussion

A. Maximum temperature

The average maximum temperature at the dashboard, steering wheel, front and rear cabin are presented in Fig. 1.

The highest average maximum temperature for all cases is recorded at the dashboard, which can reach a maximum of 87.5^{o}C. At this location, it be seen that sunshades application is the most effective method in reducing the dashboard temperature by as much as 18^{o}C (refer Table 2) or 21.7% from the base case. This could be due to the blockage of a large amount of sun radiation entering the front windshield by the sunshades.

TABLE 2:
REDUCTION IN MAXIMUM TEMPERATURE AT DIFFERENT LOCATION

Experiment	Reduction in maximum temperature (^oC)				Reduction in maximum temperature (%)			
	Dashboard	Ambient front	Steering	Ambient rear	Dashboard	Ambient front	Steering	Ambient rear
Case 2: Sunshade	18.1	-1.0	4.0	-2.3	21.7%	-1.8%	7.0%	-4.1%
Case 3: Ventilator	-3.9	3.3	-2.5	3.2	-4.6%	5.8%	-4.3%	5.6%
Case 4: Window tint	4.7	4.8	4.4	5.3	5.6%	8.5%	7.7%	9.3%

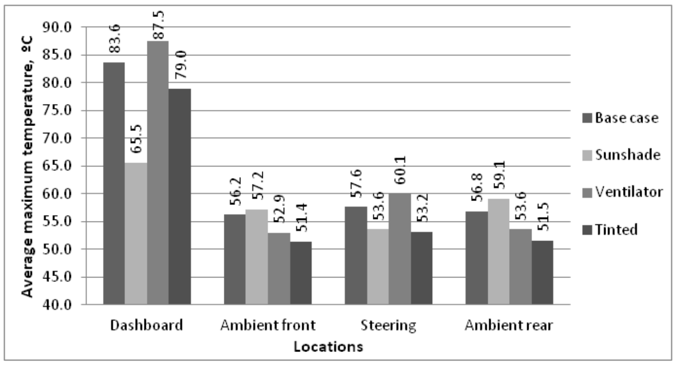

Fig. 1Average maximum temperature at different locations

For both front and rear ambient air, the window tint is the most effective method in reducing the temperatures by as much as 4.8°C and 5.3°C respectively. The tints are also outperforming other methods in reducing the temperature at the steering wheel by as much as 7.7%. This shows that the transmitted radiation through the tinted windows that will heat up the ambient air inside the vehicle has been decreased.

The ventilation method is observed to be only reducing the temperature for the ambient air, with no cooling effect for the dashboard and the steering wheel. This could be attributed by the upper hot air exchange from the interior to the outside of the vehicle, which affects the cooling down of the ambient air. The low fan speed of the ventilators may not be sufficient to reduce the temperature of the car interior surfaces, such as the dashboard and the steering wheel.

The usage of ventilators is found to reduce the average maximum temperature for the ambient air inside the car by as much as 3.3°C. Although their performance is more or less similar with that for the window tints, their application is impractical since the car windows must be rolled down a few centimeters to fit the ventilators. Overall, it can be observed that the window tint performance in reducing the interior temperature is the best, because it has decreased the average maximum temperature at all of the locations of interest in the vehicle by at least 5.6% from the base case.

B. Soaking temperature

The soaking temperatures are the hourly temperature readings. The experiments started at 10:00 am, and stopped at 3.00 pm, hence the soaking period is 5 hours. The average soaking temperature for the four different locations is shown in Fig. 2 to Fig. 6.

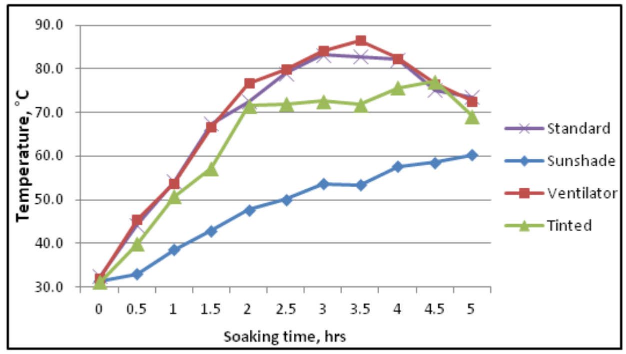

Fig. 2 Average soak temperature at the dashboard

From Fig. 2, it can be seen that the average soak temperatures for the base case (or standard) and the ventilators experiments are almost identical, indicating poor performance of ventilators in reducing the dashboard temperature. The average soak temperatures of the dashboard in the sunshade experiment are the lowest during the entire soaking period.

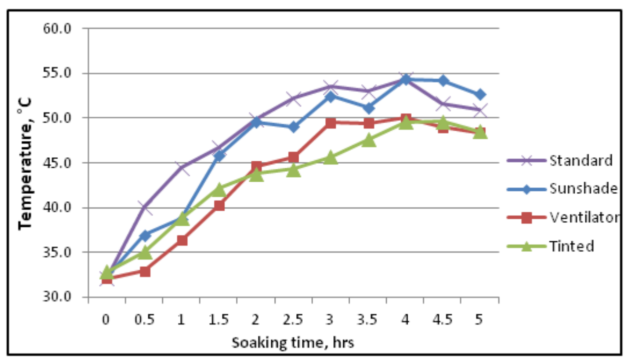

Fig. 3 Average soak temperature for the front ambient air

In Fig. 3, both the window tints and the ventilators have similar performance in reducing the front ambient air temperature. Their performance outperforms that for the sunshading method. In Fig. 4, similar performances by the sunshades and window tints can be observed. These two methods have significant effect in reducing the temperature of the steering wheel. Ventilators are only effective during the first 2 hours, after which it is not capable of maintaining lower temperature of the steering wheel.

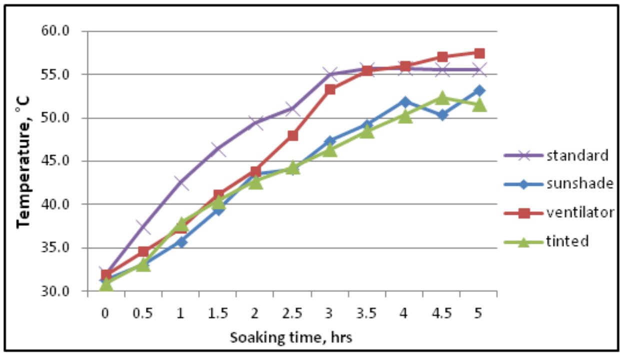

Fig. 4 Average soak temperature at the steering wheel

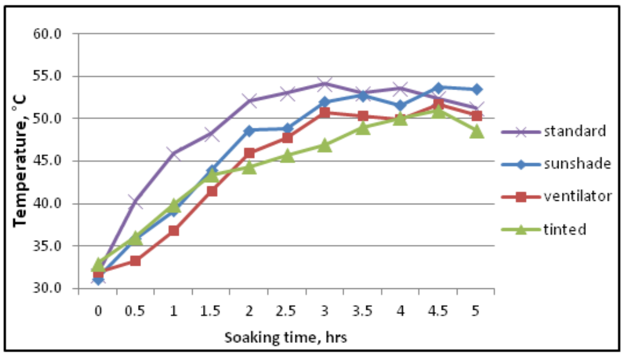

Fig.5 Average soak temperature for the rear ambient air

The results of the average soak temperature for the rear ambient air (Fig. 5) is quite similar in profile with that for the front ambient air. The window tints and ventilators have the best performance in reducing the average soak temperature for the rear ambient air.

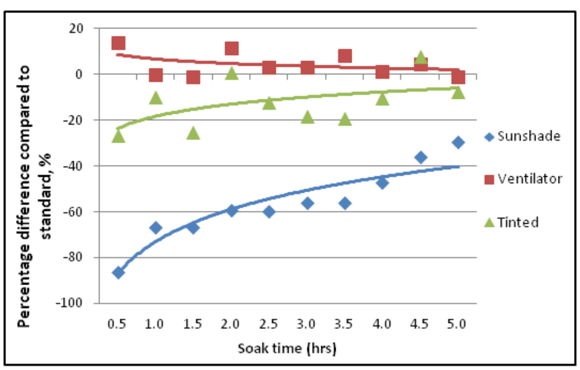

Fig. 6 Soak temperature difference at the dashboard from the base case.

Fig.6 shows the comparison of the dashboard temperature change of each method to the base case. During the entire soaking period, the dashboard temperature difference in the sunshade experiment is the lowest, ranging from 80% initially, to 40%. The temperature change in the window tints experiments has significant reduction only during the two and a half hours of soaking period. On the other hand, the dashboard temperature change in the ventilator experiment does not have any significant difference from the base case.

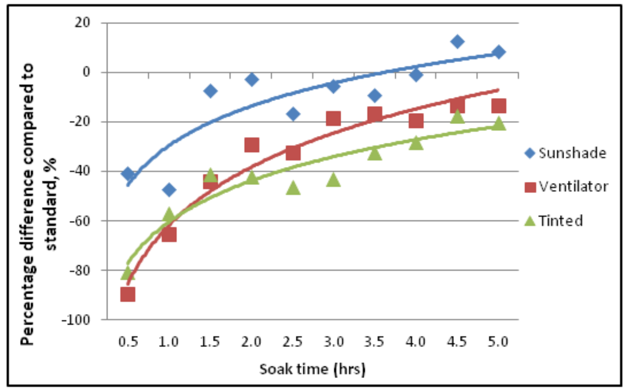

Fig.7 Soak temperature difference for the front ambient air from the base case.

From Fig. 7, in the sunshade experiment, the change in temperature of the front ambient air is significantly lower than the base case only in the first two and a half hours of soaking period, after which it does not have any significant effect in reducing the temperature. The window tints have reduced the front ambient temperature change significantly during the entire five hours of soak period, ranging from 80% to about 20% reduction. The ventilators perform in the similar trend as the window tints, but with lower percentage difference.

From the results in Fig. 8, it can be seen the sunshades and the window tints capable of reducing the soak temperature of the steering wheel in the range of 10% to 50% from the base case. The ventilators are effective during the first 4 hours, after which it increases the steering temperature.

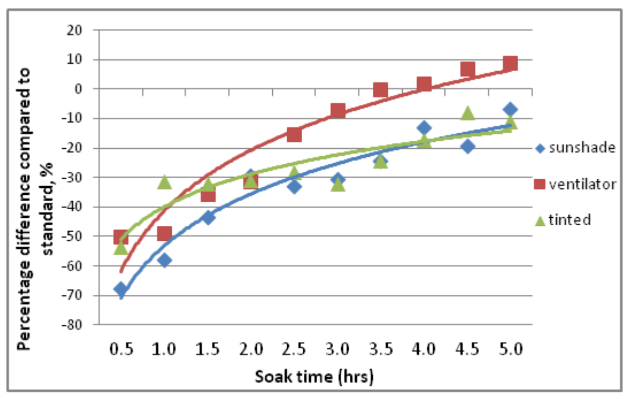

Fig. 8 Soak temperature difference at the steering wheel from the base case

As observed in Fig. 9, only ventilators and window tints are effective in reducing the rear ambient air temperature during the entire soaking period. Meanwhile, the sunshades increase the rear ambient air temperature after 4 hours of soaking period.

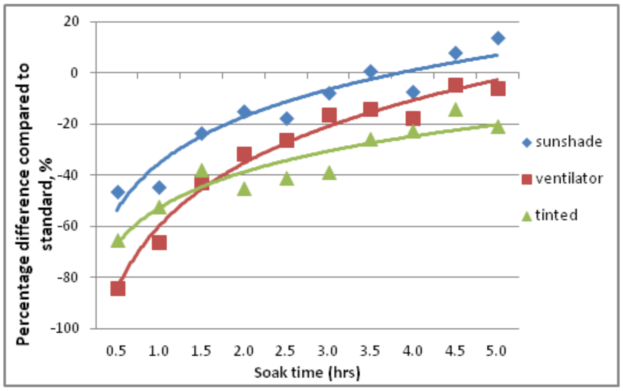

Fig. 9 Soak temperature difference for the rear ambient from the base case

C. Results summary

Based on the results, it can be observed that window tints did reduce the car interior temperatures at all location of interests, albeit small reductions measured at the dashboard. Among the three methods, the usage of sunshades is the best in reducing the dashboard temperature. Obviously, it has blocked a significant amount of heat radiation coming from the front windshield from contacting the dashboard's and steering wheel's surface.

The ventilators were observed to be only useful in reducing the ambient temperature inside the car, as they enhance the convection heat transfer occurring inside. Their performance is comparable with that for the window tints. However, bear in mind that in order to use the ventilators, car windows must be rolled down for a few centimeters. Besides, the built-in solar panels of the ventilators were not adequate to furnish enough energy for the ventilators to be properly functioning.

V. CONCLUSIONS

- The window tints treatment has achieved an overall good performance in reducing the average maximum temperature at all interior locations of the test vehicle, with higher percentage of reduction at steering wheel, front and rear ambient locations
- The usage of sunshades only manages to reduce the maximum temperature by 28% at the dashboard and 7% at the steering wheel. It has insignificant effect on the ambient air.
- The ventilators enhance the convection heat transfer inside of the car. Hence they are capable of reducing the average maximum front and rear ambient air temperatures by 5.8% and 5.6% respectively. They have insignificant effect in cooling of the car interior surfaces' temperatures.
- The usage of ventilators is found to reduce the average maximum temperature for the ambient air inside the car by as much as 3.3^{o}C. Although their performance is more or less similar with that for the window tints, their application is impractical.
- Considering the vehicle interior locations average maximum temperature reductions and the hourly average soak temperature behavior it can be concluded that the window tints outperform other methods. Hence, it would be the best choice in reducing the interior temperature of a soaked vehicle.

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