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Effects of Using a Special Car Cover on the Temperatures and Cooling Load Inside a Parked Car Under Severe Summer Conditions; Iraq Case of Study

Hasan Abbas Hussein[1*], Issam M. Ali Aljubury [2]

MSc Student Assistant Professor

[1,2]*Mechanical Engineering Department, College of Engineering, University of Baghdad, Baghdad, Iraq*

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Abstract

Summer in Iraq is extremely hot and dry, with temperatures reaching around 50 °C with extremely dry conditions. Due to a shortage of shaded parking spots, many drivers park their automobiles in the sunlight. Many of those drivers complain about the heated interior temperature of their vehicles after a few hours of parking. This issue is not only harmful to the driver and passengers, but it also causes damage to the vehicle's components. Furthermore, the high temperature inside the compartment implies a large cooling load in order to keep the cabin at thermal comfort limits. In the present study, a special car cover was suggested to reduce the high temperature inside the car cabin. Different arrangements of the suggested cover with window openings have been examined. The results revealed that in the unshaded situation, the temperature of the air inside the cabin could reach 74.8 °C, and the dashboard temperature could reach up to 93 °C. The optimum solution was found by covering all windows, with opening the windows by 15 mm. This solution reduced the average inside air temperature to 53.3 °C, representing 20.8 % lower than the unshaded case and 7.4 °C higher than the average ambient temperature. It also led to about 32.3 % reduction in the average cooling load compared to the unshaded case.

Keywords: Parked Car, External Car Cover, Cabin Temperature, Thermal Comfort, Cooling Load, Dashboard Temperature, Vehicle Cabin.

Nomenclature

$c_{p,a}$	Air specific heat at constant pressure (J/kg.K)
$\dot{m}$	Mass flow rate of the AC (air conditioning) ventilation air (kg/s)
Q_{sens}	Sensible cooling load (W)
$T_{a,avg}$	Average temperature of the inside air (°C)
T_{amb}	Ambient temperature (°C)
T_{case}	Temperature of measuring points in each case (°C)
T_{comf}	Air temperature at thermal comfort level (°C)

1. INTRODUCTION

In hot weather conditions such as in Iraq, when the temperature in summer reaches 50 °C, the temperature inside a parked car during summer could rise to 70 °C[1], [2], [3]. One of the solutions that the drivers do is to use internal sunshades, due to the lack of shaded parking areas. That temperature rise could be harmful to both the driver and passengers since the solar radiation during summer in Iraq and near countries that penetrates the cabin is at high levels, around 1000 W/m^2[4],[5], [6]. According to a study by [7],among 23 incidents, about 40 fatalities were reported due to hyperthermia between 2011-2020 in India. These incidents involved children between 4 to 6 years old who got locked inside the car accidentally. In addition, the high temperature inside the cabin could cause damage to the components of the cabin. Also, the heating, ventilation, and air conditioning (HVAC) system will require more energy to reach thermal comfort. Consequently, this increase in energy leads to more fuel consumption.

To reduce the high temperature inside the cabin, the researchers have studied the effects of some passive methods, such as sunshades, ventilation systems, solar reflecting cover and films, windowgaps, etc. on the cabin soak temperature. Figure 1 shows some of these passive methods.

Some researchers have conducted some experiments to study the soak temperature of a car's cabin when parked under the direct sun.The results indicated that the maximum temperatures inside the cabin were at the dashboard, the steering wheel, and the inside air by 87.5 °C, 60 °C, and 59 °C respectively. The application of the sunshades reduced the dashboard's temperature by about 21.7% and the steering wheel by 7%; however, it was not effective with the air temperature[8]. Another study showed the effect of a ventilation system consisting of a PV panel and a set of DC fans to extract the hot air from

* Corresponding author e-mail: h.hussien1303@coeng.uobaghdad.edu.iq.

the cabin and supply fresh air. Without the ventilation system, the air temperature inside the cabin was about 66 °C, representing 22 °C above the ambient temperature, while installing the ventilation system reduced the temperature difference between the cabin and the ambient to 10 °C[9]. Another study used solar panels to run a mini air cooler installed on the dashboard to reduce the high temperature resulting from parked under the sunlight. They used two cars, and only one car was equipped with mini air cooler. Before using the mini air cooler, both cars reached same cabin temperature of 56 °C after being soaked in the sun. The results showed that the car with the mini air cooler experinced about 6°C reduction in the cabin temperature without adding fresh air [10]. Other researchrers used the mini air cooler and exhuast fans with the PV panels to extract the hot air and replace it with fresh air. The mini air cooler is an evaporative cooler with a wet foam so that the water evaporates when the hot air passes through it. Without the proposed device, the cabin temperature reached about 57 °C after 7 hours of soaking in the sun. With the help of the suggested system, the cabin temperature was reduced by about 10 °C. Furthrtmore, the amount of heat rejected by this system was about 0.356 kW [11]. Other researchers investigated the effect of solar reflective cover and the solar reflective film on the air temperature inside the cabin. They found that the highest air temperature in the car with the solar reflective cover was about 45.6 °C, while the maximum air temperature in the car with the solar reflective film was about 60.1 °C, indicating a 14.5 °C difference between the two approaches[12]. Others studied the effects of solar radiation on the soak temperature, and they found that the air temperature inside the cabin could reach 70 °C and about 100 °C at the dashboard. To reduce this increase in temperature, they suggested a cover on the windows with lowering the side windows by 1 cm.They found that using the cardboard inside the cabin did not reduce the cabin air temperature, but it reduced the dashboard's temperature by 40% from the unshaded case. In addition, the cardboard from outside the windscreen, with lowering the side windows by 1 cm, reduced the average maximum temperature in different locations inside the car cabin. [1]. Another study on heat accumulation and temperature variations was done by [13], which involved different methods to reduce the high temperature inside the compartment such as sunshades and window openings. The findings showed that opening the front windows by 20 mm resulted in a 10 °C drop in front air temperature compared to the case of the closed windows. While utilizing a sunshade beneath the front windscreen reduced the dashboard by25 °C.The effect of solar reflectance on the soak temperature has been studied by [14]. They used two identical cars, one was black and the other was silver. For the black car, it was found that the maximum temperature was located on the roof. On the other hand, the maximum temperature in the silver car was found on the black dashboard. That was due to the reflectance of the silver car being higher than the black one, so it reflects more solar radiation. The maximum temperature difference between the black and silver cars was 25 °C at the roof. Also, the difference between the ceiling temperature in the two cars was 11 °C, and it was less than 5°C and 2 °C, in the dashboard and the windshield, respectively.Table 1 provides a summary of prior experimental research, as well as the technique employed and the reduction in air temperature attained. The summary focused solely on the air temperature because it is the most essential parameter in estimating the cooling load needed to maintain thermal comfort within the automobile cabin.The present paper research will investigate experimentally the temperature patterns inside a parked automobile, and the effects of various arrangements of a suggested automobile cover on temperature and cooling loads. Seven distinct parking setups were tested, with and without externally and internally sunshades, and in various cover and window gap combinations have been studied. Also, the research focuses on the difference between the internal and external shading on the temperatures inside the cabin.

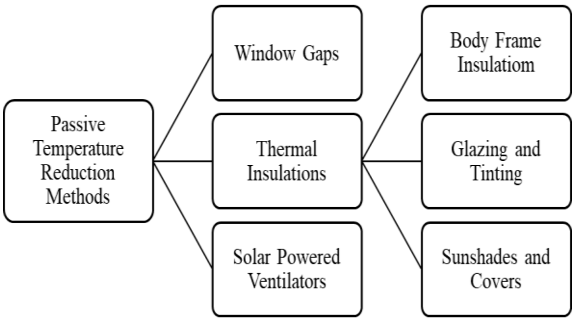


Figure 1. Passive temperature reduction methods.

2. METHODOLOGY

2.1. Materials

The test vehicle for this study was a yellow SAIPA 131. The vehicle was oriented South, as shown in **Figure 2**.to ensure full sun exposure for the whole period of the test. The car was parked in an open area in Amarah, Iraq (31.8 N, 47.1 E)and it was ensured that there was no shading on the car during the tests. Before each test, the doors and the windows were opened for 30 minutes to let the temperature of the cabin reach a steady-state temperature with the ambient.

Table 1. Summary of the previous experimental research on the air temperature inside the car cabin

Approach	Setup	Maximum Reduction(°C)	Maximum Ambient Temperature(°C)	Reference
Sunshades	All windows	19	n/a	[8]
	Under the front windshield	0	44	[1]
	Front windshield only	6.2	34	[16]
Cover	Cover on all vehicle	30.5	23.1	[17]
	On the roof and all windows	13.4	36	[12]
Tinted Glass	All windows	5.3	n/a	[8]
Solar Reflective Glass	SRF on all glazing	4.6	46.1	[18]
	SRF all glazing except the windshield	0	36	[12]
	Increasing the reflectivity from 0.05 to 0.58	6	36	[14]
Window Gap	All windows 4 cm	12.4	34	[16]
	front windows by 2 cm	10	n/a	[13]
	Driver’s window by 2.5 cm	3	45	[19]
	Driver’s window by 5 cm	6-7		
PV powered ventilators	On all windows	3.3	n/a	[8]
	Two fans to exhaust hot air and one fan to supply fresh air	10	44	[9]
	Using blower evaporator with a mass flow rate of 0.0114 kg/s	9.5	35	[20]
Solar Chimney		20.5	36	[21]
PCM Insulation	Inserting PCM materials under the roof	15	23	[22]

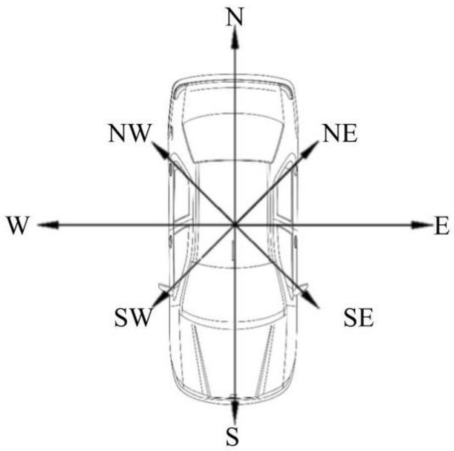


Figure 2. Direction of the test vehicle.

2.2. Measurements and Instruments

In order to take measurements for the temperature, six thermocouples of type K were placed inside the car. The accuracy of the thermocouples is within±0.75 °Cand the range of measurement within -50~204°C. Only one of them was set to measure the air temperature, and it was hung in the middle of the cabin at 5 cm below the ceiling. The other thermocouples were set to measure the temperature of the internal components such as the dashboard, steering wheel, windshield, and front seats. The locations of the thermocouples are shown in**Figure 3**. and Table 2. The thermocouples attached to the surfaces were covered with opaque adhesive tape to prevent the influence of solar radiation. To collect data, the thermocouples were connected to a 12-channel data logger (BTM-4208SD). The data logger has a measuring range of -100~1300 °C with a resolution of 0.1 °C and an accuracy of ±0.5 °C. The temperature was recorded at an interval of 10 minutes from the start to the end of each test. Figure4. shows a type-K thermocouple and the data logger. The measurements were taken from 8 A.M to 5 P.M.

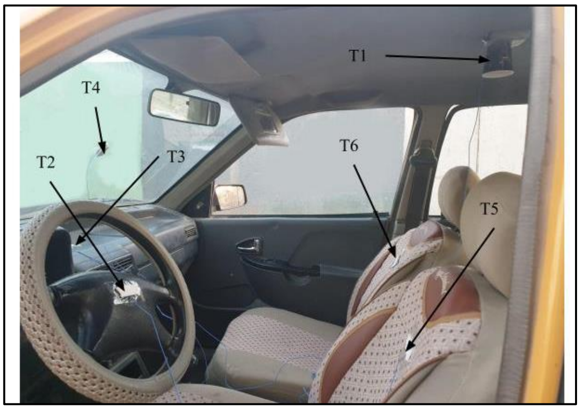


Figure 3. Locations of the thermocouples inside the cabin.

Table 2. Location of the thermocouples inside the cabin.

Thermocouple	Measuring type	Location
T1	Air	Middle of the cabin, 5 cm below the ceiling.
T2	Surface	Steering Wheel
T3	Surface	Dashboard
T4	Surface	Front Windshield
T5	Surface	Passenger Seat
T6	Surface	Driver Seat

2.3. Special Car Cover

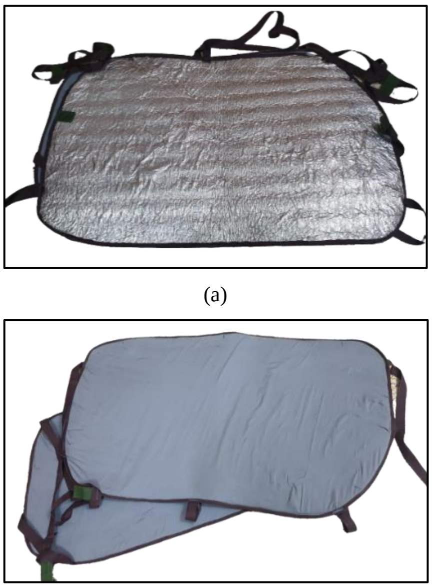
A special car cover was suggested to reduce the temperature inside the cabin. The cover is available commercially and it is made of polyethylene foam of 5 mm thickness with a thin aluminum foil on the top side, then another layer of cloth was added to the bottom side of the cover. The cover was cut into the shape of the windows and the windshields only since a high percentage of the solar radiation that falls on the vehicle passes through the glass into the cabin.The cover consists of 4 pieces, 2 for the side windows and 2 for the windshields. Figure 5. (a &b) shows two sides of the cover.

The advantages of this cover compared to the traditional car coverare[1]:

- Lighter and smaller.
- Relatively cheap and easy to assemble.
- Reflect solar radiation.
- Provide thermal insulation.

(a) (b)

Figure 4. Measuring instruments: (a) data logger, (b) type-K thermocouple.



(a)

(b)

Figure 5. The suggested car cover: (a) front side, (b) back side

2.4. Climate Conditions

Iraq weather is known for the high temperatures and dryness in summer, especially the south region (Amarah city), where the temperature hit 50 °C. Figure 6. and Figure 7. show the ambient temperature and relative humidity for each day of the experiments, respectively. The average wind speed during test days was around 2.6 m/s. For all cases, the meteorological data was taken from the Iraqi Meteorological Organization & Seismology, and it included ambient temperature, relative humidity, and wind speed. The solar radiation intensity was obtained from Metonorm software and it is shown in Figure 8.

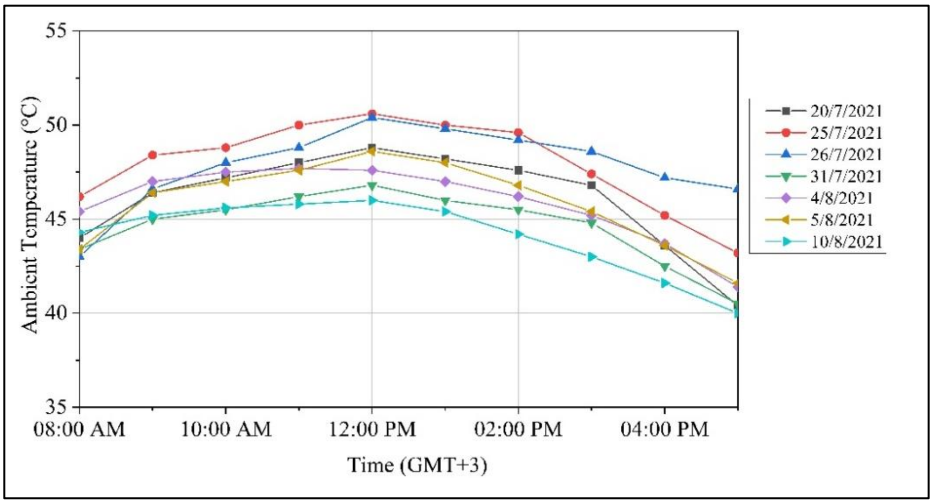


Figure 6. Ambient temperature during the test days.

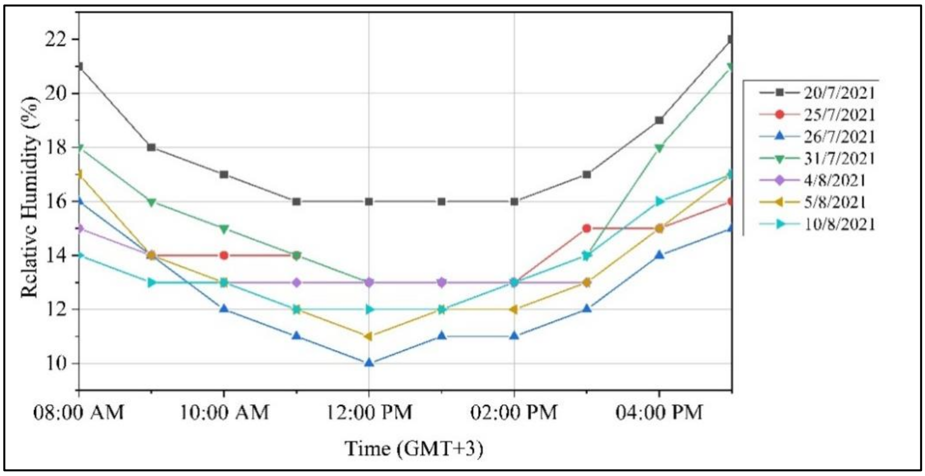


Figure 7. Relative humidity during the test days.

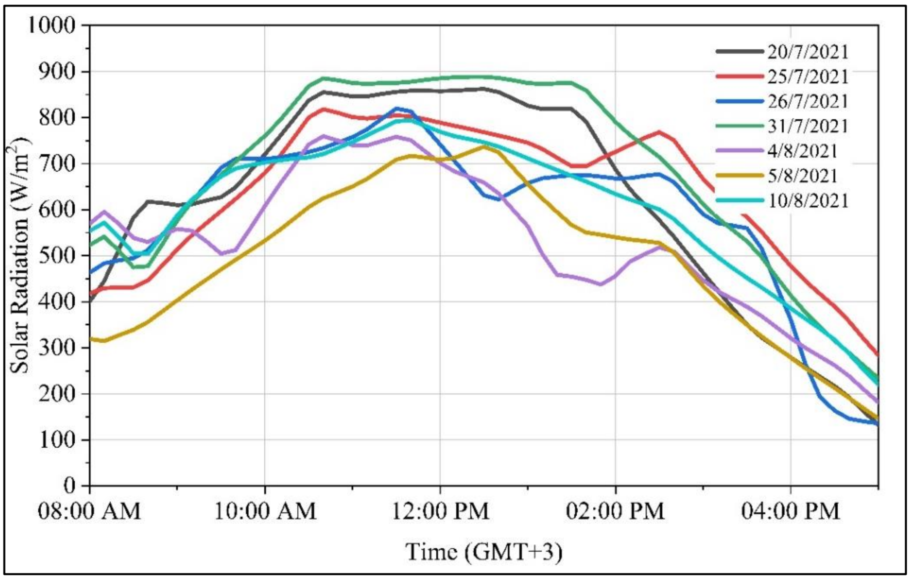


Figure 8. Global horizontal radiation during the test days.

2.5. Experimental Procedure

Seven different parking cases under direct exposure to sunlight were conducted between July and August of 2021, in which the effects of different arrangements of special car cover with window openings were studied.

The cases can be summarized as follows, see Table 3:

Case #1: In thiscase, no shading and windows opening were employed and it was considered as the base case.

Case #2: The secondcase was conducted with windows opened 15 mm only, without any shading.

Case #3:only shades were used and the cover was externally placed above the front and rear windshields (partially shaded).

Case #4: Windows were opened 15 mm and the cover was externally placed above the front and rear windshields (partially shaded).The vehicle with the cover used for cases #3 and case #4 is shown in Figure9.

Case #5: All windows and the windshields were covered (totally shaded) and the windows were 15 mm open.

Case #6: All windows and the windshields were covered (totally shaded) and the windows were closed. The vehicle with the cover used for case#5 and case #6 is shown in Figure10.

Case #7: In the last case, the cover was internally placed beneath the front and rear windshields. The vehicle with the cover used for case #7 is shown in Figure 11.

Table 3. Summary of the studied cases.

Case	Parking setup			
	All windows open 15 mm	Shading above the windshields	Shading beneath the windshields	Shading on all the glass
Case #1				
Case #2	✓			
Case #3		✓		
Case #4	✓	✓		
Case #5				✓
Case #6	✓			✓
Case #7			✓	

Figure 9. The external cover above the windshields.

Figure 10. The external cover on all glass.

Figure 11. The internal cover beneath the windshields.

3. Results and Discussion

The cases were carried out on the hottest days of the summer in Iraq during July and August during the period from the 20th of July to the 10th of August. Each test was carried out for 9 hours of soaking in the sun from 8 A.M. to 5 P.M. The results of these cases in presented below.

3.1. Temperature Variations

The temperature of each measuring point was plotted for different cases to indicate the temperature reduction obtained from each case. Figure 12. shows a summary of the average temperature reductions of the measuring points compared to the base case.

3.1.1. Inside Air Temperature:

Figure 13 shows the inside air temperature of all cases. It is clear that the temperature was the highest in the cases with no covers; case #1 and case #2. The temperature in case #1 reached about 75 °C, while in case #2it was about 73 °C. The temperature curves in these two cases are rising steeply until reaching the maximum temperature, then they start to decrease in the afternoon. Also, the cases with a car cover on the windshields only (case #3, case #4, and case #7) all have similar behavior with a maximum temperature less than the first two cases. The last two curves represent case #5 and case #6, where full coverage on all windows was used, but only in case #5, the windows were opened. The temperature in these two cases (#5 and #6) has the minimum peak temperature (60.9 °C in case #5 and 58.2 °C in case #6). It can be seen that in the cases without the car cover (#1 and #2), solar radiation has a significant effect on the temperature inside the car cabin. The high intensity of solar radiation that penetrates the walls and windows of the cabin warms up the surfaces and components inside thus increasing the temperature of these surfaces. While using the car cover, a large percentage of solar radiation is being blocked and is not transmitted through the windows.

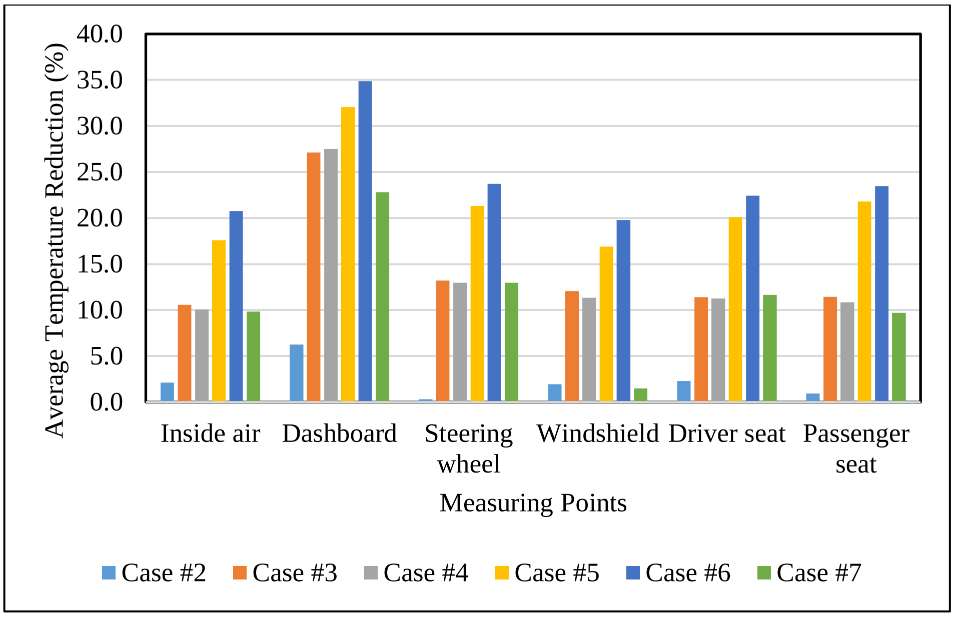


Figure 12. Average temperature reductions of the measuring points compared to the base case.

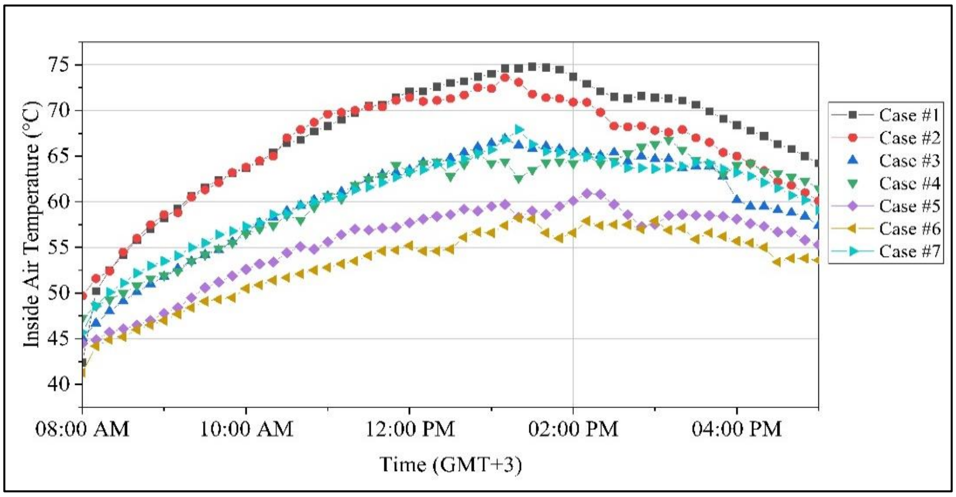


Figure 13. Car cabin inside air temperature.

3.1.2. Dashboard Temperature:

As the dashboard is located beneath the front windshield, it receives the most solar radiation transmitted through it, consequently, having a higher temperature than other components inside the cabin. As shown in **Figure 14**, the maximum temperature of the dashboard in case #1 is about 92.8 °C, while in case #2 when the windows were opened, the air was allowed to exchange with surrounding air due to air movement, and the temperature dropped to a maximum of 86.1 °C. The temperature curves in these two cases are rising steeply until reaching the maximum temperature, then they start to decrease in the afternoon. The effect of using the car cover from the outside is more obvious in the temperature of the dashboard. The temperature dropped from 86.1 °C in case #2 to 66.3 °C in case #3 due to the usage of the external car cover on the windshields which blocked the solar radiation that enters the cabin through them. In case #4, in addition to the cover on the windshields, the side windows were also opened, and the average temperature drop was about 25 % compared to case #1. Further decrease in temperature was achieved by using full cover in case #5, which reached a maximum of 59.4 °C since more solar radiation has been blocked from penetrating the glass, while with the opening of the windows in case #6 it dropped further to 56.5°C due to the air circulation between the cabin and the ambient.Using the cover internally beneath the windshields in case #7 resulted in a slightly higher temperature in most measuring points compared with using a car cover on the external side of windshields. As the cover is beneath, the windshield still absorbs some solar radiation that causes the temperature inside the cabin to rise.

The cover on all windows (case #5) reduced the average temperature of the dashboard by about 32% from the base case, while [8]achieved only a 21% reduction.

3.1.3. Steering Wheel Temperature:

As in the dashboard, the steering wheel is also subjected to a large amount of solar radiation that is transmitted through the windshield. As shown in Figure 15 the temperature in case #2 was higher than in case #1 before the afternoon, but after the afternoon, it starts to decrease more rapidly in case #1. The maximum temperatures in case #1 and case #2 were 77.3°C and 78.5 °C, respectively. The external sunshades on the windshields in case #3 led to a significant drop in the average temperature, about 13.2% relative to case #1 as shown in**Figure 15**. The temperature curves with the external and internal sunshades have similar patterns and have maximum temperatures lower than in the first two cases, about 65.5 °C and 65.4 in case #3 and case #7, respectively. The average temperature drops while using the external sunshades on the windshields with opening the windows by 15 mm (case #4) was about 12.9 % relative to case #1. In cases 5 and 6, a further reduction in temperature was achieved by using the sunshades on all windows. In case #5, the average temperature decrease was about 21.3 % and about 23.7 % in case #6, compared to case #1.

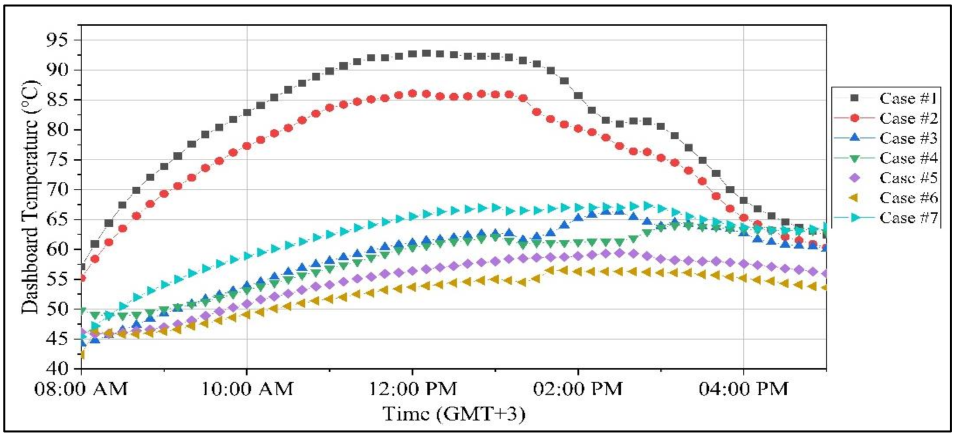


Figure 14. Dashboard temperature.

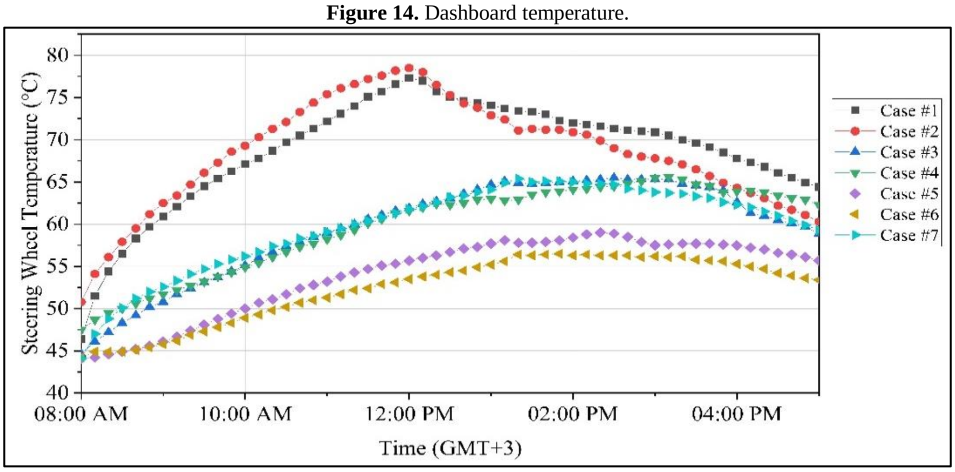


Figure 15. Steering wheel temperature.

3.1.4. Windshield Temperature:

The windshield represents the largest glazed area in the car which through the solar radiation enters the cabin. In addition to the ability of the glass to transmit solar radiation, it also absorbs some of that radiation, which leads to an increase in the temperature of the windshield. From **Figure 16** it can be seen that the windshield temperature could reach 74.6 °C in case #1. The curve of case #2with windows openings looks almost similar to case #1curve with an average temperature difference of 2% less than case #1. It can be seen that the temperature reaches its peak between 12:00 and 1:00 PM and it drops more rapidly after the afternoon. In case #3, the temperature peak dropped to 63.6 °C. However, with the window gap in case #4, the temperature did not drop further, since the windshield is more affected by the external parameters (ambient temperature and solar radiation). Further reduction in the average temperature was achieved in case #5 and case #6, about 17 %, and 19.8 %, respectively. In these cases where the full cover was used, almost no solar radiation entered the cabin which led to an average temperature for the windshield; being about 53.5°C in case #6. Case #7with the cover on the inside of the windshield looks similar to the first two cases, and with a maximum temperature of 72.8 °C. That's because the cover on the inside does block the solar radiation from entering the cabin, but it does not cover the windshield, so it gets hot by absorbing a portion of solar radiation.

3.1.5. Driver Seat Temperature:

Figure 17 shows the temperature of the driver's seat. It is clear that the temperature is highest in case #1 with a maximum temperature of 71.5 °C followed by 69.6 °C in case #2, so the ventilation without covering the windows did not achieve a significant reduction in the seat temperature. In case #3, the temperature was dropped to a maximum of 64.7 °C by using the cover on the windshields. While in case #4, no considerable reduction in the temperature was obtained where the average temperature was 59.1°C which is 11.2 % lower than the average base case. A similar result was achieved in case #7 since only 11 % drop in the average temperature was achieved. The highest temperature drop compared to the base case was recorded in cases 5 and 6. In case #5, the average temperature was 53.2°C representing a 22.4 % drop in the average seat temperature. The average temperature drops in case #6 was about 22.4 %.

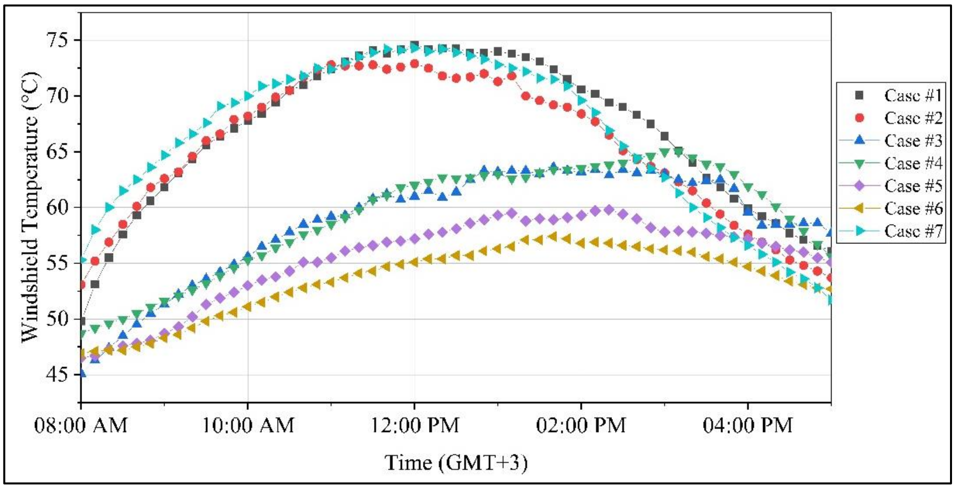


Figure 16. Windshield temperature.

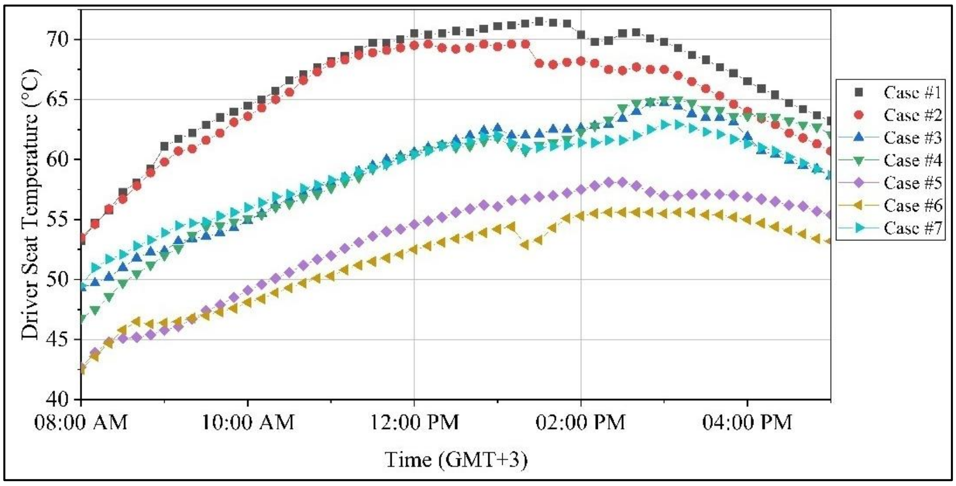


Figure 17. Driver seat temperature.

3.1.6. Passenger Seat Temperature:

The patterns of temperature in the passenger seat are comparable to those in the driver's seat. Case #1 had a maximum temperature of 73.7 °C at 1:30 PM, whereas Case #2 had a maximum temperature of 72.9 °C at 1:10 PM. As a result, opening the windows by 15 mm did not result in a significant drop in passenger seat temperature. The highest temperature in case #3 was around 67.3 °C, whereas adding ventilation air in case #4 did not result in a substantial drop in passenger seat temperature. Cases #5 and #6 exhibited much more reduction since covering all windows and windshields resulted in more sunlight being blocked. In case #5, the temperature reached a peak of 58 °C, whereas in case #6, it was 57 °C after adding ventilation air. The use of internal shading had no effect on lowering the temperature of the passenger seat. Temperatures reached greater levels than in the external shading (case #3), as indicated in **Figure 18**, with a maximum of 68.7 °C.

3.2. Temperature Reductions from the Ambient

Since the tests were conducted on different days, showing the obtained temperature measurements compared to the ambient would give a clear idea about the reductions achieved by the suggested solutions (the sunshades and window openings). **Figure 19** shows the average temperature reduction of measuring points minus ambient temperature for all cases. For the inside air, the average temperature difference was 21.2°C in case #1, since there was no method used to reduce the inside air temperature. In case #2, the difference was also high, about 17.9 °C, since the sunlight is still entering the cabin through the unshaded glass. Using the suggested cover with opening the windowsin case #6, achieved a minimum difference relative to the ambient of 7.4°C. On the dashboard, it reached the highest temperature difference between the measuring points and the ambient, since it recorded 34.4°C. Only about 27.5°C drop was achieved in case #2, thus the ventilation alone could not decrease the temperature to levels near the ambient temperature. While the lowest recorded temperature relative to the ambient was in case #6with only 6.6°C.

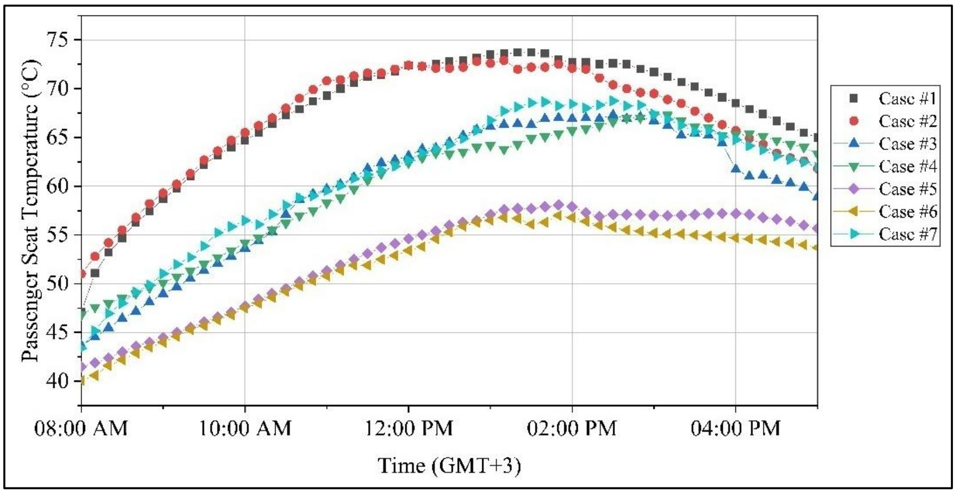


Figure 18. Passenger seat temperature.

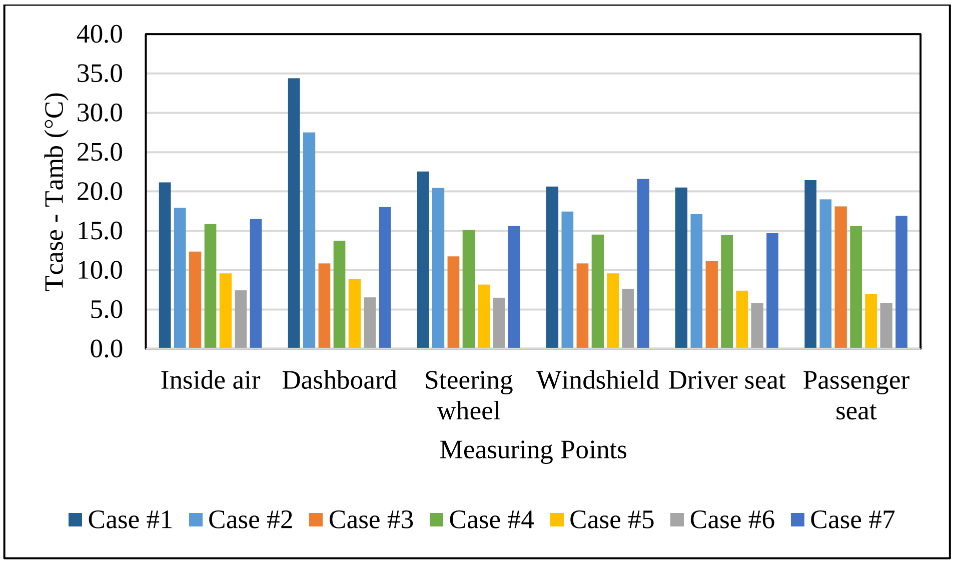


Figure 19. Reductions in average temperature of measuring points minus the ambient temperature.

The steering wheel temperature recorded a temperature difference of 22.5 °C in case #1. Cases #2, #3,and #4 had high temperatures with a difference of 20.5 °C, 11.8 °C, and 15.1 °C, respectively. On the other hand, cases #5 and #6 had the lowest temperature difference about 8.2 °C and 6.5°C respectively.On the windshield, the high temperatures were recorded in cases #1, #2, and #4, and the recorded difference was about 20.6 °C, 17.5 °C, and 14.5 °C, respectively. However, the lowest difference was in cases #3, #5, and #6, since the temperature difference was 10.8 °C, 9.6, °C, and 7.6 °C, respectively. The front seats (driver's seat and passenger's seat) also had the highest temperature in the first 4 cases, and the lowest in cases #5, and #6. For the driver's seat, the highest temperature difference was in case #1 with about 20.5 °C, while the minimum difference was in case #6 with about 5.8 °C. The same was for the passenger's seat since the highest temperature difference in case #1 was about 21.5 °C, and the lowest was in case #6 with about 5.8 °C. It can be noticed that in all measuring points, using the internal shading (case #7) resulted in a high-temperature difference, and it was higher than the cases with external shading and window openings (cases #3, and #4). For the inside air, the difference was about 16.5 °C, and for the dashboard, it was 18 °C, while for the steering wheel and the windshield it was 15.6 °C, and 21.6 °C, respectively. For the driver's seat, it was about 14.7 °C. and for the passenger's seat, it reached 16.9 °C. Comparing the cases #3 and #4, it can be noticed that in case #3 with using the external cover on the windshields only, the maximum difference was lower than the case #4, even with opening the windows in addition to the cover on the windshields, that's due to the ambient temperature in case #3 (day 4/8/2021 in Figure6) is lower in case #4 (day 26/7/2021 in Figure 6).

3.3. Reductions in Cooling Load

The comparison of internally (case #7), partially external (case #4), and totally external (case #6) shading relative to the baseline scenario is shown below as the research's point. Table 4 shows the average drop in interior air temperature as a result of utilizing the proposed cover, as well as the situation of using the cover inside the cabin. It also illustrates the theoretical average reduction in the cooling load that may be gained by employing this cover.

The sensiable cooling load that required to bring the cabin temperature to a comfort level can be estimated from the air temperature based on Equation (1)

$$Q_{sens} = \dot{m}c_{p,a}\left(T_{a,avg} - T_{comf}\right) \quad (1)$$

Where: $\dot{m}$is the mass flow rate of the AC (air conditioning) ventilation air, assumed 0.055 kg/s,

$c_{p,a}$ is the specific heat of the air, computed at the average temperature (J/kg°C),

$T_{a,avg}$ is the average temperature of the inside air (°C),

T_{comf} is the air temperature at thermal comfort level, assumed to 24 °C[15]

Table 4. Average reduction in air temperature and cooling load.

Case	Average Temperature (°C)	Average Temperature Reduction (%)	Average Cooling Load (kW)	Average Cooling Load Reduction (%)
Case #1	67.3	0	2.397	0
Case #2	65.8	2.1	2.318	3.3
Case #3	60.2	10.4	2.01	16.3
Case #4	60.5	10.1	2.024	15.6
Case #5	55.4	17.5	1.742	27.3
Case #6	53.3	20.8	1.624	32.3
Case #7	60.6	9.9	2.031	15.3

As seen in the Table 4, the average temperature in the baseline case reached around 67.3 °C, resulting in a considerable average cooling load of approximately 2.4 kW. The average temperature in case #4 was around 60.5 °C, which was 10.1 % lower than in case #1. In addition, the average cooling load was roughly 2.024 kW, which represented a 15.6 % reduction over the basic case. Case #6 saw a significant fall in average air temperature, reaching 53.3 °C, reflecting a 20.8 % reduction from the base case. The average cooling load was also significantly reduced. Case #6 had an average cooling load of roughly 1.624 kW, showing a 32.3% decrease over the base case.Case #7 had an average temperature of 60.6 °C, which was 9.9 % lower than the unshaded case. Furthermore, the cooling load was 2.031 kW, which is 15.3 % less than the base scenario.As can be seen above, the greatest reductions obtained in the air temperature and cooling load were in case #6 (totally external shading with opening the windows by 15 mm). While the internal shading (case #7) could not provide a considerable reduction in both air temperature, and cooling load.

4. Conclusions

These points can be drawn from the current research:

1. The air temperature inside the cabin in the unshaded situation (case #1) could reach a level of 74.8 °C, while the dashboard temperature reached a maximum of 92.8 °C.
2. Using the suggested cover externally and on all windows while opening the windows by 15 mm (case #6) resulted in the greatest temperature drop across all measuring points.
3. In case #6, the average temperature of the inside air was reduced to 53.3 °C, representing 20.8 % lower than the unshaded case and 7.4 °C higher than the average ambient temperature, while the average temperature of the dashboard was reduced to 52.4 representing nearly 35 %lower than the unshaded case, and approximately 6.6 °C higher than the average ambient temperature.
4. Using the cover inside the cabin (case #7) did not achieve any significant reduction in the average temperature of the measuring points. The average temperature of the inside air was decreased by only 9.9 %, however, the average temperature of the dashboard was lowered by 22.8 %.
5. The temperature reductions resulted from using the suggested cover (case #6) led to significant reductions

in the cooling load required to keep the cabin thermally comfort, where the average cooling load dropped by 32.3 % from the unshaded case. However, the internal shading (case #7) resulted in only 15.3 %.

Future Work:

As for future work, the temperature reduction inside the cabin can be enhanced by combining the suggested cover with other passive techniques. Also, the cooling load estimation can be enhanced by considering the latent part as well, and validate the results with CFD softwares.

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