Experimental study of the Cabin Temperature of a parked Vehicle under Scorching Sunlight in Nsukka, Nigeria

Olisa S. C[1*], Asiegbu N. C[2], Anoliefo E. C[3], Oparaku O. U[4], Iloanusi O. N[5]

[1,2,3,4,5] Department of Electronic Engineering, University of Nigeria, Nsukka
Samuel.olisa@unn.edu.ng[1*],
Nnaemeka.asiegbu@unn.edu.ng[2],
Edward.anoliefo@unn.edu.ng[3],
Ogbonna.oparaku@unn.edu.ng[4],
Ogechukwu.iloanusi@unn.edu.ng[5]

Abstract— **The harsh weather condition experienced in Nigeria, especially during the dry season, is of concern for the comfort of human inhabitants. During the day, vehicles parked under direct and scorching sunlight with the window glasses closed tend to build up high temperature inside the cabin. The upsurge in temperature inside the car poses serious discomfort and potential ill health to the vehicle occupants when they return to use it. This study focused on the degree of temperature rise as well as on the rate of rise at specific positions inside the cabin of a saloon vehicle parked under intense sun. The vehicle was parked in North-South direction under direct sunlight at the University of Nigeria Nsukka campus. Two cases were adopted in the study. Case A involved winding up the window glasses for a long period of 5 hours while in Case B, the effect of having the two front glass windows lowered with a gap of 0.04m and monitored for 5 hours was evaluated. The vehicle cabin temperature was measured at different locations of the cabin using LM35 DZ temperature sensor. The maximum cabin air temperatures were recorded at the dashboard, rear compartment, driver head rest and center of back seat which gave temperatures of 72.4^0C, 72.4^0C, 62.6^0C, 60.2^0C respectively for Case A. For Case B, the maximum temperatures were 56.2^0C, 60.6^0C, 52.8^0C, 48.4^0C, respectively. It was deduced that air temperature in the cabin can increase to health threatening temperature in 8-10 minutes after parking under intense sunlight exposure. T-tail test analysis showed that there is statistical significant difference between the two considered Cases. It was equally deduced from the study that it is not safe to leave a child, pet or items that cannot withstand higher temperature in a parked car as such could lead to heat stroke, death and damage of items.**

Keyword - Automobile, Heat stroke, Temperature, Thermal Loads, Pull-down time, t-test

1. INTRODUCTION

In the recent time, human driven activities have given rise to climate change and global warming. One of the core indicators of global climate change is in Earth surface temperature. The average global temperature rise across land and ocean surface areas for 2016 was $0.94 ^0C$ above the 20th century average of $13.9 ^0C$[1]. The 2016 average global temperature surpasses the warmth record of 2015 by $0.04 ^0C$. The year 2016 was marked as the warmest global average temperature ever recorded[1]. Climate change over a region has an adverse effect on earth's habitants and its environment. The depletion of ozone layer has caused more UV radiations to penetrate the earth leading to high increase in air temperature, increase in ocean rise, wide spread of diseases and general discomfort to the aggregate populace[2, 3]. In recent years, comfort in car interior has been observed to be diminishing due to temperature rise in the cabin [4]. This is quite noticeable after parking a car under scorching day sunlight with the entire glass window closed. Overtime, the updated temperature in the car cabin dries out natural oil in the leather seat causing it to age quickly, fade in colour, and become stiff which then leads to crack. Cases are bound of cracked mobile phone screen left on a dashboard of a car parked directly under intense sunlight due to high temperature that causes uneven expansion. There is also health implications associated with high updated heat in the car due to rise in temperature. Annually, hundreds of children experience varying degrees of heat illness from being left in vehicles which are parked under the sun. Though no statistics was found about Nigeria but annual infant mortality due to heat stroke in US is 37 [5]. The mostly affected age bracket of children is 1-3 years[5].Furthermore, the high discomforting temperature in the car cabin is highly associated with second hand cars and these are grade of cars with nonfunctional Air Conditioner are commonly used in most developing countries. In curbing this situation, many drivers resort to different ways of cooling the car such as parking under constructed car parking canopy or tree shades, **Figure 1**, winding down the vehicle window a bit to allow cool air in for heat exchange, using tinted glasses to restrict some reasonable amount of Ultra Violet radiations from penetrating into the car cabin, and cooling down the car using Air Conditioner before driving off. In this research work, we studied temperature situation at selected locations within a parked

car cabin using temperature sensor network, data logging module, Adruino microcontroller module, LCD module and the setup was powered solar system. The investigation was done under two cases, using a car parked under scorching sunlight with all the window glasses well closed and temperature sensors well networked. In each case, ambient temperature was recorded in order to monitor how cabin temperature varies with it. The result so achieved will be beneficial to car users, guide further research on how to design distributed and install solar powered heat extractor and temperature cooling system for a parked cars parked under sunlight with nonfunctional Air Conditioner. It will equally highlight the health implications of updated temperature in car cabin to the general populace. The investigation will give a clear view of the cabin maximum and minimum temperature at specific locations of the car, at given time of the day. Limited works have been reported on the issues and matters concerned with cabin temperature buildup in cars exposed under intense sunlight. It is paramount to buttress these issues as they have become inevitable owing to the harsh adverse climate change of the present time. The authors in [6] showed that the internal vehicle temperature can reach 117°F within 60 minutes, with 80% of the temperature rise occurring in the first 30 minutes. This temperature buildup in parked car cabin under the scourging sunlight with a child or children inside can cause heat stress which is its mildest form, and heat stroke, a life-threatening illness characterized by an elevated body temperature greater than 40°C with central nervous system dysfunction resulting in delirium, convulsions, coma, and death[7]. Saidur et al[8] studied ventilation systems to increase the air flow rate and decrease the steady state temperature inside a car compartment under the sunlight. Also, the heat transfer and energy balance inside the car were investigated. In another study [9] the temperature rise inside a parked car was considered. Further work was carried out to minimize the temperature rise inside the car by developing and installing simple ventilation systems on the rear end of the car with a set of fans to purge the hot air trapped inside the cabin. In [10] also, the authors did series of study which included how much influence body paint have on cabin temperature, typical peak steering wheel temperature rise during parked condition, heat reflection efficiency and window tinting film effect on cabin temperature. It was reported that colour has negligible impact on the rate of temperature rise, and at peak temperature, the difference was 3.1°C. Also steering wheel was reported to be hotter than the inside cabin by 7.5°C, the tint test showed that tint films slow the rate of temperature buildup in the car cabin. Shireesha et al[11] proposed a low cost portable car cooling system which consists of two fans clamped at the rear, 12v dc pump introduced at the centre of the base provided with PVC piping at outlet. Investigations conducted in Poland [12] focused on unsteady air-conditioning of the vehicle interior. It proposed a set of equations describing the thermal conditions inside the vehicle, which are the result of appropriate energy balances for air, interior elements, and glass. The measured data was compared with the results obtained through numerical solutions of the proposed set of equations.

Figure 1a: Cars parked under constructed canopy

Figure 1b: Cars parked under trees behind Mechanical Engineering Department, University of Nigeria, Nsukka

2.   THERMAL LOAD IN A CAR CABIN

The instantaneous cabin thermal load in a parked car is the summation of all the thermal load forms as shown figure and depicted in equation 1. Such thermal loads are shown in **Figure 2**.
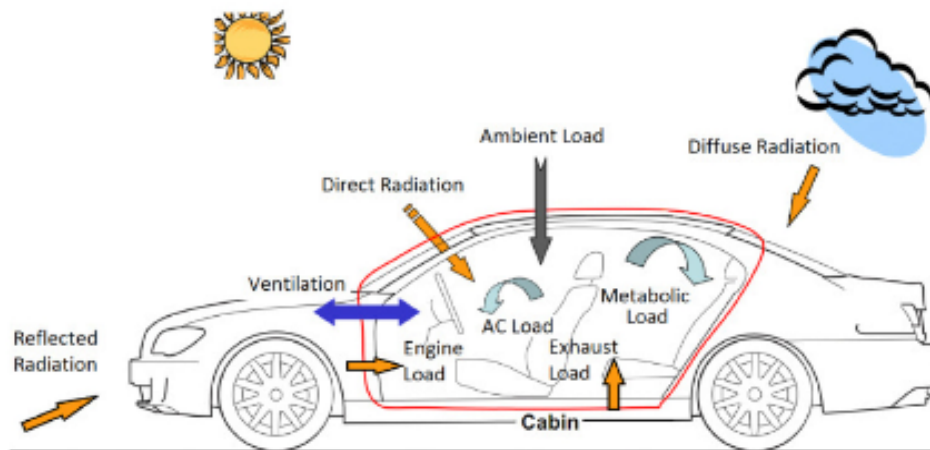

Figure 2: Schematic representation of thermal loads in a typical vehicle cabin

$$\dot{Q}_{Tot} = \dot{Q}_{Dir} + \dot{Q}_{Dif} + \dot{Q}_{Ref} + \dot{Q}_{Met} + \dot{Q}_{Amb} + \dot{Q}_{Exh} + \dot{Q}_{Eng} + \dot{Q}_{Ven} + \dot{Q}_{AC} \qquad 1$$

Where $\dot{Q}_{Tot}$ is the total thermal experienced by the cabin. $\dot{Q}_{Dir}$, $\dot{Q}_{Dif}$ and $\dot{Q}_{Ref}$ are thermal loads due to direct, diffusion and reflected radiations of the sun rays. $\dot{Q}_{Met}$ is the metabolic load due to passenger's interaction with cabin environment.. $\dot{Q}_{Amb}$ is the thermal load due to ambient or environmental temperature surrounding the car. $\dot{Q}_{Exh}$ is the thermal load due to exhaust. $\dot{Q}_{Eng}$ is thermal load due to hotness of the car engine. $\dot{Q}_{Ven}$ is thermal load through car vents and $\dot{Q}_{AC}$ is thermal loads due to Air Conditioner of the car.

However, the $\dot{Q}_{Met}$, $\dot{Q}_{Eng}$, $\dot{Q}_{Exh}$ and $\dot{Q}_{AC}$ are assumed to be zero since the car parked with neither passenger nor driver in it and the engine is OFF likewise the car Air conditioner in the both considered case scenarios.

The mentioned thermal loads aggregate over time to update the car cabin temperature as well as the surface element temperature as shown in equation 2 and 3 respectively.

$$\Delta T_a = \frac{Q_{Tot}}{m_a c_a + DTM} \Delta t \qquad 2$$

$$\Delta T_s = \frac{Q_s}{m_s c_s} \Delta t \qquad 3$$

3. RADIATION LOAD

The sun radiation contributes in car cabin temperature buildup through three forms which are: direct radiation which strikes the surface elements, diffuse radiations that results from indirect radiation of daylight on the surface element which occurs mostly during a cloudy day and reflected radiations that consists of heat reflected from the ground and strikes the car surface. According to ASHRAE [13], the three radiation loads that contribute to heat buildup in the car cabin are formulated as follows:

$$Thermal\ load\ due\ to\ direct\ radiation,\ \dot{Q}_{Dir} = \sum_{Surface} \tau A I_{Dir} \cos\theta \qquad 4$$

$$Where \quad I_{Dir} = \frac{A}{\exp\left(\frac{B}{\sin\beta}\right)} \qquad 5$$

$$Thermal\ load\ due\ to\ diffuse\ radiation,\ \dot{Q}_{Dif} = \sum_{Surface} \tau A I_{Dif} \qquad 6$$

$$Where \quad I_{Dif} = \tau I_{Dir} \frac{1+\cos Z}{2} \qquad 7$$

$$Thermal\ load\ due\ to\ reflected\ radiation,\ \dot{Q}_{Ref} = \sum_{surface} \tau A I_{Ref} \qquad 8$$

$$Where \quad I_{Ref} = (I_{Dir} + I_{Dif})\rho_g \frac{1-\cos Z}{2} \qquad 9$$

However, the net absorbed heat over surface element due to radiation is given as

$$\dot{Q}_{s,Rad} = \alpha A(I_{Dir}\cos\theta + I_{Dif} + I_{Ref}) \qquad 10$$

Where α is the surface absorptivity.

4. AMBIENT THERMAL LOAD IN THE CAR CARBIN

This thermal heat load occur due to difference between ambient temperature and cabin air temperature. It is formulated as in equation 11.

$$\dot{Q}_{Amb} = \sum_{Surface} UA(T_s - T_a) \qquad 11$$

Where the overall heat tranfer coefficient U is given as

$$For\ the\ internal\ side\ of\ the\ car,\ U = \frac{1}{R_{ti}}, R_{ti} = \frac{b}{2k} + \frac{1}{h_i} \qquad 12$$

$$For\ the\ external\ side,\ U = \frac{1}{R_{to}}, R_{to} = \frac{b}{2k} + \frac{1}{h_o} \qquad 13$$

R_{ti} and R_{to} are internal and external resistances for unit surface area. h_i and h_o are internal and external convection coefficient while k and b are thermal conductivity and thickness of the surface element respectively. Equation 14 is often used to estimate the convection coefficient, h using ambient air velocity instead of car velocity when considering parked car.

$$h = 0.6 + 6.64\sqrt{V_{amb,air}} \qquad 14$$

To estimate the pull-down time constant, t_c, when Air conditioner is turned ON in order to achieve the targeted comfort temperature, t_{comf}, equation 15 is often used,

$$t_c = \frac{t_p}{\ln|T_o - T_{comf}|} \qquad 15$$

Where,

t_p = targeted pull-down time. This is often taken to be 10minutes and such interval was used in this study.

T_o = Initial car cabin temperature which is often assumed to be the heighest or average cabin temperature

T_{comf} = Comfort temperature and it is often 23 ^{0}C.

5. TWO TAILS T-TEST ANALYSIS

This kind of t-test is use to find out if there is any statistically significant difference between two independent sample values of a populace. In this case, the sample populaces are the two cases scenarios temperature obtained from a particular location in the two different cases. The assumed null hypothesis was that there is no statistically significant difference between the temperatures obtained in a particular location in the two case scenarios. The mean value, variance value and standard deviation value of each location where obtained using equation 16, 17 and 18. The degree of freedom was obtained using equation 20.

$$Mean\ value\ of\ temperature\ at\ a\ particular\ location,\quad \bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \qquad 16$$

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Variance value of temperature at a particular location, $S^2 = \dfrac{\sum (X - \bar{x})^2}{N-1}$ 17

Standard deviation value of the temp. at a particular location, $S = \sqrt{\dfrac{\sum (X - \bar{x})^2}{N-1}}$ 18

$\text{T - Value} = \dfrac{Signal}{Noise} = \dfrac{Difference\ between\ a\ particular\ location\ in\ the\ two\ scenarios}{Variability\ of\ the\ two\ scenarios}$

$\qquad = \dfrac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\dfrac{(S_1)^2}{N_1} + \dfrac{(S_2)^2}{N_2}}}$ 19

The degree of freedom, $df = N_1 + N_2 - 2$ 20

The t-test value for two tail samples will be compared with a critical value of the null hypothesis obtained from the t-distribution table using the degree of freedom value. If the t-test value is greater than the critical value, the null hypothesis will be rejected meaning that there is statistical significance between the samples. However, if the t-test value is less than the critical value, the null hypothesis will be accepted, meaning there is no statistical difference between the two samples. This is as formulated in equation **21.**

$(Don't\ reject)\ t \quad value \le H_0 \le t \quad value\ (Reject)$ 21

In this analysis, we used probability of , p = 0.05 to obtain the critical value from two tail table of probability.

6.   EQUIPMENT AND METHODOLOGY

The sets of equipment used in this study included: Arduino nano microcontroller, Arduino Data logger Module, Arduino compatible Liquid Crystal Display (LCD), BP Solar Panel (50watt @1000w/m², A.M 1.5, 25 °C), Solar Charge controller, 12V, 18HA rechargeable battery, LM35 DZ temperature sensor with specification detailed in the datasheet [14], light green Honda Accord 1990 series as the test Car which is shown in **Figure 3**. Two Case scenarios were considered in carrying out the experimental study.

A. A case of parking the test Car in a fixed position under direct scorching sunlight with the window glasses fully wound up, between 10:30 A.M - 4:30 P.M on 24th October, 2017

B. A case of parking the test Car in a fixed position under direct scorching sunlight with the two front door windows lowered 0.04m, between 10:30 A.M – 4:30 P.M on 25th October, 2017.

Figure 3 The experimental Honda Accord 1999 series Car

In the first scenario, the system was setup as shown in **Figure 4** below, the temperature sensors were placed in four (4) different locations in the car: Middle of the front dashboard (T1), driver's head rest seat (T2), rear compartment (T3), Middle of back passenger's seat (T4) and one (1) temperature sensor was placed outside (T5) to measure the ambient temperature. Solar panel and solar charge controller were used to charge the system battery and equally power the setup. The data logger collates and saves the temperature reading of each sensor in an SD memory card while the LCD displays the reading of each of the temperature sensors. The temperature sensor output terminals were wired to the Arduino microcontroller which then sent the values to the data logger module and LCD. The system was run for 5 hours (10:30 a.m – 4:30 p.m) and temperature values of the targeted locations were saved every 10 minutes interval. In the second scenario, the same system setup was used with the installation of one more temperature sensor at the interior center of the car cabin which reads T6 temperature. The two front windows were 0.04m opened and the setup was run for exactly 5 hours at which readings were collated and saved every 10 minutes interval.
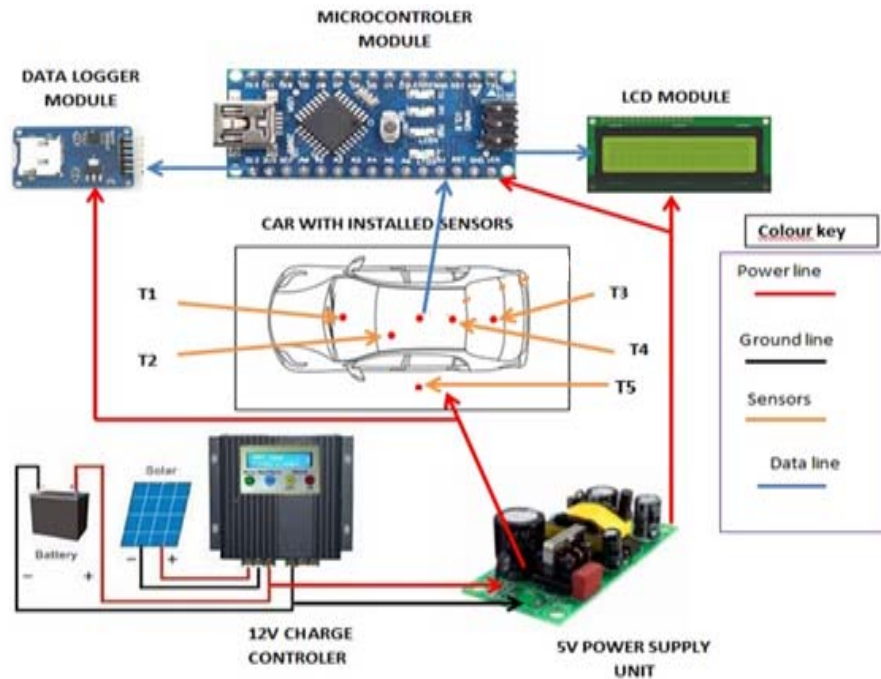
Figure 4: Experimental Setup Systems

Legend for Temperature

T1 – Dashboard Temp;   T2 – Driver head rest Temp;

T3 – Rare Compartment Temp;   T4 - Passenger back seat Temp;

T5 – Ambient Temp;

7. RESULTS AND DISCUSSION

Table 1 presents the test data recorded from the temperature sensors placed at four (4) different locations inside the car cabin, as well as the one (1) placed outside the car which collated the ambient temperature. The first case scenario was labeled **A** while the second case scenario was labelled **B** in the table.

Table 1: Temperature Readings for the Five Sensors at 10minutes time intervals

TIME	TEMP1 (^{0}C)		TEMP2(^{0}C)		TEMP3(^{0}C)		TEMP4(^{0}C)		TEMP 5(^{0}C)	
CASES	A	B	A	B	A	B	A	B	A	B
10:30:00 AM	44.5	40.1	30.8	35.7	42.5	40.1	30.3	37.2	21.0	31.3
10:40:00 AM	56.7	41.1	45.0	43.0	53.8	40.1	40.6	37.2	27.4	28.4
10:50:00 AM	62.1	42.5	49.9	41.1	59.2	43.0	44.5	35.7	36.7	28.9
11:00:00 AM	65.0	44.0	59.2	37.7	62.1	44.0	47.9	36.7	33.7	28.9
11:10:00 AM	69.0	44.0	57.7	39.1	65.5	44.0	52.3	36.7	34.2	28.9
11:20:00 AM	70.9	44.0	58.2	40.6	67.5	44.0	52.3	36.7	32.8	28.9
11:30:00 AM	72.4	44.5	60.2	40.6	69.4	45.0	52.8	37.2	32.8	28.9
11:40:00 AM	72.4	44.5	61.1	40.6	70.4	45.0	54.3	37.7	34.7	31.8
11:50:00 AM	69.4	44.5	61.6	40.6	68.5	45.0	54.3	41.6	33.3	30.3
12:00:00 PM	61.6	44.5	59.2	37.2	61.6	38.6	51.8	40.6	31.3	23.0
12:10:00 PM	58.7	44.0	52.8	39.1	54.3	41.6	51.3	40.1	28.9	27.4
12:20:00 PM	55.8	44.0	52.8	39.1	53.3	43.0	50.9	41.1	28.4	27.9
12:30:00 PM	52.8	44.0	51.3	40.6	51.3	52.3	49.4	41.1	28.4	29.3
12:40:00 PM	50.9	46.0	49.9	41.1	49.9	52.3	48.9	41.1	28.4	30.3
12:50:00 PM	50.9	48.4	49.4	43.5	45.0	52.3	48.4	41.1	24.9	31.3

1:00:00 PM	55.3	48.4	49.4	44.0	54.8	51.8	48.4	41.1	28.4	30.8
1:10:00 PM	61.6	48.4	51.3	41.6	61.6	50.9	48.9	45.0	29.3	30.8
1:20:00 PM	68.0	47.9	55.8	43.5	67.5	50.4	55.8	43.0	33.3	30.8
1:30:00 PM	69.9	47.9	59.2	43.5	70.9	49.9	55.8	38.6	35.2	32.3
1:40:00 PM	69.9	47.9	60.6	43.5	72.4	49.4	55.8	39.6	33.7	31.3
1:50:00 PM	68.5	47.9	60.6	43.5	71.4	51.3	55.8	46.5	33.7	31.3
2:00:00 PM	64.1	47.9	62.6	43.5	54.8	49.9	55.8	44.0	30.8	31.3
2:10:00 PM	60.6	49.4	57.2	45.0	55.8	51.3	54.3	42.5	29.8	30.3
2:20:00 PM	60.2	49.4	55.3	45.0	58.7	51.8	53.8	42.5	29.8	30.3
2:30:00 PM	68.5	49.9	55.3	46.5	65.0	52.8	53.8	48.4	31.3	30.3
2:40:00 PM	67.5	51.8	57.2	47.4	67.5	55.3	55.8	46.0	31.8	30.8
2:50:00 PM	65.0	54.8	55.8	52.8	66.0	56.2	55.8	46.0	31.3	33.3
3:00:00 PM	63.6	56.2	55.8	52.8	63.6	60.6	55.8	46.0	31.3	33.7
3:10:00 PM	62.6	55.3	55.8	52.3	63.6	57.2	55.8	46.0	32.8	27.9
3:20:00 PM	62.1	51.3	55.8	50.4	63.1	53.8	60.2	45.5	26.9	28.9
3:30:00 PM	63.1	54.3	52.8	48.4	64.1	51.3	58.2	45.5	36.2	30.3
3:40:00 PM	65.5	50.4	56.7	38.6	67.0	50.9	58.2	45.5	36.7	30.3
3:50:00 PM	67.0	49.9	62.1	50.9	68.5	50.9	58.2	45.5	37.2	30.8
4:00:00 PM	68.0	50.9	54.3	47.9	69.4	50.9	58.2	45.5	37.2	30.8
4:10:00 PM	68.5	47.9	62.1	46.5	69.9	49.4	58.7	45.0	36.2	30.8
4:20:00 PM	68.5	47.4	62.1	46.0	69.9	48.4	58.7	44.5	36.2	30.8
4:30:00 PM	68.5	47.4	62.1	45.0	69.9	50.4	53.8	44.5	36.2	30.8

A. THE CASE OF CAR WINDOWS COMPLETELY CLOSED.

The weather was sunny and the cloud was clear. The car was parked in North-South direction in order to be fully exposed to the sun radiation. Temperature recordings were started at 10:30 A.M and continued at an interval of 10 minutes. The experiment lasted for 5 hours (10:30 a.m – 4:30 p.m) without interruption. Shade was totally avoided and the sensors were working properly. **Table 2** below showed the statistical result of the temperature reading of the first case scenario while **Figure 5** showed the histogram of the average temperature at each location of temperature sensor. The graph of the recorded temperatures against time of measurement was presented in **Figure 6**.

Table 2: Statistical Result for Case A (Car windows completely closed).

	Temperature at Dash Board (Temp1) in ^{0}C	Temperature at Driver's Head Rest (Temp2) in ^{0}C	Temperature at rear compartment (Temp3) in ^{0}C	Temperature at the middle of Back Seat (Temp4) in ^{0}C	Ambient Temperature (Temp5) in ^{0}C
N	37	37	37	37	37
Mean	63.5	55.6	62.4	52.9	32.0
Median	65.0	55.8	64.1	54.3	32.8
Mode	68.5	55.8	67.5[a]	55.8	28.4[a]
Std. Deviation	6.6312	6.1090	7.7785	5.6953	3.7473
Range	27.9	31.8	29.9	29.9	16.2
Minimum	44.5	30.8	42.5	30.3	21.0
Maximum	72.4	62.6	72.4	60.2	37.2

a. Multiple modes exist. The smallest value is shown

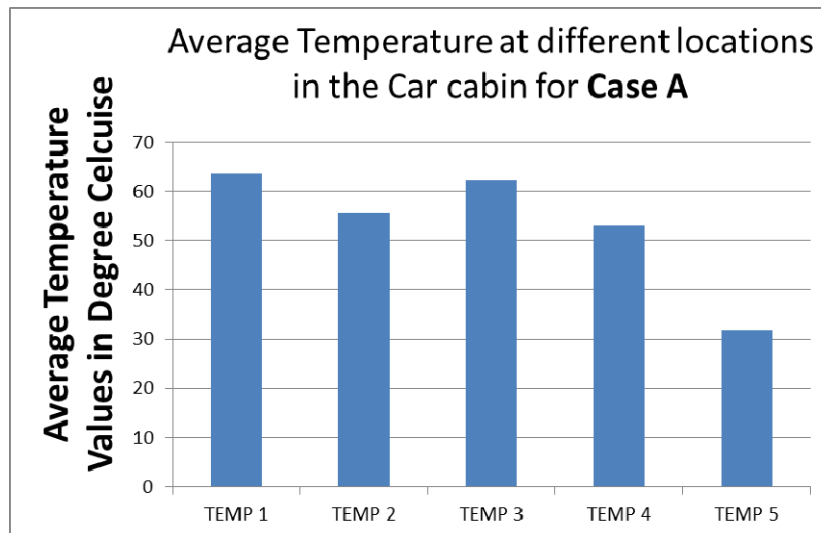Olisa S. C et al. / International Journal of Engineering and Technology (IJET)

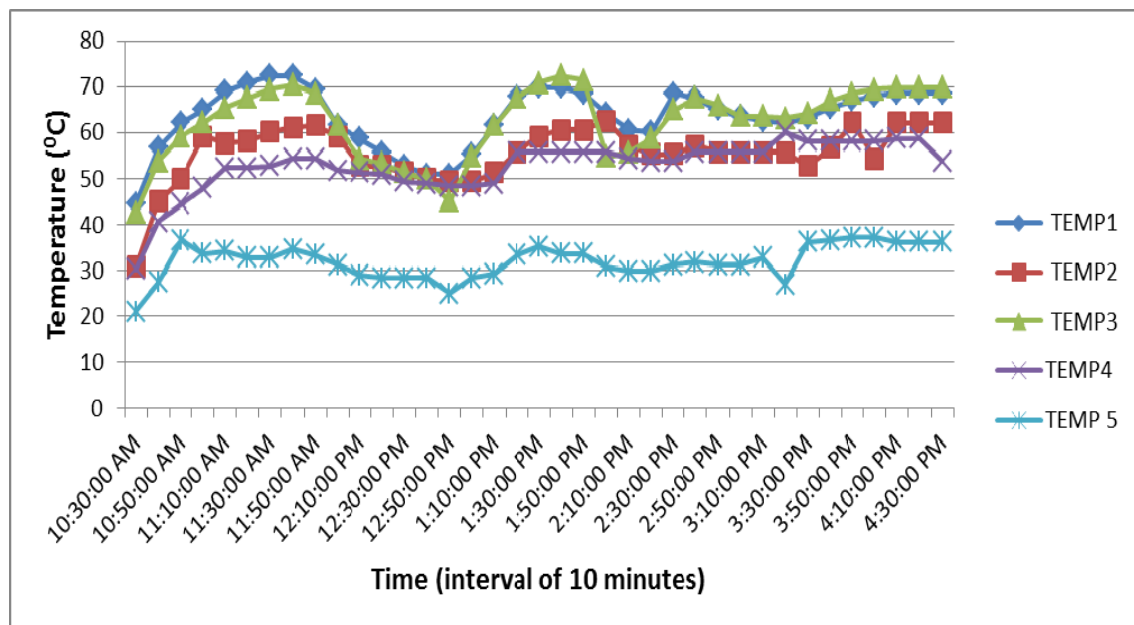Figure 5: Histogram of Average temperature for Case A

Figure 6: Graph of first case scenario when all the glasses were completely closed up

I. Temperature at the Dashboard, T1 (Temp1)

From the statistical result of **case A** as shown in **Table 2**, the mean temperature recoded at the dashboard was 63.5^0C as against the mean ambient temperature of $32.0\ ^0C$. The maximum and minimum temperature recorded after the initial low starting temperatures ($44.5\ ^0C$) were $72.4\ ^0C$ and $50.9\ ^0C$ respectively. See **Table 1 and 2** above. These temperatures occurred in 60 minutes and 70 minutes of the starting time respectively. It was observed that dashboard temperature reached $56.7\ ^0C$ in 10 minutes from the staring time. This is a very high ill threatening temperature that has the potential of causing heatstroke by 1.3 times [5,11]. From Table 1 and **Figure 6**, the maximum recorded temperature lasted for about 20 minutes before dropping down by 4.04%. The average temperature at the dashboard suggested that the dashboard can expose one to heat stroke which can occurs from temperature of 42^0C and above [11, 12].

II. Temperature at the driver's head rest seat, T2 (Temp 2)

From the statistical result, the mean temperature recorded at this location in 5 hours duration was $55.6\ ^0C$ as against the obtained average ambient temperature of $32.0\ ^0C$. The mean temperature recorded in this position was about 12.36% less than that of the dashboard. The maximum and minimum temperatures recorded in this location were $62.6\ ^0C$ and $49.4\ ^0C$ respectively. These temperatures occurred when the ambient temperatures were $24.9\ ^0C$ and $30.8\ ^0C$ accordingly. It is evident that heat generated at this location can cause heatstroke and discomfort to the driver [15,16].

III. Temperature at the rear compartment, T3 (Temp 3)

The statistical mean temperature recorded at this location was 62.42 ^{0}C. The maximum and minimum temperatures recorded in this location were 72.37 ^{0}C and 42.54 ^{0}C respectively. See **Table 1** and **2** above. The maximum temperature was exactly the same value with the dashboard maximum temperature and it occurred at about 120 minutes after the occurrence of the maximum temperature at the dashboard. It was observed from **Table 1** and **Figure 6** that the dashboard and rear compartment achieved the same value of maximum temperature though at different time of the day. On the contrary, their minimum temperature value differed by 11.54 %. The ambient maximum temperature and minimum temperature at this location was 33.7 ^{0}C and 24.9 ^{0}C respectively. The higher temperature readings recorded from this location could be attributed to the large size of the back windshield and the angle of ray reflection on the windshield.

IV. Temperature at the middle backrest of the back passenger seat, T4 (Temp 4).

The statistical mean temperature recorded at this location in 5 hour duration was 52.8 ^{0}C. The maximum and minimum temperatures recorded at this location were 30.3 ^{0}C and 60.2 ^{0}C. From **Figure 6**, the temperature behavior here is almost the same pattern with that of the dashboard except between 1:20 pm – 2:00 pm and 2:40 pm – 3:10 pm when temperature was steady at 55.8 ^{0}C which lasted for about 40 minutes and 30 minutes respectively. It was evident from the readings obtained for the back passenger seat that hot air rises higher than cold air and that there was no direct heating on this location as compared to the dashboard and rare compartment.

B. WHEN THE FRONT PASSENGER AND DRIVER WINDOWS WERE LOWERED (0.04m)

This second experiment was carried out to have a clearer understanding of the temperature rise inside a parked car in a different scenario to the first case studied. The parking coordinate and location was maintained. The system temperature collation and storage commenced by 10:30 AM at interval of 10minutes and ran for 5 hours duration. The front passenger and driver's window were lowered by 0.04m to observe the effect of the outside air inflow for the time frame of the test. The recorded temperatures and its statistical results were presented in **Table 1** and **3**. The graph of the recorded temperatures against time of measurement was presented in **Figure 8**.

Table 3: Statistical Result for Case B (front passenger and driver windows were lowered by 0.04m)

	Temperature at Dash Board (Temp1) in ^{0}C	Temperature at Driver's Head Rest (Temp2) in ^{0}C	Temperature at rear compartment (Temp3) in ^{0}C	Temperature at the middle of Back Seat (Temp4) in ^{0}C	Ambient Temperature (Temp5) in ^{0}C
N	37	37	37	37	37
Mean	47.6	43.7	49.1	42.1	30.1
Median	47.9	43.5	50.4	42.5	30.3
Mode	44.0^a	43.5	50.9	41.1^a	30.8
Std. Deviation	3.8832	4.4543	5.0879	3.5769	1.8436
Range	16.1	17.1	22.0	12.7	10.7
Minimum	40.1	35.7	38.6	35.7	23.0
Maximum	56.2	52.8	60.6	48.4	33.7

a. Multiple modes exist. The smallest value is shown

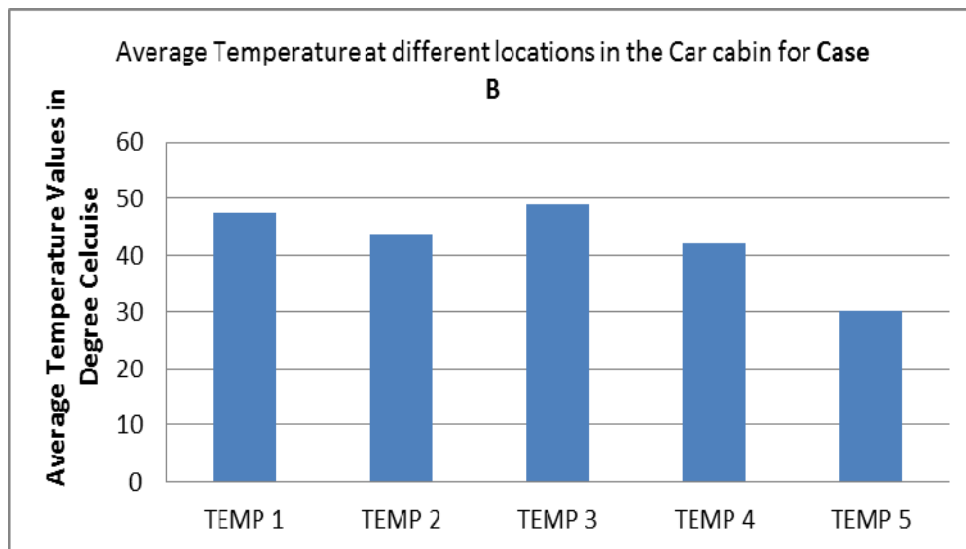Olisa S. C et al. / International Journal of Engineering and Technology (IJET)

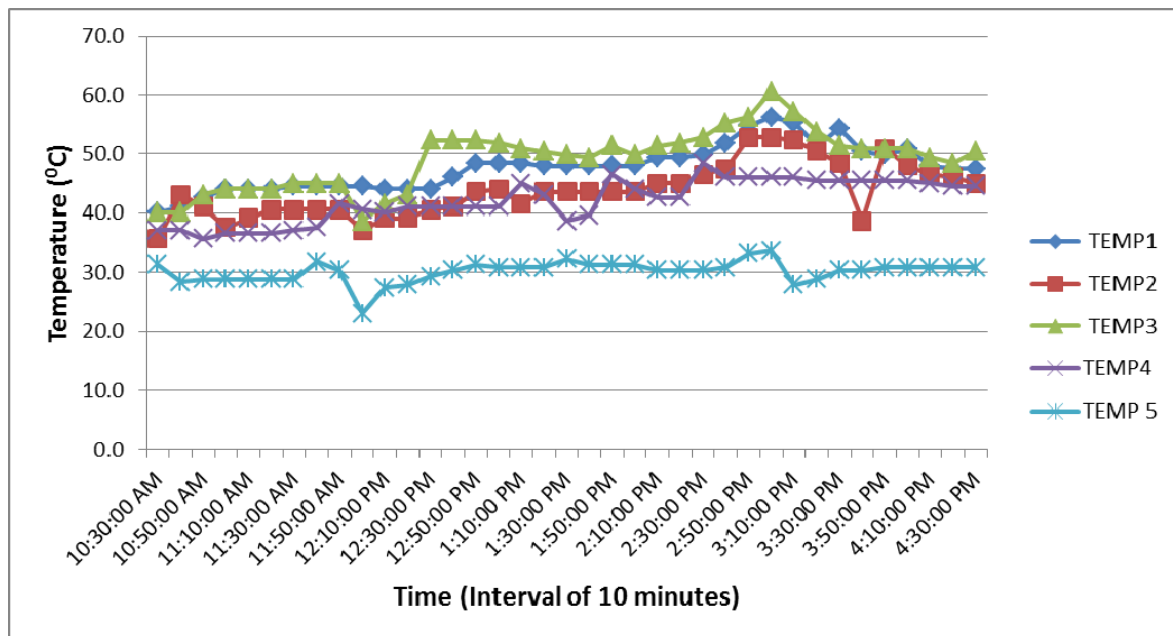Figure 7: Histogram of average temperature for Case B

Figure 8: Graph of second scenario when the two front window glasses were lowered down by 0.04m each.

I. Temperature at the dashboard, T1 (Temp 1)

From the statistical result presented in **Table 3** above, the mean dashboard temperature for 5 hours duration was $47.6\,^0C$ as against the average ambient temperature of $30.1\,^0C$. The maximum and minimum recorded temperatures were $56.2\,^0C$ and $44.0\,^0C$ respectively. The lowering of the two front window glasses by 0.04m contributed to about 26.67% reduction in the dashboard temperature. This suggested that there was better air circulation and slower temperature rise at the dashboard during the second case experiment.

II. Temperature at the driver's head rest seat, T2 (Temp 2)

From the statistical result presented in **Table 1** and **3**, the mean recorded temperature was $43.7\,^0C$. The maximum and minimum recorded temperatures were $52.8\,^0C$ and $35.7\,^0C$ respectively. However, it was observed that T2 was less than T1 with a reasonable percentage and it was equally less than the statistical mean temperature of the driver's head rest seat in the first experiment. This implied that the slight lowering of the window glass led to about 4.20% reduction in T2 temperature.

III. Temperature at the rare compartment, T3 (Temp 3)

From the statistical result presented in **Table 1** and **3**, the mean recorded temperature was 49.1 ^{0}C. The maximum and minimum temperatures recorded here were 60.6 ^{0}C and 38.6 ^{0}C respectively. It was observed that the rare compartment maximum and statistical mean temperatures were greater than those recorded at the dashboard. Consequently, the statistical mean temperature was about 30.12% less than previously recorded rear compartment temperature in the first experiment. Apparently, it was observed that slight lowering of the window contributed to the reduced temperature values recorded here though the effect is more evident at the dashboard.

IV. Temperature at the middle back rest of the back passenger seat, T4 (Temp 4)

From the statistical result presented in **Table 1** and **3**, the mean recorded temperature was 42.1 ^{0}C. The maximum and minimum temperature recorded here were 48.4 ^{0}C and 35.7 ^{0}C respectively. The statistical mean temperature obtained in this location of case scenario was less than the statistical mean temperature recorded in the previous experimental case scenario at the same cabin location. Though, the slight wind down of the two front door glasses contributed to the lower temperature but it was still within the range of causing heatstroke which is pandemic in children left in a parked hot car cabin
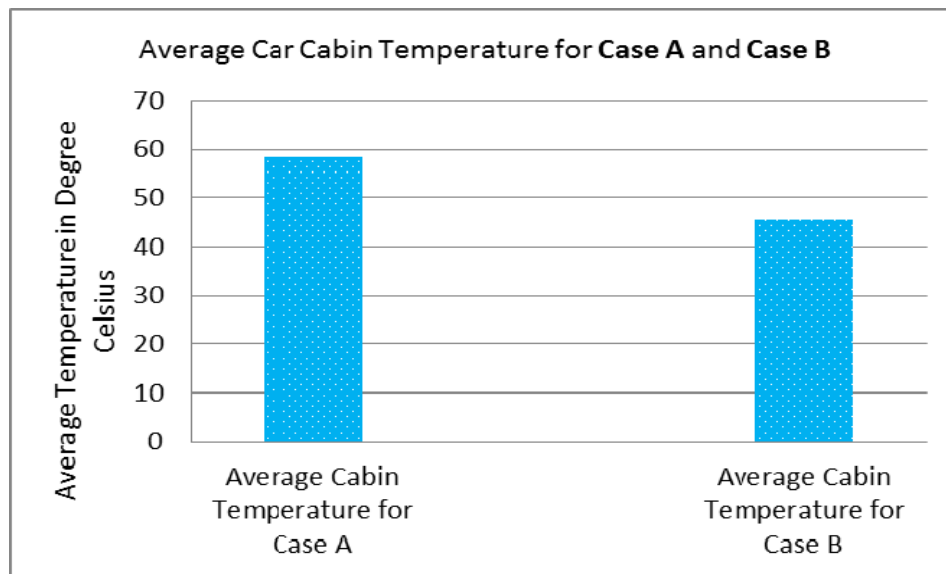

Figure 9: Histogram of interior average temperature in Case A and Case B.

8.   STATISTICAL EFFECT OF LOWERING THE WINDOW GLASS

The degree of freedom for the test is 72 while the critical value based on probability of 0.05 is 1.67. The obtained t-value between Temp1 (Case A) – Temp1 (Case B), Temp2 (Case A) – Temp2 (Case B), Temp3 (Case A) – Temp3 (Case B), and Temp4 (Case A) – Temp4 (Case B) are 12.58, 9.57, 8.76 and 9.64 respectively. The critical value is less than the t-value of any the compared location of the two scenarios. Hence, the lowering the front window glasses significantly decrease the heat accumulation in the car interior.

9.   DEDUCTIONS

- The result analysis showed that the temperature inside the car cabin can rise to health threatening level in the space of 8 -10 minutes when parked under sunlight. Hence, there is no safe location in the car cabin in the two scenarios we studied.
- The result showed that the dashboard and rear compartment are the two locations in the car cabin with the highest heat accumulation. Hence, there is need to develop heat evacuation mechanism for a parked car.
- From the result of the study, it could be inferred that it is not safe to leave children and items which cannot withstand temperatures above **40 - 75** degree Celsius inside a parked car.
- The average interior cabin temperature varies with about 1.84 times the ambient temperature in Case A while it is about 1.51 times the ambient temperature.
- Case B showed a reduction of about 22.13% on the total average interior temperature as seen from figure 7.

10. CONCLUSION

The temperature time profile inside a car parked under direct sunlight was studied for closed window and slightly opened window scenarios. It was evident from the result analysis that the temperature rise inside the car cabin was high especially at the driver headrest, dashboard and back compartment due to the car windshield, (back and front) which allows the larger quantum of radiation to enter the car cabin. Though case B showed reduced temperature build up due to inflow of outside air from the lowered window glasses. Both cases A and B showed temperature increase above the human thermal comfort, thus posing health risk to the driver as well as the passenger entering a car after parking under the sun. There is need to develop either heat evacuation mechanism or adequate and effective shading and ventilation systems to mitigate the issue of excessive cabin temperature on a sunny day for the case of a parked car. This will provide greater comfort for passengers on their initial entrance to the vehicle and will also help in preserving items placed inside the car as well as improve lifetime of the vehicle's interior and upholstery makeup such as seats, vehicle roof, dashboard, carpets and door panels.

Conflict of Interest: We declare no conflict of interest of any kind in this study.

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