Development and investigation of a cooling system for a parked vehicle using solar energy

Mohiuddin A.K.M, Amirah Osman, Mohammad Faisal Uddin

Abstract— ***The temperature of the interior of a car gets increased substantially during day time when parked under un-shaded parking area for long duration. It is very uncomfortable for the passengers and driver during the start of the driving as the air conditioner will take time to fully cool the interior of the vehicle. This paper mainly focuses on ways to reduce the interior temperature of the parked vehicle. A system has been designed that employs the solar panel, battery, inlet and exhaust fans, temperature sensor and an electric control circuit. The experiment was performed on a car cabin prototype model made using CPU casing of a desktop computer. The inlet air fan is located lower than the exhaust air fan at the car model as the hot air moves up and to have a better air flow distribution. It was observed that the interior temperature of the car model decreased significantly when the system was installed. The simulation was done by using ANSYS FLUENT R15 to investigate the airflow distribution inside the car cabin when inlet and outlet fans were in action. The results showed that the car interior has a better airflow distribution when the inlet fan is positioned lower than the outlet fan.***

Keywords: Cooling System; Flow Distribution; Interior Temperature; Parked Vehicle; Prototype; Solar Energy.

1. INTRODUCTION

Nowadays, vehicles are the main means of modern day transportation. The demand for personal transportation has induced many undesirable problems. Drivers are having difficulty to get an indoor or roof parking space, particularly during peak hours as the number of vehicles on the road are increasing day by day. As a result, they have no choice except to leave their car in an open space parking. In this situation, the temperature inside the car increases proportional to the outside temperature and it gets worse in the afternoon, especially when the car owners leave their car for few hours. This phenomenon happens because of the thermal radiation caused by the solar energy and it is known as the Greenhouse Effect [1]. As the thermal radiation travels through the car window, it is converted into waveform. As the wavelength gets shorter, the heat is trapped inside the car as it cannot pass through the glass to go outside the car. At this point, the interior of the car experiences a constant increase in temperature, adding the fact that the interior of the car deficits air flow circulation as the car windows are closed. The more time the car is uncovered in the sun with no air flow circulation, the higher the temperature collected inside the car.

Temperature variations in a parked vehicle had been investigated by Dadour et al. [2]. A simple 'greenhouse' model was developed using available local meteorological data for predicting the vehicle interior temperatures. The meteorological data and temperature data collected on parked vehicles during particular summer seasons were employed to measure the statistical model. The environmental temperature and radiation data were used as input for the model. The results showed that the temperature inside the cabin of a black vehicle is 5 ^{0}C higher than that of a white vehicle on a hot summer day. The cabin's temperature has reduced about 3 ^{0}C by lowering the driver's window of the vehicle by 2.5 cm.

Rugh, Chaney, and Lustbader [3] compared the effect of ventilation with several conditions which include the HVAC heater ducts drawn in the air, air being purged of the vehicle and without any ventilation. The results exhibited that the maximum temperature reduced as much as 2.3 ^{0}C and 8.3 ^{0}C respectively at the windshield and the dashboard from the ventilation. Their study also showed that the ventilator has lowered the cabin air temperature by 8.3 ^{0}C. A study about the performance of improved solar car ventilator has been conducted by Saidur et al. [4]. In order to increase the air flow rate and decrease the steady state temperature, the existing ventilation has been modified. The improved ventilators can minimize temperature better than existing ventilator by 10.9 % reduction compared to a car using existing ventilator. Other than that, it can supply a higher comfort level and the flow rate was 5.5 times greater than existing ventilator. The higher flow rate will give a better result at the soak temperature. Also, the passengers will experience greater comfort after entering the vehicle as it keeps the interior cooler.

Abin et al. [5] fabricated solar powered heat control system to control the temperature of parked car. The principle of this system is based on Newton's law of cooling. Two micro high efficiency fans are fitted into the system to circulate air in and out of the parked car and acts as inlet and outlet. The micro fan drawn in air which later passed through a closed chamber containing acetone as liquid coolant. The fans are electric powered using solar panels based on solar energy controlling principle. The result indicated that the

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temperature inside the car cabin increased rapidly for the first 5 minutes when the system was installed with acetone coolant. Then, it decreased with constant step to the next 10 minutes and remained constant. The system manifested an average of 8.40 ^{0}C reduction of temperature within a short interval and it runs completely on green energy.

2. HEAT DISTRIBUTION INSIDE THE VEHICLE

Al-Kayiem et al. [6] had conducted experimental and numerical analyses on the thermal accumulation and distribution in the interior of a parked vehicle. The experimental data were obtained from measurements of six different cases consisting of full windows closing, four different windows opening settings and usage of sun shade. The temperatures at 12 different locations were recorded. Among all the measurements inside the car, the spot near the glass windshields recorded the highest temperature. Since the spot exposed directly to the transmitted solar radiation it accumulated more thermal energy than the interior spots due to convective heat transfer. The CFD simulation was carried out using FLUENT. From experimental and CFD simulation, it was observed that the regions at the front and rear glass windows have the highest temperature.

Jalil and Alwan [7] had developed a numerical study of a two-dimensional, turbulent, recirculating flow within a passenger car cabin. The study is based on the solution of the elliptic partial differential equations representing conservation of mass, momentum, temperature, turbulence energy and its dissipation rate in the finite volume form. Different parameter were taken into account, including the number and location of the air conditioning systems, inlets inside car cabin, different air temperatures at the inlets, different air velocities at the inlets, different solar intensity during day-time for a certain day of the year, and different diffuse solar radiation (variation in the kind of car glass). These parameters will exhibit their influences on the flow field and temperature distribution inside the car's cabin. The results indicated that the increase of air inlet vents lead to a decrease of the hot zones and lower temperature gradient near the interior surfaces and a uniform temperature distribution.

The variation of car cabin temperature influenced by ventilation under direct sun exposure shows that the cabin temperature can reach up to 60°C after less than half an hour's exposure to direct sunlight at various sunlight intensity. Other factors such as ambient wind velocity, natural conduction, natural convection and radiation also influenced cabin temperature. The highest temperature difference was obtained when one front window was opened. This was followed by one front and one rear window opened simultaneously, and one rear window opened. It is suggested that the reduction of the cabin temperature will be accelerated if there is a ventilation fan to vent the hot air out of the vehicle.

Giri, Tripathi, and Thakur [8] conducted a 2-D CFD analysis of the passenger compartment for thermal comfort and ventilation. In order to find velocity and temperature distributions, velocity and temperature from governing equations were solved numerically with CFD software (ANSYS Fluent V.14.0) with SIMPLEC algorithm. The results revealed that air circulation in the rear of the compartment is more comparable to front and it improved with the increase in the inlet air velocity. There is improvement in temperature distribution as the temperature difference between compartment and ambient temperature is reduced by increasing in inlet velocity. This proved that providing the vents in the compartment can reduce the problem of heat accumulation and ventilation and give better thermal comfort to the passengers.

Quadri and Jose [9] studied on computational analysis of thermal distribution within the passenger car cabin during parking. The 3D car cabin model was simulated using Fluent 6.3.26. The car has been subjected to various external and internal parameters. To determine the intensity of radiations falling on the window panes, solar calculator has been used. Slits with specific dimensions were cut on the model and cold air was allowed to enter into the cabin to represent the inlet and outlet vents in a car. The areas around the window panes experienced the highest temperatures when the solar radiations fall on them and a porous slit positioned above the windows could act as a vent for hot air. The simulation proved that the location of the vents plays a vital role in determining the cabin environment and the velocity inlets can reduce the high thermal accumulation due to the incoming solar radiations.

A study on the thermal comfort inside the passenger car cabin by numerical model developed by Mezrhab and Bouzidi [10]. The model was created according to the nodal and the finite difference methods which defines the transient mode by taking into account the merged convection, conduction and radiation heat transfer, two solar fluxes (beam and diffuse) and the coupling of two spectral bands (short-wave and long-wave radiation). The rise of its temperature is based on the establishment of the heat balance for each node. The results indicated that the air and the materials reach considerable temperatures, as high as 100 ^{0}C, for the dashboard if the car parked facing the sun. The use of a reflecting glazing and a white colour of the bodywork of the car caused a reduction of the temperature inside the compartment.

The effect of solar radiation on the automobile environment through natural convection and mixed convection was performed by Kader, Jinnah, and Lee [11] by both experimental and numerical studies. The numerical analysis was done using Computational Fluid Dynamics (CFD) to investigate the flow field and temperature distribution within a full scale 3D model of a car compartment and on the windshield. The impact of the discharge from the defroster nozzle on the vehicle interior aerodynamics and radiation has been observed from the model. And, the solar radiation becomes an important parameter to raise the compartment temperature above the ambient temperature during summer. The rate of heat transfer is fast at the initial period during natural convection. Experimental are carried out to find out the local temperature at certain point and for further validation of the temperature contour on the windshield of the numerical results.

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Zhang et al. [12] studied the air-flow and temperature fields inside a passenger compartment to improve thermal comfort and save energy consumption. First, he carried out simulation on an automobile without passengers to investigate the temperature distributions and its variation trend. 3-D steady and unsteady simulation results inside the compartment were obtained by using FLUENT. Then, steady and unsteady states are calculated for the compartment with passengers. To validate the computational model and numerical simulation results, measurements were also conducted for transient situation and comparisons were made between predicted and measured air temperatures. The effects of outside temperature, vehicle velocity, conditions of inlet air (temperature, volume, and directions), vehicle thermal insulation and solar radiation were investigated. Meanwhile the cooling load of air conditioner and the amenity of passengers was analyzed in detail.

The variation in the temperature of a car parked in open space was studied by conducting an experiment on a Proton Saga car. The temperature at 4 locations of the car and the ambient temperature were measured using laboratory thermometers. The measurements were taken 3 times for three days to reduce uncertainty. For each day, the measurements were carried out from 11am until 4 pm. Table 1 shows the average temperature distribution of the car measured for three days.

Table 1: Temperature distribution of car

Time	Temperature (^{0}C)				
	Glass Window	Roof	Dashboard	Interior Car	Ambient Temperature
11 am	40.1	37.3	39.5	42.0	35.3
12 noon	42.0	43.8	44.4	46.2	36.6
1 pm	48.8	46.8	52.0	54.0	37.3
2 pm	56.9	55.3	58.5	60.2	38.9
3 pm	52.0	50.1	54.9	57.4	37.2
4 pm	43.7	42.8	45.0	48.7	35.4

3. EXPERIMENTAL INVESTIGATION

3.1. Fabrication of prototype model

Prototype model of car was fabricated using CPU casing of desktop computer. Two fans of the same size, which act as inlet air fan and exhaust air fan were fitted in front and rear side of the prototype model. The position of inlet air fan was placed lower than exhaust air fan. The material used for front and rear windshields is Perspex so that the solar radiation can penetrate into the model. The other material like zinc was used at the front and rear of the model to cover any openings. The LM 35 sensor was attached at the location near the window in the model. A microcontroller based program has been constructed in such a way that when the temperature inside the prototype model is greater than 35 ^{0}C, both inlet and exhaust air fans would be powered on by the battery to cool the model. The battery is automatically recharged when it is less than 12V using solar panel.

3.2. Data collection

The first experiment was performed when the system is not fully installed to investigate the temperature variation inside the prototype model, Figure 1(a). The temperatures were measured using thermocouples from 11.00 am until 4.00 pm. The experiment was carried out at the open parking lot. The second experiment was performed when the solar panel and the electric control circuit(ECU) were installed in the prototype model of the car. The temperature at the same location was recorded, Figure 1 (b).

4. SIMULATION

Simulation was carried out to study the flow distribution within the car and the interior temperature when the inlet and outlet fans are applied. The simulation was performed using ANSYS (FLUENT R15).

Fig. 1: Testing when the system is (a) not installed and (b) installed

4.1. Car cabin modelling

The geometry of the car model was prepared using Design Modeller. The model is based on the size of the passenger compartment of an ALTO car model. The inlet vent is drawn just below the rear window and outlet is taken below the front windshield. The position of inlet is lower than the position of outlet. The total volume of model is 4.2815 m^3 and surface area of 16.062 m^2 with 18 faces, 42 edges and 28 vertices. The model is shown in Figure 2.

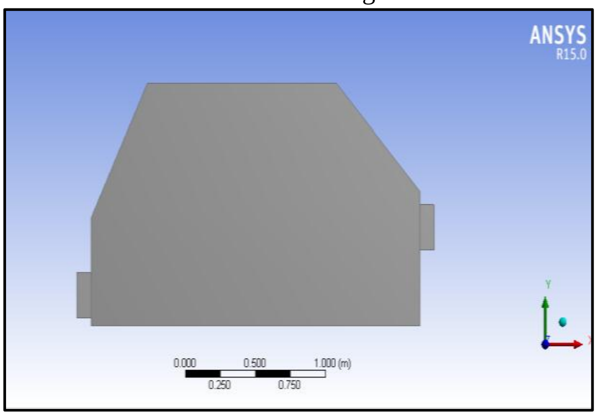

Fig. 2: Car cabin modelling

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4.2. Meshing criteria and boundary conditions

A patch conforming method was chosen for the algorithm and tetrahedral meshing was selected. The total number of nodes were 30336 with 158802 elements. The inlet was set to be below the rear windshield while the outlet was selected below the front windshield. The front and rear windshield, right and left side frame were designated as window. While wall was used to define the top and bottom surfaces of the car. The meshing is shown in Figure 3.

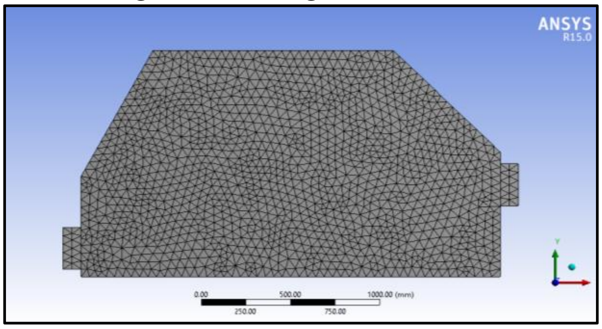

Fig. 3: Meshing

4.3. Solver

The solver used was pressure based type with an absolute velocity formation and a steady time. The energy equation was chosen and the k-epsilon was taken as viscous model with a realizable model and scalable wall functions. The surface to surface Radiation model was applied and Solar Ray Tracing was set on to analyze the problem.

The Sun direction vector has been computed from the solar calculator with the fair weather conditions and a sunshine factor of 1. The direct Solar Irradiation was set to 1423 W/m^2 and the Diffuse Solar Irradiation was set as 200 W/m2 for the Illumination parameters. The material properties of air were taken as constant. The specified operating density was defined in the cell boundary condition.

The inlet velocity was 0.65 m/s with initial gauge pressure of 25000 Pa at the temperature of 300 K. Meanwhile, a pressure outlet was chosen for the outlet and a gauge pressure was set to 0 Pa at an external backflow temperature of 300 K.

A stationary wall motion, no slip shear condition and constant wall roughness were considered for the momentum properties of the window. The thermal conditions are mixed (convection and radiation) with heat transfer coefficient of 28 $W/m^2.K$, free stream temperature as 310 K, external emissivity as 1 and an external radiation of 310 K. The windows considered in the solar ray tracing has Absorptivity of 1 and Transmissivity of 0.8. The materials were glass and semi-transparent BC types. For the wall, convection was chosen for thermal condition. Steel with heat transfer coefficient of 25 $W/m^2.K$ and free stream temperature of 300 K with internal emissivity 1 was considered as the wall material.

Simple scheme is adopted for pressure-velocity coupling. The spatial discretization is chosen as second order pressure, second order upwind momentum, and first order upwind for turbulent kinetic energy and dissipation rate. The hybrid initialization is employed and the solution is run for 300 iterations.

5. RESULTS AND DISCUSSIONS

5.1. Experimental results

The results of the car's temperature for the measurement period from 11.00 am to 4.00 pm are presented in the Figure 4. The interior of the car has recorded the highest temperature among the roof, dashboard and glass window. The peak hour is at 2.00 pm where all the surface measurements and interior showed the maximum temperatures. The temperature raised for glass window and dashboard are also significant compared to the roof's temperature.

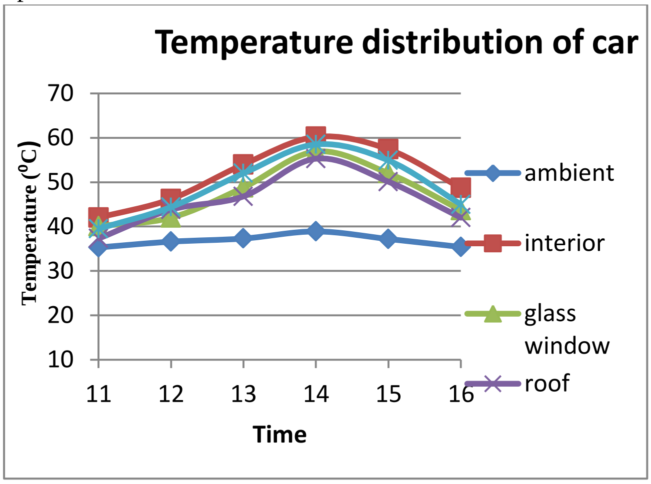

Fig. 4: Temperature distribution of car

Figure 5 shows that the temperature of the prototype model of the car increased compared to ambient temperature when the system is not fully applied. It can be observed that the results were of the same pattern with the real car temperature measurements. It is also observed that the interior temperature reduced and it reached close to ambient temperature when the system is fully installed in the model. Reduction of temperature is contributed by the air circulation by inlet and exhaust air fans in a way that the inlet fan would supply fresh air from outside into the prototype model while the exhaust fan would purge the hot air from the car model. The fans would continue to run as long as the temperature inside is greater than 35 ^{0}C.

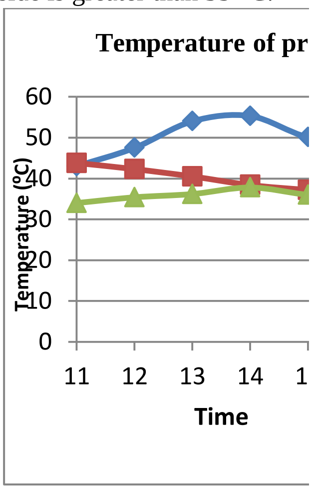

Fig. 5: Temperature of prototype model

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5.2. Simulation results

Figures 6 and 7 show the air flow distribution inside the car cabin model when the inlet and outlet fans were applied.

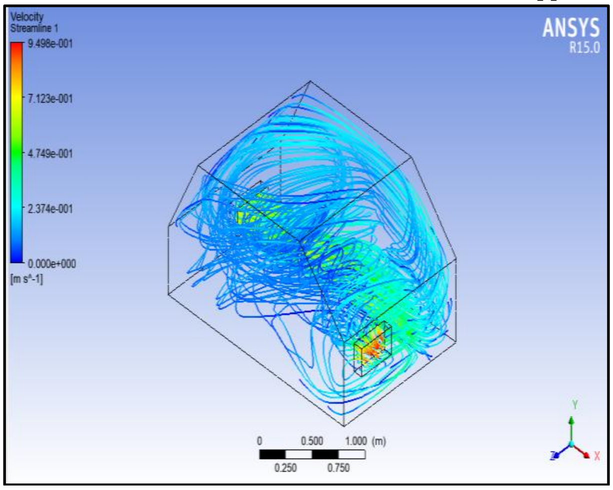

Fig. 6: Isometric view

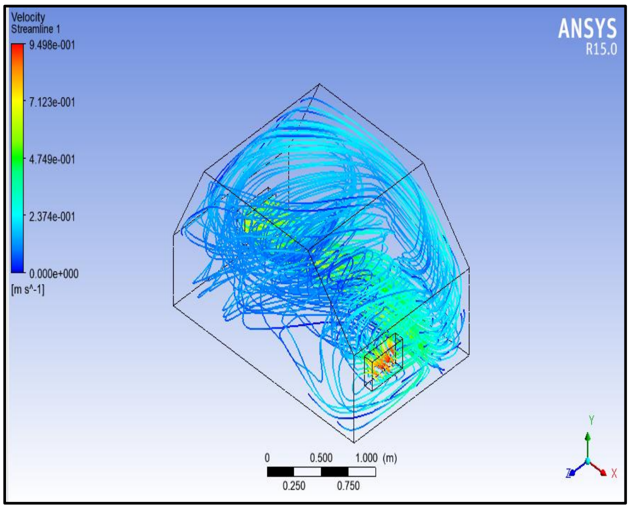

Fig. 7: Top view

Figures 8 and 9 illustrate the contours of temperature inside car cabin. From the figures, it can be observed that the temperature drops as it moved towards the centre of cabin. The blue colour recorded the lowest temperature which is about 301 K near the outlet. Hence, it can be deduced that the design of inlet lower than outlet has a better distribution of airflow and reduced the interior temperature effectively.

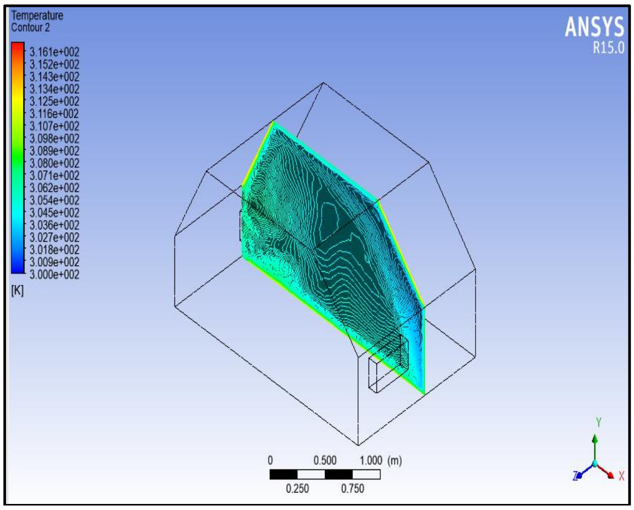

Fig. 8: Isometric view of interior plane

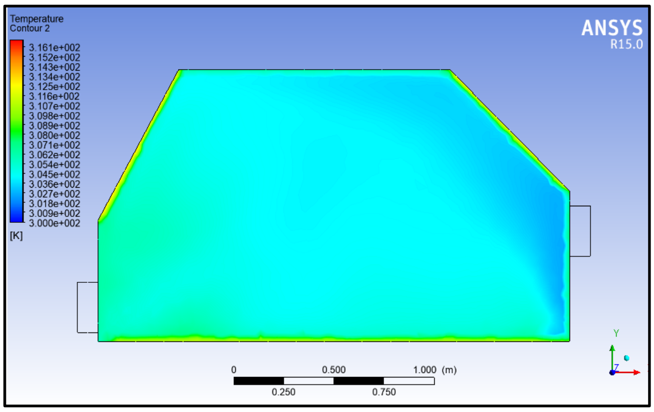

Fig. 9: Side view of interior plane

6. CONCLUSION

A study on the temperature distribution of the vehicle during parking had been carried out experimentally. The results show all the surface measurements recorded the highest temperature at 2.00 pm. The dashboard temperature is also the highest as it functions as a sink for solar radiation and source of heat convection to the adjacent air particles. The roof and glass window participated in both convection and radiation, which lead to the high temperature. The interior has the highest temperature between glass window, roof and dashboard which is 60.2 ^{0}C at 2.00 pm.

A system was developed and investigated with the aim to reduce the temperature of the car interior. The experiment was performed on a prototype model of the car using CPU casing. The system employs solar panel, battery, exhaust with blower fans, and electronic control circuit. It was observed that the temperature inside the car model decreased significantly to about 36.3 ^{0}C at 4.00 pm which is close to ambient temperature when the system is installed into the model. Also, it is noticed that the temperature is reduced about 2 ^{0}C every hour after both fans were powered on.

Simulation has been carried out to investigate the airflow distribution and interior temperature when the inlet and outlet are applied. The inlet and outlet represent the exhaust

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and blower fans that used for the experiment. The results exhibit that the airflow distributed throughout the car cabin with the position of inlet lowered than outlet. The interior temperature is also decreased about 301 K to 305 K compared to ambient temperature of 310 K.

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