

Cabin Temperature Control of a Parked Car through Forced Ventilation

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CERTIFICATE

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*Dedicated to
My parents and friends*

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Abstract

Temperature level in a car parked under direct sunlight rise up to 30°C to 40°C above the atmospheric temperature due to green house effect of solar radiation. Thermal Comfort of the passengers in a car is of major concern for car manufacturers as well as for passenger in peak summer season. Children and pets sometimes left unattended inside a parked car, even for short duration are vulnerable to heat stress and illness. Cooling loads also tend to increase with rapid rise in temperature once the car becomes hot. The material inside the car cabin is more prone to damages due to high temperature.

The main objective of present work is to control the temperature variation inside a parked car by rejecting the accumulating heat with the help of forced ventilation. This report includes the study of temperature variation inside the car cabin, while car is parked for long duration of 5 hours and for short duration of 15 minutes. Temperature variation was recorded with the help of thirteen different temperature sensors placed at different location inside the car cabin. The same was also verified with thermal imaging technique. Maximum temperature reduction is of 11-13 °C for cabin air, 24.4 °C for dashboard and 23.1 °C for the steering wheel. The experiments also found that air conditioner achieve the temperature of 32.7 °C in 15 minute from hot cabin at 50 °C with the proposed technique, whereas 39.9 °C was achieved in 15 minutes from 61 °C with the conventional system. The proposed system with auxiliary fans prevent the car cabin from high accumulating heat and facilitates the passenger to enter the cabin at much lower temperature.

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CHAPTER 1

INTRODUCTION

In the modern era of globalization and development, global warming has posed a major problem in day to day life. Our car has become an essential part of a person's life. Outside our homes our car is our home or living area. When we are not in our car, it is mostly parked outside. During summer when the atmospheric temperature is at its peak, cars tend to become very hot from inside and it is very uncomfortable for the driver and passengers to enter the car at a temperature of about 60°C to 70°C [1]. It takes a long time for the air conditioner to make a comfortable environment in the car and therefore results in less cooling and more ancillary loads during first 15 minutes of the drive. The air conditioner cannot cool down the cabin temperature of the car instantly; hence, this time needs to be minimized. It is very uncomfortable for the passengers to sit in an extremely hot environment for first 10 to 15 minutes in a closed cabin. We cannot increase the air conditioning capacity after some limit but surely we can make efforts to restrict the accumulating heat while car is parked under direct sunlight from a few minutes to few hours.

Passenger comfort and thermal comfort are the two aspects of an automotive industry which needs to be taken care of and optimised. For many years now much research has been done on the improvement on the thermal comfort inside a car, like improving the technology of the air conditioning by upgrading the type of refrigerants used in air conditioning unit.

At the same time there can be some initial measures which can be taken to improve the vehicle's thermal and air conditioning ancillary loads. Improving the air conditioning loads can lead to improve the fuel economy of the car. As summer is the hottest of all the seasons, during this season the atmospheric temperature (i.e. the temperature of the surrounding environment) is normally between 40°C to 50°C . This demands the use of air conditioners at their highest speed. The accumulation of solar radiation in a vehicle parked under the direct sunlight leads to rise in temperature of the interior cabin environment and other interior body parts like the dashboard, gear

lever, steering wheel, seat belt and seats. This rise in temperature needs to be controlled for improving the thermal comfort of the vehicle.

1.1 Background and Motivation

Many a times people use to park their cars under direct sunlight due unavailability of the covered parking space. Solar radiation enter into the cabin of the car via windshield, side and rear window glass by the means of convection and radiation and through the roof the car by the means of conduction. The radiation gets trapped due to the green house effect and increases the temperature in the car cabin which affects interiors of the car cabin such as the dashboard material, steering wheel, seat covers and the several components left inside the car. Due to the effect of solar exposure, average temperature in the car cabin becomes very high. Experimental readings show that the increase in solar radiation in the car can cause rise in temperature up to 70⁰C inside the car and up to 95⁰C on the dashboard of the car [2]. It becomes intolerable and uncomfortable for the passengers to enter and sit in the car with a cabin temperature of around 70⁰C. Moreover, the interior parts of the car need to be constructed from superior quality materials to sustain at high temperatures. There have been many cases of children and pets being left behind unattended in the car on a hot summer day leading to dangers of heat stress and illness which can be fatal and even lead to deaths. Moreover, many deaths have been encountered over the past few years in various parts of the world due to the rise in the cabin temperature of the car.

Hence, when a car is parked under the Sun, it has been a concern and an important aspect to cool down the temperature of the cabin of the car quickly and efficiently to improve the thermal comfort for the passengers.

1.2 Thermal Comfort

Thermal comfort and human comfort is more or less the same thing. It is the satisfaction level of any person in a thermal environment. It can also be stated as a sense of relaxation and a comfortable human thermal sensation in a thermal environment. Climatic conditions are an important parameter to which thermal comfort is sensitive towards. Thermal comfort has no absolute standard. In a vehicle, a comfortable environment is achieved when the human body comes in conjunction

with the thermal comfort. In cool conditions it is easier to achieve thermal comfort in a vehicle than in warm conditions. Thermal environment in passenger cars differs from those in buildings and is often highly non-uniform. Temperature is one of the main factors which affect thermal comfort apart from some important factors like air velocity, relative humidity, radiation, clothing, metabolic rate and other contributing factors like acclimatization, age and gender, state of health, etc.

1.3 Solar Heat Waves

The Sun is the major source of energy of our solar system. The energy produced by the Sun is by the process of nuclear fusion which is required to drive various systems like ecosystem, climate-system, hydro-system, etc. The electromagnetic radiation emitted by the Sun reaching the Earth ranges from the Ultraviolet (UV) rays to Infrared (IR) ray in the electromagnetic spectrum. Visible light is also included which lays between UV and IR radiation in the electromagnetic spectrum. Sun also emits Gamma rays and X rays which are absorbed by the atmosphere but eventually does not reach the Earth's surface.

The solar electromagnetic radiation that reaches the earth atmosphere has a spectral span of 100 nm to 1 mm. The solar spectrum is shown in the figure below:

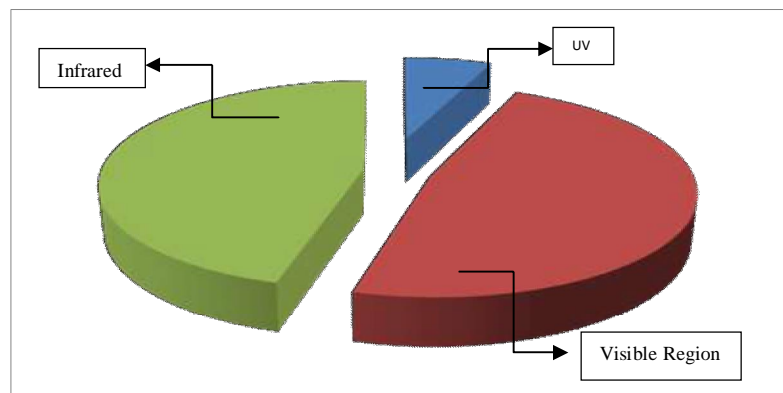


Figure 1.1 Solar spectrum

1.3.1 Electromagnetic rays emitted by the sun

- **Ultra-violet C (UVC):** It is short wavelength radiation ranging from 100nm to 280nm in the spectral span. It is the most dangerous form of UV radiation,

however, these are completely filtered by the atmosphere and do not reach the earth's surface.

- **Ultra-violet B (UVB):** It lies between 280nm and 320nm in the spectral span. It affects the top layer or epidermal layers of the skin and is highly dangerous and becomes main cause of skin reddening, tanning, sunburn and skin cancer.
- **Ultra-violet A (UVA):** It lies between the wavelength range of 320nm and 400nm in the spectral span. It penetrates the skin deeper than the UVB and is more vulnerable to the skin leading to premature skin aging, wrinkling, damaging of skin tissues, skin cancer and cataract. Immune system of the body is also affected.
- **Visible Light:** It ranges from 390 ó 700nm in the spectral span. Apart from being visible to the naked eye, it does not have any major harmful effects to the human body.
- **Infrared (IR):** It ranges from 700 ó 1mm in the electromagnetic spectrum. Like the UV radiation, these are also not visible to the human eye. Infrared is emitted by almost all objects.

1.3.2 Direct and Diffuse Solar Radiation

Solar energy that reaches the earth is further categorized in the form of direct and diffuse radiations.

- **Diffuse:** As the visible light passes through the Sun's atmosphere it gets reflected, scattered and absorbed by various elements such as the clouds, pollutants, dust, air molecules, etc. This radiation is known as diffuse radiation.
- **Direct:** The portion of the sunlight which does not get diffused and reaches the earth is known as direct radiation. On a clear, dry sunny day, the atmosphere can block up to 10% of direct radiation whereas this can reach up to 100% on very thick cloudy day.

1.4 Modes of Heat Transfer

Dissipation of heat is the basis of heat transfer which means that it is the exchange of heat from a high temperature medium to a low temperature medium. Temperature and

pressure are two aspects on which exchange of thermal energy between physical systems is dependent. Heat transfer in the cabin of the car takes place due to the green house effect and the accumulation of heat in the interior of the car which needs to be dissipated out of the car. Heat transfer takes place through the following three fundamental modes:

- **Conduction:** It is the mode of heat transfer or exchange of thermal energy within solids or when two solid bodies come in contact with each other. It occurs due to transfer of energy from fast moving and vibrating particles (atoms and molecules) when they interact with their neighbouring particles when heated upon.
- **Convection:** This mode of heat transfer takes place between a fluid medium (liquids or gases) and another medium. Fluid matter is needed in this case for the heat transfer to take place when the heated fluid progresses away from the source of heat transfer, carrying energy with it. Convection can be of two types namely, natural convection and forced convection.
 - a. **Natural Convection:** In the process of heat transfer through convection, the mechanism in which the motion of the fluid is due to density difference caused by the temperature gradient between solid and fluid and no external force is required to cause the fluid to flow. It is also termed as free convection.
 - b. **Forced Convection:** It is the mechanism of heat transfer which leads to the motion of fluid by the use of external force like a fan, pump, compressor, slope, etc. This method is used to efficiently transport a significant amount of heat energy.
- **Radiation:** It is the mechanism which uses the concept of electromagnetic waves for the transfer of heat energy. As electromagnetic waves are emitted from each and every surface of this earth, no material medium is required for the transport of thermal energy in case to heat transfer through radiation. Thermal energy is carried and transferred by these propagating electromagnetic waves in the form of small packets when they impinge on a surface or body. Any matter or even vacuum can be used for the transfer of heat through radiation.

1.5 Temperature Variation

Temperature variation occurs when there is a certain rise or fall of temperature in a cabin, compartment, building or any other place. In most parts of the world, area of concern is the temperature rise and not temperature fall.

The temperature rise in a car takes place due to the following reasons:

- **Green house effect** ó Solar radiation (of all wavelengths) from the Sun which is incident on the car is either reflected or absorbed hitting the external metal surfaces. There are basically two types of solar radiation, light (short wavelength) radiation and thermal (long wavelength) radiation. The property of transparency of glass to light radiation but on the same account being opaque to thermal radiation plays an important role. As Sun's rays, primary heat input during the day reaches the surface of a car, are transmitted into the cabin through the windows, the glass of the car absorbs a little portion of the sunlight. This absorbed radiation is converted into heat by the dashboard, the seats, floor, steering wheel and the interior of the car. When almost all of the (short wavelength) light radiation entering the vehicle is absorbed, they are converted into (long wavelength) thermal radiation. As a result, the thermal radiation thus generated is trapped in the cabin of the car since the windows as well as the vehicle interior are opaque to it leading to the rise the temperature of the car.
- Direct radiation and indirect sky radiation which occur due to scattering from the winds and particles in the sky, and additionally cloud cover and humidity also greatly affect the amount of radiation reaching the Earth.
- The energy absorbed by the Sun literally pours through the windows and it is absorbed by all it touches which increases the thermal loads of the car.
- The solar glazing of a car is kept tilted to a certain angle which tends to increase the amount of radiation reaching the cabin of the car.

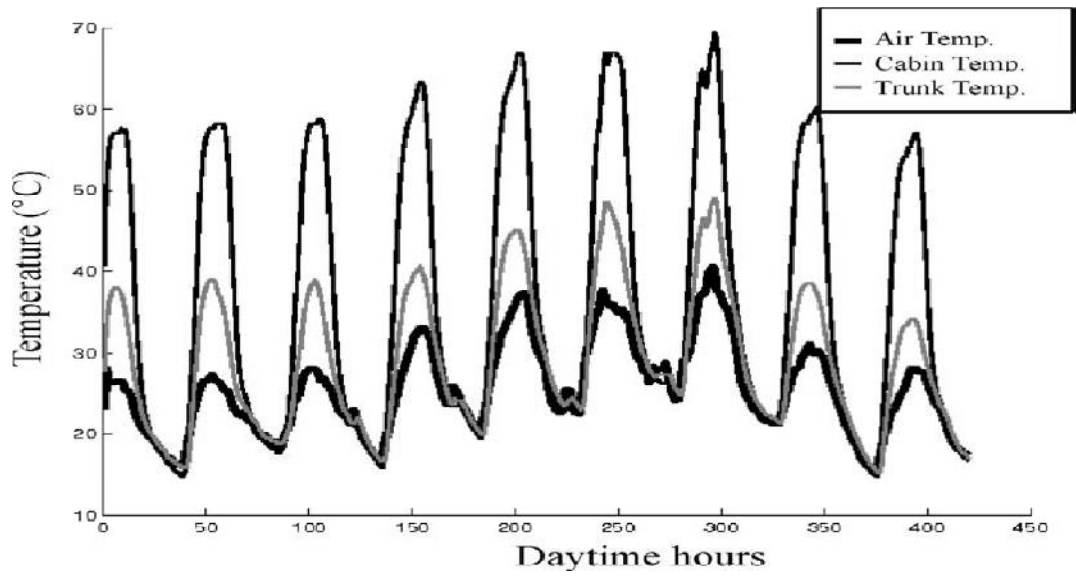


Figure 1.2 Outside air temperature (the lowest curve), Temperature measured in the trunk (middle curve) and the cabin air temperature (upper curve) over a 9 day period [1]

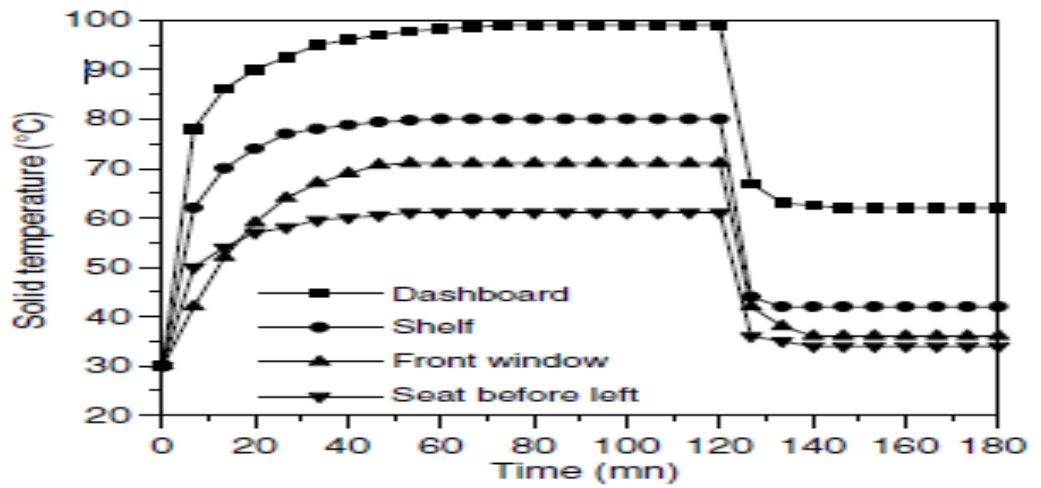


Figure 1.3 Variation of solid temperature vs. Time [3]

1.6 Technologies used

There are many technologies which can be used for controlling the temperature variation and preventing the solar radiation from entering into the cabin of a car thus reducing the rise in temperature. All of these technologies have some pros and cons which are explained below:

- **Solar reflective glazing**

These are solar control glasses which prevent the solar radiation entering into building in which solar reflective glazing is used thus, reducing solar heat gain and providing a comfortable and pleasant environment. These have good reflectivity to provide a cool and relaxed environment. They reduce heat up to 80% [4] and can even eliminate the use of air conditioning system. Their high cost and a reason in increasing global temperature make them ineffective to be used in cars.

- **Solar reflective shells**

These refer to the opaque parts of the car such as the bonnet, trunk lid, and doors. Depending upon the solar reflectance, they can decrease cabin temperature by 2-5°C [1] as well as help in reducing the air conditioning loads [3]. This technology is not very efficient as the reduction in temperature do not satisfy the needs of the passenger.

- **Window shading**

It is also called as *window tinting* which is a thin film coating installed to the interior of glass surfaces of automobiles. They help in reducing the amount of Infrared and UV rays entering through the windows of cars. There has not been much support for window tinting in today's times as dark tinted cars are sometimes looked at with suspicion as large number of illegal activities have taken place using these vehicles, therefore demanding stricter regulations from the local law. As a result, it is banned in some countries across the world, including India.

- **Ventilation and infiltration**

Infiltration refers to the unintentional and inadvertent introduction of outside air into a cabin of a building or a car for example through the doors of a car.

Ventilation refers to the intentional introduction of air into a cabin of a building or a car. Choosing appropriate ventilation and infiltration rates to solve thermal comfort and to reduce energy consumption can affect indoor air quality. There are two types of ventilation processes viz. Natural and forced ventilation. Natural ventilation occurs when pressure differences are produced naturally or artificially like ventilation through windows, doors and grills. Forced ventilation is produced by the use of fans and other external medium for the in and out movement of air. Forced As stated in the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) fundamentals, the most effective method of controlling flow of air exchange is through forced ventilation.

For the purpose of the research work, forced ventilation holds an upper hand as compared to natural ventilation due to dangers of theft, entering of rain and formation of precipitation which may damage the contents.

1.7 Organization of Thesis

This thesis incorporates a total of five chapters. A brief outline of these chapters is mentioned below:

First chapter comprises of the introduction part which includes the background and motivation behind doing this thesis work, reasons for the variation of temperature in the cabin of a car, modes of heat transfer, technologies used for the control of rise in temperature and types of solar heat waves.

Second chapter comprises of the literature review which has been studied in the course of this thesis work. It includes what advancements and technologies have been used so far to control the cabin temperature of a car. It also includes the literature gap of the literature review.

Third chapter comprises of the methodology, process and procedure in which the manner of the research work has been done, experimental setup of this research work, detailed description of the equipments used, working of the model.

Fourth chapter includes the results and discussion of the thesis work.

Conclusion and future scope of work are included in the fifth chapter.

CHAPTER 2

LITERATURE REVIEW

The following chapter highlights the work that has been done previously in the field of vehicle thermal and passenger comfort by controlling temperature variation. In this context, a brief description of certain existing topologies has been explained. It explains the technologies and methods along with their advantages, disadvantages and applications that have been used by numerous researchers all over the world. This chapter reviews the previously published literature in this area, which lays foundation and basis for further work and investigation. This helps to give a better understanding of the topic and also acts as a guideline for the present work. This chapter concludes by identifying the literature gap and formulating the problem as the starting point for further analysis.

2.1 Investigation

Dadour *et al.* (2011) [1], conducted a research on estimating the temperature variation in a parked car using available metrological and weather bureau data. This research work was conducted for merely two reasons. One of which was to determine the time of death of suicide or homicide victims inside vehicles and second reason being the investigation of serious threat to children's and pets' lives, left unattended in a vehicle parked in hot days of summer. Temperature levels inside the cabin of a vehicle can reach about 20°C above the ambient temperature when a car is parked under the Sun. Various experiments were performed on two different sedans considering different conditions such as the vehicle location and orientation, status of windows whether they are opened or closed, and vehicle type and colour. Development of a 'greenhouse model' was incorporated to predict the temperature variations in the vehicle on a daily basis. Experiments and readings were taken over several summer seasons using the metrological and collected data on temperature in a parked vehicle. Radiation data and environmental data are considered as input parameters.

It was concluded that the temperature inside a black vehicle was higher by 5°C as compared to that in a white vehicle due to the relatively higher absorptivity of the black surface. It was also seen that lowering down of the driver's side window by 2.5 cm and 5 cm can reduce the maximum temperature in the car cabin by 3°C and 6-7°C respectively. The calculated results can be used to evaluate the heat stress levels in children and pets left in cars which can help in establishing the safety limits.

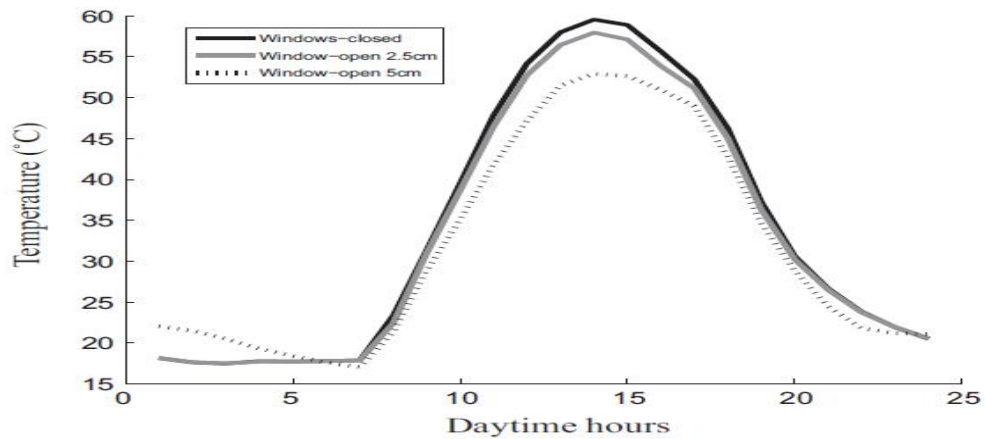


Figure 2.1 Ventilation effects (Ford Sedan) [1]

Al-Kayiem *et al.* (2010) [2], conducted the experimental and numerical analysis of study on the thermal accumulation and distribution inside a parked car cabin. Experiments were done on a car parked in an unshaded area. The research work involved the investigation of six different cases which consist of closing of all the windows of the car, four cases of opening the windows one after the other on different occasions and using of sun shade case. 12 different locations inside the car were chosen for the temperature to be recorded. Out of these 12 locations, 3 locations were chosen for the record of the air temperature and 9 locations were chosen for the record of the surface temperature distribution in the cabin. The experiments were performed for many days and mean values were used as boundary conditions for the 3D computational simulation to run successively. FLUENT was used for the CFD simulation.

Through the experimental results and CFD simulation it was observed that for the air temperature measurement the major part of accumulated hot air was in the cabin extreme top part and simultaneously for the surface temperature measurements the maximum temperature was on the dashboard in the interior and spots near the front

and rear windshields which were directly exposed to the transmitted solar radiation. It was also found out that 20% of the front air gap was reduced by lowering down the front side window by 20mm. A considerable amount of reduction was observed in the accumulated heat inside the cabin by drop down of front side window. From the CFD simulation results it was revealed that the dashboard acts as a sink to the solar heat radiation and at the same time as a source to the adjacent interior parts of the car cabin. Usage of sunshade on the front had reduced the dashboard surface temperature and the maximum air temperature inside the car cabin by 26% and 27% respectively.

Mezrhab and Bouzidi (2005) [3], gave a description of a model by doing the numerical analysis of the study of presence of thermal comfort in the interior compartment of a car. The numerical model was based on the climatic conditions and the material that constitute the car. The numerical model developed in based on the finite difference method and the nodal method where the compartment of the car has been split into various solid and fluid nodes. The solid nodes are the material medium which the interior car compartment is composed of and the fluid nodes are the volumes of air inside the compartment. In this paper a theoretical support of the developed numerical model has been described. Experiments have been performed in a compartment of a car which is parked in sunny conditions under direct sun and when it is in running state with the air conditioner switched on. Investigation of the effect of types of glazing, solar radiation and car colour has been done in this paper.

It has been concluded that when a car is parked in direct sunlight, the temperature in the cabin reaches a considerable amount such as about 70°C in the interior and about 100°C on the dashboard. Reflective glazing and white coloured car can reduced the temperature inside the car cabin to a considerable amount. Thirdly, when the car is running with the air conditioner switched on, the solid nodes temperature decreases, which are directly exposed to the blast of cold air.

Levinson et al. (2011) [4], performed an experiment on the study of the potential benefits of using solar reflective car shells. The study focuses on the reduction of soak or absorbed temperature of the air in the car cabin, reducing the vehicle's thermal and ancillary loads, decrease in fuel consumption and fuel economy improvement as well as emission reductions.

Experiments were performed on silver and a black coloured car due to the difference in their reflectance properties. Different zones were taken inside and outside the body like the roof, ceiling, door, windshield, cabin air, etc. where the temperatures were recorded according to the theoretical model developed. A thermal model was developed for the prediction of the AC capacity to cool down the cabin of the car within first 30 minutes. Calibration of AC was done with trials of indoor cooling and heating. Fuel consumption and emission of pollutants were estimate by a vehicle simulation tool named as ADVISOR.

It was concluded that according to the thermal analysis done, the required capacity of the air conditioning to cool the cabin of silver coloured car was 13% less as compared to that of a black car. The reflectivity of black coloured car was found to be 0.05 which was much less as compared to that of a white coloured car which was 0.58. The thermal model predicted the time required to cool down each vehicle to a temperature of 25°C was to be 30 minutes. To achieve the desired cooling, the AC cooling capacity of black car should be 3.83 kW and that of the white car should be 3.34 kW. It was also concluded from the ADVISOR simulations that use of a cool coloured shell instead of a black shell reduced fuel consumption and increase fuel economy by 1.1 % and use of a white shell instead of black shell reduced fuel consumption and increase fuel economy by 1.9 % and 2% respectively.

Grundstein and Meentemeyer (2009) [5], performed an experimental analysis on examining the maximum vehicle cabin temperatures under different weather and metrological conditions. A unique temperature dataset was formed in conjunction with solar radiation, cloud cover and ambient air temperature data. The research work consisted of building of a dataset on a daily basis constituting the maximum cabin temperature, solar radiation, cloud cover and maximum ambient air temperature. The experimentation was done for 58 days out of which 42 were clear days and 16 were cloudy days. A gray Honda Civic was used for the experiment. The car was parked in an unshaded area with direct sunlight impinging on the car. HOBO temperature sensors were used to collect the car temperature data which were calibrated to give the temperature readings after every 5 minutes. In addition to it, two models of maximum daily car cabin temperature were developed adopting the available weather and metrological data. One model was for determining the maximum car cabin air

temperature and the daily solar radiation on an average. The other model was formed for the cloud cover data was used to determine the rise in the vehicle compartment.

It was concluded that the maximum temperature inside the car cabin would vary from 41°C to 76°C under different metrological and weather conditions. On an average, in clear days the temperature inside the vehicle would reach 68°C in summer and 61°C in spring and on the other it was observed that it was 10°C cooler in both the seasons on cloudy days. It was also observed that dangerous levels of temperature could reach inside a car cabin even with ambient air temperature in cloudy days. Temperature inside the car cabin is increased by an average of 22°C over the ambient air temperatures. Even on the coolest day the temperature inside the car cabin was recorded as 47°C when the ambient temperature was 22°C.

Table 2.1 Maximum vehicle cabin temperature index using solar radiation and maximum ambient air temperature

Maximum Ambient Air Temperature (°C)	40	57	59	60	62	64	66	68	69	71	73	75	77	78
	38	55	57	58	60	62	64	66	67	69	71	73	75	76
	36	53	55	56	58	60	62	64	65	67	69	71	73	74
	34	51	52	54	56	58	60	61	63	65	67	69	70	72
	32	49	50	52	54	56	58	59	61	63	65	67	68	70
	30	47	48	50	52	54	56	57	59	61	63	65	66	68
	28	45	46	48	50	52	54	55	57	59	61	63	64	66
	26	43	44	46	48	50	52	53	55	57	59	61	62	64
	24	40	42	44	46	48	49	51	53	55	57	58	60	62
	22	38	40	42	44	46	47	49	51	53	55	56	58	60
20	36	38	40	42	44	45	47	49	51	53	54	56	58	
		200	250	300	350	400	450	500	550	600	650	700	750	800
		Average Daily Solar Radiation ($W m^{-2}$)												

Nakagawa *et al.* (1999) [6], described the construction of a prototype of an automated ventilation system that helps in the prevention of intake of exhaust gases coming from foreign vehicles while driving, to delve into the applications of various gas sensors. Investigation of the sensing characteristics of sensors was done. Gas sensors have an ability to judge the pollution level to control the intake of fresh and natural outside air. Three metal oxide semiconductor type gas sensors were used which included two sensors for the detection of CO/HC and NO₂ and one odour sensor for supervising the inside air quality. This research work also included an investigation of humidity effects as humidity interference cannot be neglected.

Experiments were performed in two small sedan type cars with different running and parking conditions. Position and placement of these gas sensors were such that the CO/HC sensor and NO₂ sensor were located at the entrance of the intake air and the odour sensor was placed under the dashboard to monitor the indoor air quality. The entire ventilation system was controlled by a microcontroller which was connected to the three sensors. The polluted air introduced into the system was removed by the use of an exhaust valve and an exhaust fan.

The work was concluded with a demonstration that to avoid the intake of polluted air and exhaust fumes the constructed system was well suited and effective. It was also seen that the sensitivity of the gas sensors used had satisfactory results with a backdrop of the shortcomings of humidity interference.

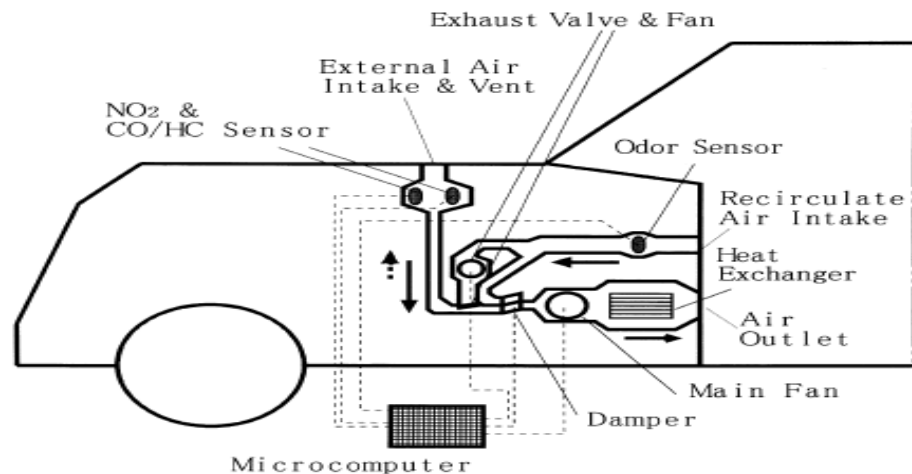


Figure 2.2 An automated ventilation system

Parisi and Kimlin (2000) [7], presented the study of annual ultraviolet-A (UVA) exposures in four cars in Australia by computing the UVA irradiances in four different seasons of a year. This research work was done due to the fact that UVA can be more harmful than UVB radiation and its harmful should not be underestimated. Four different zones inside a vehicle were chosen for the experiments to be performed upon. Among the four cars one was a small type family car while other was a normal family size car with tinted and untinted windows taken as different cases. Experimentation was done during the hours of 9:00a.m to 3:00p.m as this the time period of a day has the highest level of UV irradiances. An unshaded open field area was selected for the research. The measurement of the radiation was done in each of

the four cars with all four orientations being the front of the car facing the north, south, east and west.

It was concluded that the zenith angle was the major parameter on which the concentrations of UVA inside the vehicles was dependent on. It was observed that cars with tinting had minimum amount of UVA irradiances inside the compartment of the vehicles as compared to other cases. It was also seen that at noon when the heat of the sun is at its peak, the UVA irradiances did not necessarily reach its maximum value as was expected. It was shown that the UVA exposure ranged between 1918 and 6177 J.cm⁻² for cars with no tinting and between 489 and 2969 J.cm⁻² for cars with window-tint. For cars without window tint, the percentage corresponding to the outside UVA exposure was about 5% to 17% and for the cars with window tinting, the percentage corresponding to the outside UVA exposure was about 1% to 8%.

Table 2.2 UVA exposure in individual type and zone of car

Car	Annual UVA exposures (J.cm ⁻²)			
	Front	Sides	Side	Rear
FT	2969	508	564	489
FT	2624	6177	2889	5473
FU	2894	3238	1918	2850
S	3706	5680	2301	6210

Jamekhorshid and Sadrameli (2012) [8], explained how the use of Phase change materials (PCMs) can maintain a comfort environment and temperature inside an automobile. An innovative system has been modelled for the control of temperature using PCM in the cabin of an automobile parked facing direct sunlight as well as the amount of PCM required for the removal of heat from the car cabin has been determined. A pouch containing a very thin layer of PCM was placed in the ceiling or inner roof of the car. PCM is a heat storage system which absorbs heat energy on melting and releases heat energy on solidification therefore, maintaining as controlled temperature in the compartment of an automobile. It is a zero power usage means to decrease the temperature fluctuations for both cold and hot seasons. Among more

than 500 types of PCM, paraffin was used for the experimentation because of its melting point ranges which falls in human comfort conditions.

When the cabin temperature of the car reaches higher than the melting point of PCM, it absorbs heat energy from the environment and maintains the temperature in the cabin to a cooler state. On the other hand, when the cabin temperature becomes lower than the PCM melting point, it releases heat energy by solidification. A foam placed between the PCM layer and the metal surface of the car body prevents any heat exchange with the outer environment.

The research work was designed to maintain the temperature of the car compartment at about 35°C. The required amount of PCM used was calculated to be about 755g.

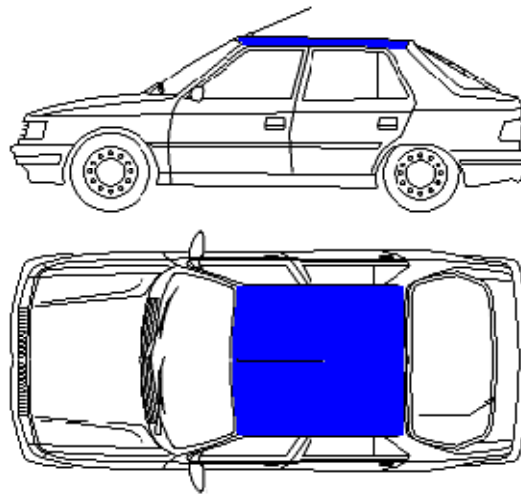


Figure 2.3 Placement of the PCM layer

Kodak (2004) [9], described a ventilation system for the interior heat of an automobile. An easy and inexpensive solution to the build-up of enormous heat in the interior of an automobile was described. For the interaction of interior air with the exterior air, a series of vents were placed in the lower. Interior vents are for the intake of outer cold air and the exterior vents are for the exhaust of inner hot air. The location of the vents was based on two important characteristics which were, need of direct and short access to exterior air and shelter from rainwater. Vents were in conjunction with a cover attached to it which was necessary to minimize air blockage and prevent injury.

The location of the interior opening of the vents was chosen on lower front part of the rear seat based on the criteria that the distance between the openings of air ducts should be less than 6 inches. The vents were operated by a solenoid powered by the car's battery for their automatic opening and closing. A heat sensing device was placed in the interior of the automobile which controlled the opening and closing of vents based on the threshold temperature in the automobile cabin. The vents were to remain closed until the temperature recorded in the heat sensing device was below 95°F and as soon as the temperature reached 95°F the vents were opened automatically by the solenoid. When the temperature dropped to 85°F the vents were again automatically closed.

Gordon (1935) [10], explained an arrangement for cooling the interior cabin of a car by providing a ventilating system in the seats. The invention was based on the objective of ensuring passenger comfort and cooling of the surface of the seats by delivering streams of air beneath all the seats of an automobile. Independent air compartments were provided on the seats with connecting pipes leading to the front of the vehicle where shutter controlled air inlet was provided for the intake of air through it. Another objective of the invention was to keep the seat covers cool and warm depending on the passenger's mood by providing an air distributor beneath the seat covering through which uniform distribution of cool and warm air could take place. This research work was done to improve the class and quality of the interior parts of an automobile so that their efficiency, durability and utility could be improved.

Werdehoff (1944) [11], described the invention of a system which accepts the intake of fresh air to a heating unit which is located in the lower framework of an automobile, between the vehicle passenger seat and the floor. A section of the vehicle frame was utilized for the intake of fresh outside air which was headed to the heating unit. The objective was to effectively heat the rear and front passenger compartment. The apparatus included a heating unit, a hollow frame side rail, various conduits, a duct and a cross member..

A cooling system was provided in the IC engine where the cooling medium such as water was made to circulate. The cooling medium was made to circulate in the heat exchanging core placed in the casing of the heating unit.. An electric motor as used to drive a fan connected in the heating unit. The air was passed as an intake through a

tube supported in the front of the car passing through a cross member to a duct which was connected to a conduit which was in turn connected to one end of a side rail. This air was passed into the vehicle compartment and was able to heat the entire compartment of the car.

Otsuka (2000) [12], designed a system in which the shock energy could be absorbed from an air duct placed in a vehicle due to its plastic deformation in case of a collision and thereby preventing the passengers from injury caused by the collision. This absorbed shock energy was used for the passage of air flow from the air conditioner to the rear compartment of the vehicle. Formation of a pipe like air duct made up of hard aluminium foil and covered by a non-metallic material such as kraft paper was placed between an inner and an outer panel in the body of a vehicle, progressing to one end of a blow off port in the rear seat.

A circular cross sectional shape was chosen for the air duct which was made up of four layers out of which the outermost layers were of kraft paper or high polymer material and inner intermediate layers were made up of hard aluminium foil. Piles are placed on one of the duct to prevent and absorb the generation of noise due to the vibrations caused in the vehicle during running. Due to increased flexibility of the air duct, it can be laid to curved sections as well as sections with some irregularities. The air duct commences from the cooling unit or the air conditioner and is laid from the side rail panel to the rear seat. In a one box type automobile in which the interior cabin is divided into three sections has a dual air conditioner and the air duct extends up to the rear part connecting the air conditioner which is located in the middle portion of the automobile.

Chen (1991) [13], described the invention of a vehicular internal fan ventilator where solar power was used to energize a motor and charge a storage battery which in turn would start a cross-flow fan for the ventilation of the inner chamber of a vehicle. The invention was based on the objective of easy installation and operation of the system, minimizing space consumption, utilization of the method of cross ventilation by using cross flow fan, mounting of the solar board obliquely and externally on the car window for the effective collection of solar energy.

The housing consisted of a retainer rib and window glass channel as the main components apart from an air inlet and, air outlet and an air exhaust. The retainer rib

was placed in the window receiving channel and the window would be laid to the window glass channel provided below the retainer rib when the window was lifted to be closed. Once the installation of the housing was done, a flexible packing strip made up of rubber was used to seal the gap left between the window glass and the upper frame of the door. The packing strip was composed of a retainer rib and a window glass channel for the installation into the window receiving channel of the vehicle. A sliding cover was provided to cover the air outlet and air exhaust simultaneously for the ventilating of the inner chamber of the vehicle. The covering of air outlet would allow the air to pass out of the vehicle from the air exhaust and the covering of air exhaust would allow the circulation of air in the vehicle cabin.

It was concluded that the invented model was easy to install and operate and the shown ventilating system could be installed in different window sizes and different vehicle models.

Chuang (1989) [14], explained a system for automatic ventilation of a closed cabin such as a vehicle compartment for the circulation of air until a formation of precipitation was sensed. A command for opening and closing of venting system as soon as precipitation was sensed was given by the means of an electric drive. The system was also based on the objective of automatically controlling the windows and sunroof, and utilization of existing vents of a vehicle.

Three forms of electric means were provided namely, a drive means for controlling the venting elements, a control means for the sensing of precipitation and temperature when the temperature has reached a threshold limit and a time means for commanding the control means to close the venting elements when a predefined time has elapsed. The control means was to command the drive means to open and close the venting system depending on two modes. The vents of the venting system were programmed to open as soon as the temperature inside the cabin reached above a threshold temperature and to close as soon as the precipitation was sensed. An intruder control means was also present which would set the control means to second on detection of an intruder.

Browne (2011) [15], has invented a fan system mounted on the roof of a vehicle describing the adoption of ventilation to regulate the rise in temperature. The fan system was based on driving a fan for the displacement of hot air from inside the

vehicle to the atmosphere. The fan system comprised of an energy harvesting system, a fan, a vent, a vent actuator, two fluid regions with different temperatures, a battery, a flywheel, a shape memory alloy wire, a vent shaft. One fluid region was within the vehicle and another fluid region was outside the vehicle. The energy harvesting system was located between the two fluid regions and was used to drive the fan by any of three methods which were, by acting as a heat engine and converting the thermal energy to mechanical energy and activating the shape memory alloy to drive the fan, by acting as a piezo-based vibrational unit and converting the vibrational energy to mechanical energy and driving the fan, and by responding to the temperature difference between the two fluid regions to drive the fan by acting as a heat engine.

The energy from the output of the energy harvesting system was stored in the battery and charges it throughout the process to drive the fan. An alternative method that was proposed to drive the fan independently was use of a flywheel which would also store the energy from the energy harvesting system. The battery could be controlled by a controller which had switches to disconnect the battery from the energy harvesting system to charge it. A governor was used to convert the mechanical energy to electrical energy to charge the battery. Vents were located between the two fluid regions for the flow of hot from one fluid region to the other and make the former cooler. Movement of the vents were actuated by an actuator which in turn was connected to a vents shaft and a shape-memory alloy wire for the closing and opening of vents.

It was concluded that the fan system would activate when the temperature difference between the two fluid regions would reach 5°C.

Kajimoto *et al.* (1990) [16], described an invention which is related to a vehicle equipped with a solar battery for the production of electrical power, a plurality of actinometer for the detection of the amount of solar radiation striking on the body of the vehicle, a controller for generating an alarm signal when the result of comparison of detection of the amount of solar radiation and the output of the solar battery gets out of hand or a predetermined condition, and a warning device which was situated in the cabin for warning the driver or passenger in case a bug or a fault is found in the storage battery and it is not able to work and produce electrical power effectively.

The position of the front actinometer is situated in the lower fragment of the front windshield and the rear actinometer is situated near the lower part of the rear windshield. The operation of the controller is based on the comparison of the solar battery output with the maximum value of detection of solar radiation among both the actinometers. A driving circuit was connected prior to the warning device which generates an alarm signal. The warning device comprises of a warning lamp which is situated on the dashboard panel giving a visual signal as a feedback to the alarm signal.

Lefevre (1974) [17], described an invention which explains an automatic device to control the movement of the shutter combined to a fan body as a relation to the relative speed of the vehicle with respect to the neighbouring atmosphere. When a vehicle is moving, the speed of a ventilating fan and the angle of the shutter opening should be adjusted automatically in relation to the speed of the vehicle relative to the wind. The control device being situated in the shutter itself was controlled by an adjustable rod flexible in length. One end of the rod is connected to a movable wall of a vacuum chamber which is controlled by the action of three springs and bending of bellows and the other end is connected to a movable part of a rheostat. Assuming a low speed movement of the vehicle, the relative wind flows through a duct as well as through a venture choke situated at the front of the car. As a result, a reduced vacuum and a negative pressure is created in the vacuum chamber and the movable wall is moved towards the fixed wall leading to the movement of the movable rod towards the movable wall of the vacuum chamber carrying along the rheostat with itself. This causes the closing of the shutter of the fan.

It was thus concluded that the speed of the fan driven by the motor decreases with the decrease in the distance between the vacuum chamber and the rheostat, and increase in the relative speed of the vehicle.

Schurle *et al.* (2005) [18], explained an air treatment module for the air intake into a vehicle interior to be thermally treated. The air treatment module consists of a support arrangement to which two heat exchangers arrangement, a fan arrangement and a heating device is supported. The support arrangement is formed in such as way that it looks like a housing and contains an outlet region for flow of air into the vehicle interior. The vehicle interior and the engine space are separated by a fire barrier. The

fuel used to drive the engine heat exchanger or the heating device is used for the transfer of heat of combustion to the first heat exchanger via a hose pipe. The fluid flows from the outlet of the first heat exchanger to the inlet of the second heat exchanger where its heat energy is transferred to the air entering into the second heat exchanger via the fan arrangement and this air is then distributed to the vehicle interior to heat it up. This fluid then goes to a duct system connected to a drive unit from where it goes back to the inlet of the first heat exchanger and the cycle continues.

It was concluded that it was also possible to provide a cooled air into the vehicle cabin by passing a hot air into the second heat exchanger which transfers its heat to the fluid thereby becoming cool.

Lino (2001) [19], described a ventilation system for a car window which was composed of a fan unit, a ventilating function for the prevention from entering of dust and rainwater. The ventilation system was flexible enough to be installed in any shape and size of different types of cars. The invention gave the passengers an option to weather only allow natural ventilation of fresh air or usage of a fan for ventilation or weather to provide a housing with sunshade.

The ventilation system made use of blocking plates by simply cutting material out of transparent resin for use in different types of windows and cars. The blocking plates were used to attach the ventilating system with the frame of the car window and the upper edge of glass of the window. A cover plate was used in the ventilating system over the cover frame where the airflow members were attached for the maintaining the quantity of flowing into the vehicle.

Gillick *et al.* (1966) [20], invented a new and an improve system for heating and ventilating a vehicle by maintaining a positive pressure in the cabin of a vehicle to prevent the inner cabin of the vehicle from dirt and reduction of excessive hot and cold air. The system consisted of a blower unit for the intake of outside atmospheric air at floor and window levels and a fan inside the vehicle chamber for the circulation of the air. A damper was also provided at the blower end opening to the atmosphere for the exhaustion of inner air out of the vehicle in a regulated amount. The system included a ducts arrangement in which there were ducts extending along the intersection of the floor and the side walls which communicated upwardly with an

elongated air passageway in upper ends of a panel to define air openings for the intake of outside air. The outlet of the blower was connected to the ducts and the inlet was connected to the interior of the vehicle. The damper was opened and closed based on a temperature means which worked by sensing the temperature and informing the damper to open and close after a desired temperature s achieved.

Dixit (2014) [21], developed a model to reduce the amount of solar radiation entering into the cabin of a car by replacing the windshield and side glasses by double layered glasses and filling argon gas in between the two layers of the glasses. The experiments were in a box with single layer of toughened glass, a box with double layer of toughened glass with air in between the two layers, a box with double layer of toughened glass with an insulating gas flowing and trapped in between the two layers which were taken as two cases separately. Bond graph theory was used for the verification the work conducted. It was concluded that the temperature was reduced to a great extent from entering into the cabin of a car.

2.2 Literature Gap

Based on the literature studied, it was observed that the work done on the thermal comfort of passengers in a vehicle was mainly focussed on ventilating the vehicle through natural processes and improving the air conditioning of the vehicle which had many gaps in the study reviewed. As per the context of the literature, research was based on lowering down of windows for ventilation which is not practical due to chances of theft and threat to the security of car, using sunshade for reducing the solar radiation entering the car but it is banned due to strict regulations of the law, use of vents for the process of ventilation which tends to formation of precipitation and humidity interference, usage of phase change materials which can only be used where temperature fluctuates very rapidly, usage of argon gas in between a double layered glass which can lead to suffocation, dizziness and loss of consciousness due to leakage or breakage of the glass. Little work that has been done on controlling the temperature variation using forced ventilation tends to be uneconomical. The present work demonstrates the solution for overcoming the gaps in literature.

2.3 Problem Formulation

This research deals with controlling the rise in temperature in the cabin of a car through forced ventilation and dissipating the rising heat out of the car when it is parked under direct sunlight. It was also observed that there is substantial rise in temperature of cabin, steering and dashboard with-in first fifteen minutes of parking in direct sunlight and becomes difficult to cool the car in frequent start-stop situation. This thesis aims at reducing the vehicle's thermal and air conditioning ancillary load which subsequently increase the effectiveness of air conditioners and maintaining the required thermal comfort in short time. Proposed work also helps in reducing the peak cabin temperature in frequent start- stop situation. Cross ventilation fans are powered by an auxiliary battery, charged with the help of solar panels provided at the roof of the car.

CHAPTER 3

EXPERIMENTAL SETUP

3.1 Introduction

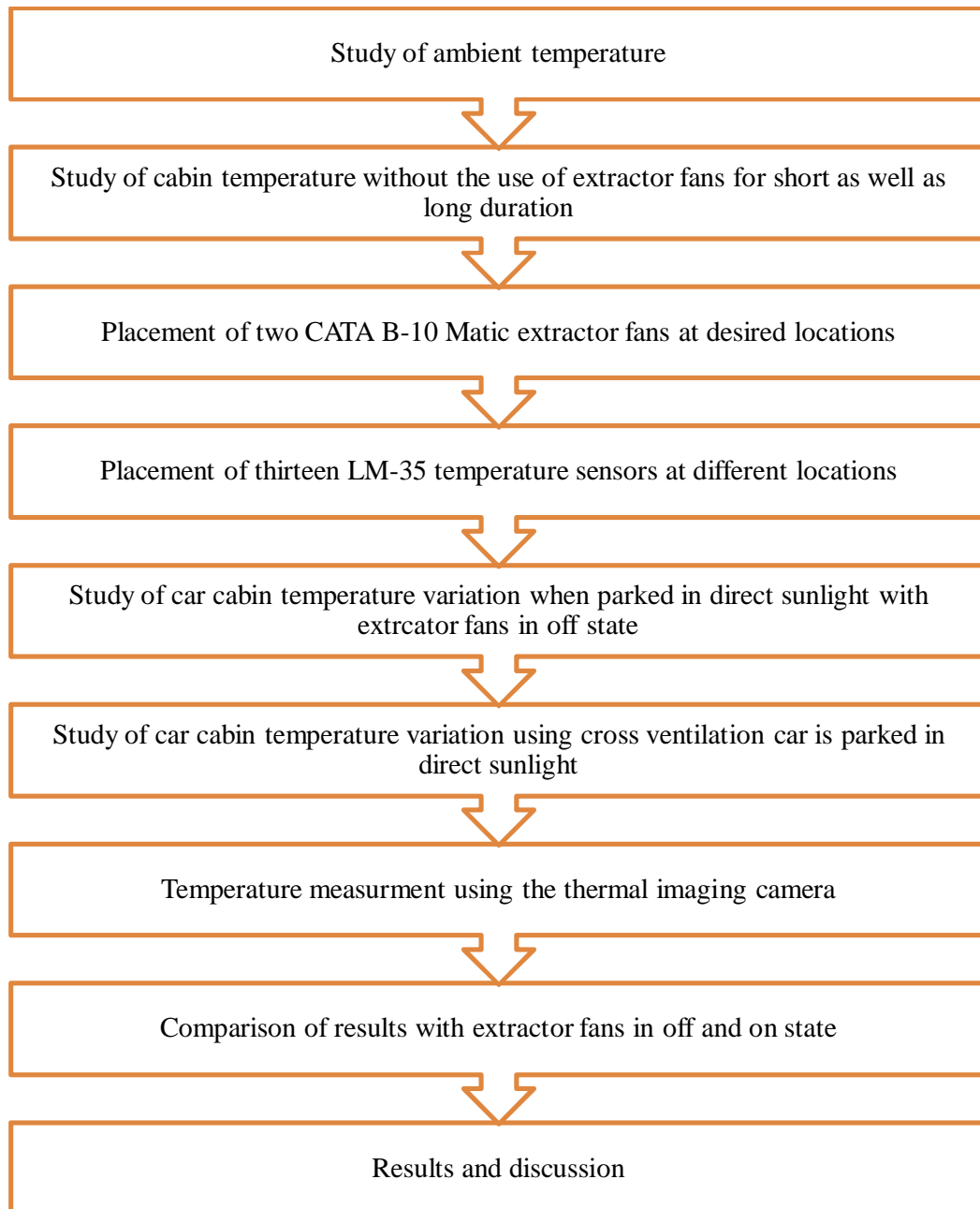
On a hot day the passenger cabin of a vehicle parked under direct sunlight gets heated up due to the entering of heat waves in the form of electromagnetic radiation coming from the Sun. Various ways through which the heat can enter into the interior cabin of the car are through the front and rear windshields, side glass and the roof of the car. The short wavelength light radiation coming through the Sun is converted in to long wavelength thermal radiation on passing into the car cabin through the glass. It is a property of glass to be transparent to the short wavelength light radiation but at the same time it behaves as an opaque object to the long wavelength thermal radiation. This leads to trapping and accumulating of heat waves in the cabin of the car which eventually increases the cabin temperature of the car. The temperature rise in the car cabin occurs due to conduction, convection and radiation but the major role is played by radiation since the hot interior material of the car keeps on radiating hot waves which cannot escape through the car.

3.2 Methodology

The objective of the present study is to reduce the temperature variation in an interior cabin of a car parked in daylight by the phenomena of forced and cross ventilation. Thermal and passenger comfort is the motivation behind the present study.

Two exhaust or extractor fans are used in the periphery of the car for the process of cross ventilation to dissipate the accumulated heat in the car compartment out of the car. One fan is installed in the front part of the cabin of the car, below the central vents of the air conditioning unit and the other fan is installed in the rear windshield. The front fan is used for the intake of cooler atmospheric air into the car cabin and the rear fan is used to dissipate the hotter air from the inner cabin to the outside atmosphere. This will help in reducing the thermal and air conditioning ancillary loads.

For the purpose of temperature measurement, thirteen LM-35 temperature sensors installed in a PCB have been placed in the car at desired locations mention further in this chapter. A thermal imaging camera has also been used for the measurement of surface temperature. The experimentation was done for six days with the working of extractor fans on alternative days. Comparisons were done for the temperature readings with the extractor fans in off and on state.



3.3 Equipments Required in the Setup

- Vehicle
- Printed Circuit Board of temperature sensors
- Extractor fans
- Thermal imaging camera

3.3.1 Vehicle

- Esteem VX 1996 model has been purchased for thesis work.



Figure 3.1 Esteem VX 1996 model

3.3.2 Printed Circuit Board with Temperature Sensors

A printed circuit board with 13 temperature sensors has been developed for the measurement of temperature inside the car cabin. PIC micro-controller has been used to integrate these sensors. An RS232 port is used to drive this controller. 3.3V, 5V power supply is required to operate this controller therefore a USB to serial convertor has been used to integrate this PCB with the laptop. A 9V adaptor has been used to power all the components in the PCB. Figure 3.2 shows the developed PCB with required temperature sensors.



Figure 3.3 Fan installed in the front part of the car cabin

The concept of cross ventilation will be used here in which this front fan will work as an intake fan which sucks the outside air into the car cabin and the fan which is installed on the rear windshield will work as an exhaust fan which will dissipate the inner accumulated heat and eventually help in reducing and maintaining the temperature inside the cabin of the car.



Figure 3.4 Fan installed on the rear windshield

Features:

- Anti vibration extractor fan
- Automatic shutter opening/closing (opening /closing time is of 30 sec)
- Intensity of noise is very low (around 41 Db)
- Can operate at DC 12 Volts
- Easy screw less installation system

Table 3.1 CATA B-10 Matic extractor fans specifications

V/Hz	Watts	R.P.M.	M ³ /h	mmca	Dia (mm)
230/50	15	2500	98	3	100

3.3.4 Thermal Imaging Camera

Flir One thermal imaging camera has been used to capture the thermal images of the experimental setup in which it gives the temperature distribution as well as shows the temperature of a focussed point. It works on the principle of infrared capturing where there is a sensor beside the camera which senses the infrared energy from the objects where the camera is focussed. This infrared energy is converted into electrical signals which produce a thermal image on the phone screen on which it is attached. Inside the cabin of the car, the temperature distribution of various surfaces like the dashboard, gear, steering wheel, seat covers, and roof of the car as well as the human body has been determined by the use of thermal imaging camera.

Features and specifications of the thermal imaging camera are mentioned below:

- Multi Spectral Dynamic Imaging (MSX) technology has been used which produces a sharper, detailed image with a better texture than a raw thermal image [W.2].
- Two cameras: Standard or visible camera and a thermal camera
- We can see in the dark as well as through the smoke
- Invisible heat sources can be observed
- Moisture detection, sensing of wet areas, leaks in ceilings, walls and floors are some of the features of this camera

- Temperature can be measured in Celsius and Fahrenheit scales
- Video capturing is also available
- Scene range temperature: 32•F to 212•F (0•C to 100•C)
- Weight: 110 gm
- Battery capacity: 1400 mAh (approx. 4 hours of use)
- Sensitivity: able to detect temperature differences as small as 0.18•F (0.1•C)
- Visible camera: VGA



Figure 3.5 FLIR ONE Thermal Imaging Camera [W.3]

3.4 Placement of PCB and LM-35 Sensors

13 LM 35 temperature sensors have been used and their positions are mentioned below:

Sensor 1: Face of rear right corner passenger

Sensor 2: Face of rear centre passenger

Sensor 3: Face of rear left corner passenger

Sensor 4: In between sensor 1 and 7

Sensor 5: In between sensor 2 and 8

Sensor 6: In between sensor 3 and 9

Sensor 7: Top of front driver's headrest

Sensor 8: In between front two seats (chest position)

Sensor 9: Top of front passenger's headrest

Sensor 10: Driver chest

Sensor 11: Front passenger chest

Sensor 12: Steering wheel

Sensor 13: Dashboard

Figure 3.6 shows the sensor arrangement in vehicle cabin. All 13 sensors are placed in their respective positions.



Figure 3.6 Placement of the PCB and sensors



Figure 3.7 Placement of a sensor on the steering wheel

CHAPTER 4

RESULTS AND DISCUSSION

In the present research work, the experiments were carried out in the month of May, 2015. Thirteen different sensors are placed at different locations inside the car compartment for the measurement of temperature over the desired places. Out of these 13 sensors, an average range of temperature has been taken for the readings of 11 sensors which are used for the temperature measurement of the cabin and the readings of the remaining two sensors which are used for the dashboard and steering wheel respectively are taken individually. During the days of experimentation, readings were recorded with the extractor fans in on and off state alternatively. Hence, experimentation was done for three days with the extractor fans in on state and for remaining three days with off state.

The results obtained are shown individually for all sensors for all the 6 days taking the average of 11 sensors as first case, sensors placed at dashboard as second case and sensor placed on the steering wheel as the third case. The experiments were performed for a span of 5 hours per day from 10:00 a.m. to 3:00 p.m. since this is the period of a day with the maximum heat intensity and maximum sunlight falling on the earth's surface [21]. Readings were recorded at an interval of 10 minutes from the commencement of the experiment. Results of the surface temperatures like that of the dashboard, steering wheel, gear lever, etc. recorded from the FLIR One thermal imaging camera have also been shown and explained in the fore coming sections.

4.1 Study of instantaneous rise in temperature under short duration (equivalent to start-stop situation)

The following results show the behaviour of the instantaneous rise in temperature in the cabin of the car for a short period of time in a day when it is parked under direct sunlight:

Short Duration Heating

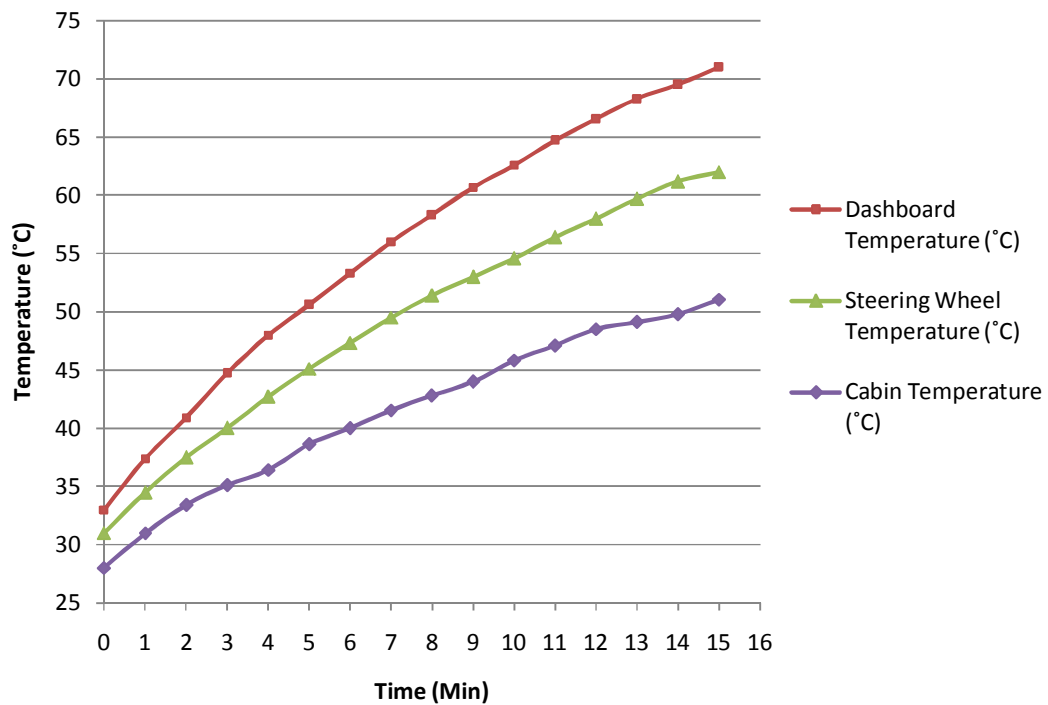


Figure 4.1 Short duration heating inside cabin

From Fig. 4.1, it can be observed that there is a steep rise in temperature of the cabin, steering wheel as well as the dashboard during first 15 minutes when a car is parked under direct sunlight just after switching off the air conditioner. When the air conditioner is switched off, the temperature of the cabin, steering wheel and the dashboard was observed to be 28°C, 31°C and 33°C respectively. As the time progresses, the temperature rises to 51°C, 62°C and 71°C for the cabin, steering wheel and dashboard respectively.

4.2 Study of instantaneous cooling in the cabin under short duration (equivalent to start-stop situation).

The following results show the behaviour of the fall in temperature of the car cabin when the air conditioner is turned on for a short period of time in a day while it is parked under direct sunlight:

Short Duration Cooling

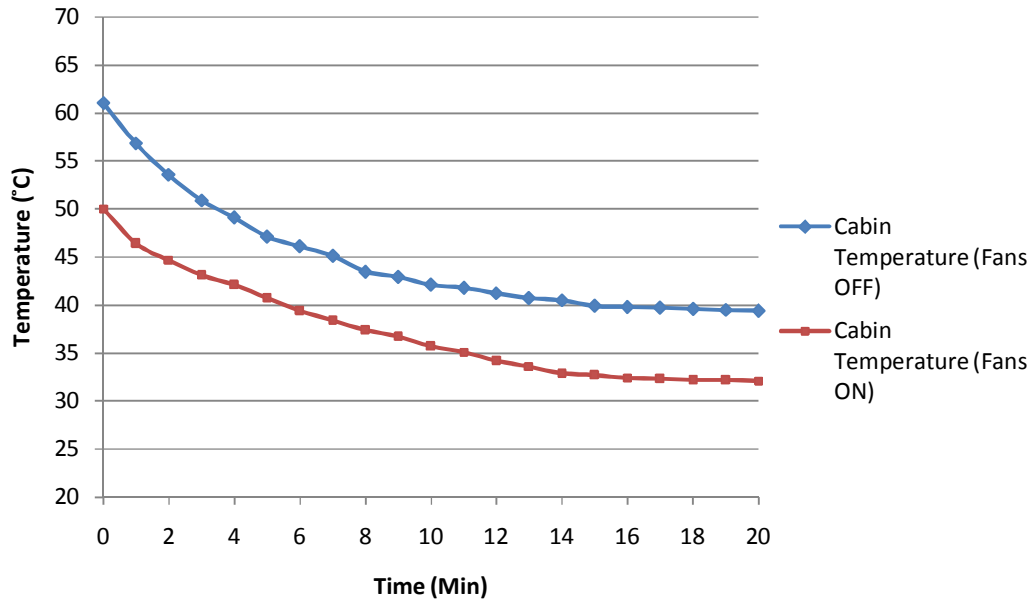


Figure 4.2 Short duration cooling inside cabin

From Fig. 4.2, it can be seen that there is a gradual fall in temperature of the cabin, during first 20 minutes when the air conditioner is turned ON when a car is parked under direct sunlight. When the extractor fans are in OFF state, the average temperature of the cabin is about 61°C which achieves a temperature of 39.9°C after 15 minutes and is observed to be constant after that for the next 5 minutes. When the extractor fans are in ON state, the average temperature of the cabin is about 11°C less than when the extractor fans are in OFF state. The cabin achieves a temperature of 32.7°C after first 15 minutes and is observed to be constant after that for the next 5 minutes. It can be noticed that in the second case, the cabin achieves a temperature of 39.9°C after 6 minutes as compared to 15 minutes in the previous case. A reduction of 7°C in the cabin temperature was observed at the end of 20 minutes when the air conditioner is working.

4.3 Experimentation on the setup with temperature readings recorded with the sensors

Experiments were performed in the following manner as explained below:

Day 1: The experiment was performed on 22nd May, 2015 with the extractor fans in non working state or switched OFF.

Day 2: The experiment was performed on 23rd May, 2015 with the extractor fans in working state or switched ON.

Day 3: The experiment was performed on 24th May, 2015 with the extractor fans in non working state or switched OFF.

Day 4: The experiment was performed on 25th May, 2015 with the extractor fans in working state or switched ON.

Day 5: The experiment was performed on 27th May, 2015 with the extractor fans in non working state or switched OFF.

Day 6: The experiment was performed on 28th May, 2015 with the extractor fans in working state or switched ON.

4.3.1 Study of the behaviour of atmospheric temperature

The behaviour of the change of atmospheric temperature during the time of the experiment have been studied and explained below:

Table 4.1 Behaviour of change of atmospheric temperature

S No.	Time	Atmospheric Temperature (°C)					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1	10:00 AM	40.6	40.7	40.9	40.9	38.7	38.5
2	10:10 AM	40.7	40.8	41.4	41.3	38.8	38.6
3	10:20 AM	40.8	40.8	41.5	41.5	38.9	38.9
4	10:30 AM	40.9	41	41.6	41.7	39.1	39
5	10:40 AM	41.1	41.2	42	41.9	39.3	39.2

6	10:50 AM	41.2	41.4	42.5	42.4	39.5	39.6
7	11:00 AM	41.8	41.9	42.8	42.9	39.6	39.7
8	11:10 AM	42.3	42.3	43.2	43.3	39.8	39.8
9	11:20 AM	42.8	42.9	43.6	43.7	40.1	40
10	11:30 AM	43.4	43.5	43.9	44	40.3	40.4
11	11:40 AM	43.5	43.8	44.1	44.2	40.5	40.5
12	11:50 AM	43.9	44.1	44.5	44.5	40.6	40.7
13	12:00 PM	44.3	44.5	44.7	44.7	40.7	40.9
14	12:10 PM	44.7	44.9	45.1	45	40.8	41.1
15	12:20 PM	44.9	45.2	45.5	45.5	40.9	41.2
16	12:30 PM	45.1	45.5	45.9	45.8	40.9	41.3
17	12:40 PM	45.2	45.6	46.1	45.9	41.1	41.5
18	12:50 PM	45.5	45.7	46	46	41	41.6
19	1:00 PM	45.2	45.5	45.9	45.9	40.9	41.5
20	1:10 PM	45.1	45.3	45.6	45.8	40.8	41.3
21	1:20 PM	44.9	45	45.1	45.5	40.7	41.1
22	1:30 PM	44.7	44.8	44.9	45	40.6	41
23	1:40 PM	44.3	44.5	44.7	44.9	40.4	40.9
24	1:50 PM	43.9	44	44.2	44.7	40.3	40.7
25	2:00 PM	43.5	43.7	43.9	44.2	40.1	40.3
26	2:10 PM	43.4	43.4	43.5	43.8	39.6	40.1
27	2:20 PM	42.8	43	43.3	43.5	39.5	39.9
28	2:30 PM	42.8	42.8	42.9	43.1	39.5	39.8
29	2:40 PM	41.9	42.3	42.8	42.9	39.3	39.5
30	2:50 PM	41.5	42	42.5	42.6	39.2	39.4
31	3:00 PM	41.1	41.6	42.1	42.2	39.1	39.3

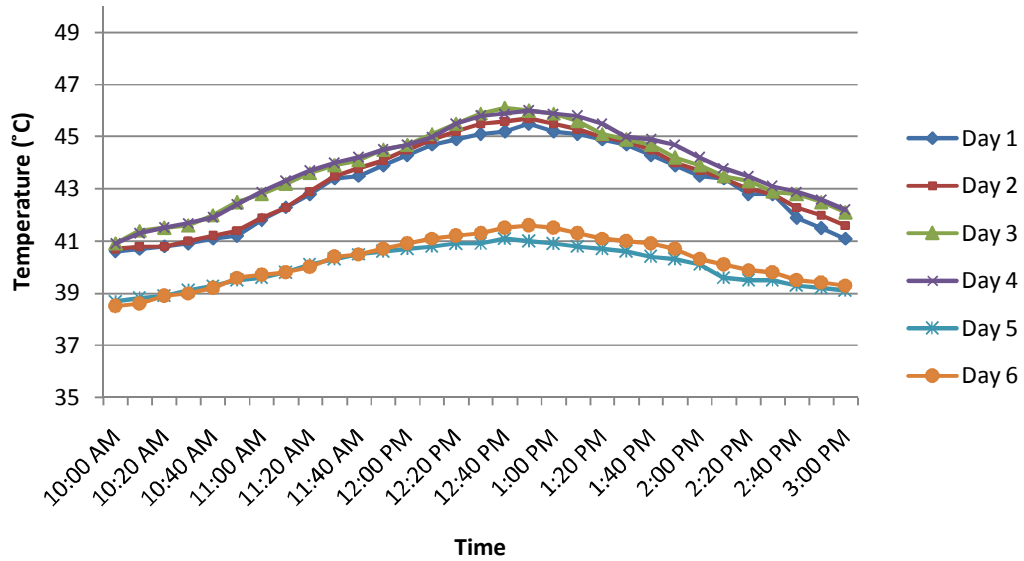


Figure 4.3 Behaviour of change of atmospheric temperature

Figure 4.3 shows that the behaviour of the change of atmospheric temperature remains the same during the days of experimentation. It can be observed that the variation in the atmospheric temperature is about 5°C to 7°C throughout the span of 5 hours. As the time progresses, there is an incremental shift in the rise in atmospheric temperature which touches its peak value between 12:30 p.m. and 1:30 p.m. during the day (most of the time between 12:40 pm to 12:50 pm). For the first four days, the temperature was quite high as those were sunny days with clear sky. During the last two days, a drop in temperature was noticed due to weather conditions.

4.3.2 Cabin temperature

The following results show the behaviour of the temperature variation in the car cabin when the extractor fans are in off and on state respectively:

Average cabin temperature when extractor fans are off

Table 4.2 Experimental results of average cabin temperature (Fans OFF)

S No.	Time	Average Cabin Temperature (°C) (Fans OFF)	Average Cabin Temperature (°C) (Fans OFF)	Average Cabin Temperature (°C) (Fans OFF)
		Day 1	Day 3	Day 5
1	10:00 AM	49.98	50.09	49.98

2	10:10 AM	54.99	56.12	54.63
3	10:20 AM	59.82	60.21	57.52
4	10:30 AM	61.10	63.44	59.69
5	10:40 AM	63.16	64.89	60.7
6	10:50 AM	63.79	65.12	61.41
7	11:00 AM	65.20	65.88	62.76
8	11:10 AM	65.94	66.61	63.3
9	11:20 AM	66.96	67.55	64.16
10	11:30 AM	66.9	67.91	64.71
11	11:40 AM	67.23	68.22	65.15
12	11:50 AM	67.65	69.12	65.12
13	12:00 PM	68.49	69.45	65.21
14	12:10 PM	68.55	69.97	65.42
15	12:20 PM	68.71	70.23	65.44
16	12:30 PM	68.58	70.8	65.78
17	12:40 PM	68.28	71.24	65.42
18	12:50 PM	68.21	71.01	65.05
19	1:00 PM	68.37	70.61	65.15
20	1:10 PM	68.22	70.21	64.88
21	1:20 PM	67.86	69.8	64.13
22	1:30 PM	67.40	69.45	63.36
23	1:40 PM	66.80	68.24	62.56
24	1:50 PM	62.56	66.87	61.51
25	2:00 PM	61.12	65.82	60.09
26	2:10 PM	57.9	63.61	58.46
27	2:20 PM	56.03	61.09	56.68
28	2:30 PM	54.42	58.34	55.3
29	2:40 PM	53.34	56.91	53.34
30	2:50 PM	52.63	55.11	52.21
31	3:00 PM	51.98	54.92	51.11

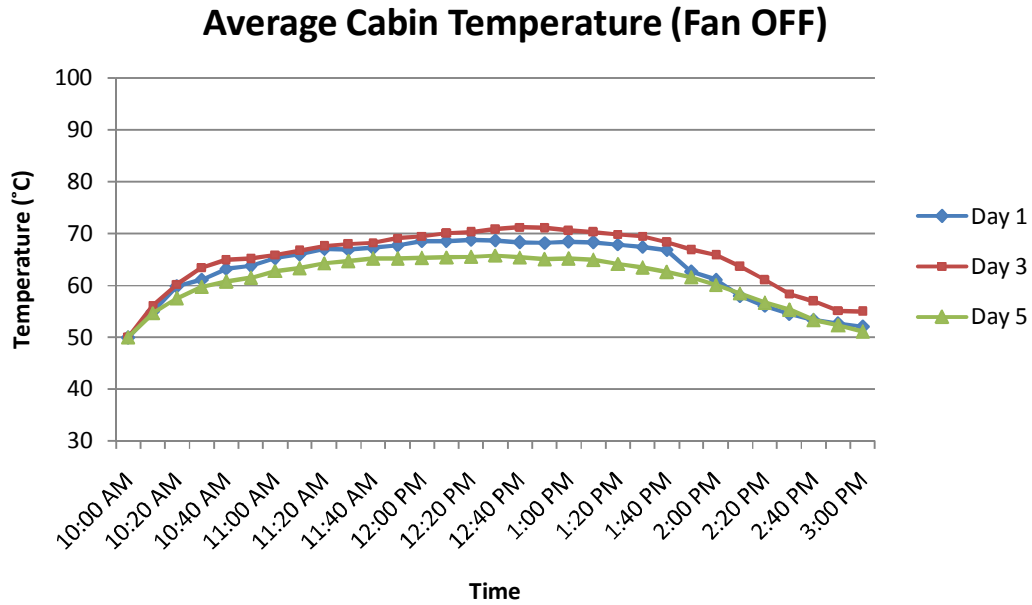


Figure 4.4 Behaviour of change of average cabin temperature

Figure 4.4 shows that the behaviour of the change of average cabin temperature remains the same during the days of experimentation. It can be observed that as the time progresses, there is an incremental shift in the average cabin temperature which gradually rises and falls in the initial and final segment of the time and attains its peak value between 12:30 p.m. and 1:00 p.m. The maximum cabin temperature rises up to 71.24°C at the peak time of the day when the sun is overhead and the extractor fans are in off state. To reduce this high rise in temperature, cross ventilation by the use of two extractor fans were incorporated whose results are shown in the following sections.

Average cabin temperature when extractor fans are on

Table 4.3 Experimental results of average cabin temperature (Fans ON)

S No.	Time	Average Cabin Temperature (°C) (Fans ON)	Average Cabin Temperature (°C) (Fans ON)	Average Cabin Temperature (°C) (Fans ON)
		Day 2	Day 4	Day 6
1	10:00 AM	44.16	43.63	45.60
2	10:10 AM	48.10	50.34	46.32
3	10:20 AM	49.11	52.14	50.10
4	10:30 AM	49.99	53.15	51.66

5	10:40 AM	50.42	53.83	50.69
6	10:50 AM	51.35	54.68	52.01
7	11:00 AM	51.77	55.5	51.31
8	11:10 AM	52.24	56.52	52.65
9	11:20 AM	52.90	56.97	52.83
10	11:30 AM	53.60	57.19	53.44
11	11:40 AM	54.49	57.41	53.37
12	11:50 AM	54.41	57.46	54.35
13	12:00 PM	55.10	57.47	54.07
14	12:10 PM	54.88	57.88	54.4
15	12:20 PM	55.85	57.89	55.60
16	12:30 PM	56.17	57.98	56.12
17	12:40 PM	56.38	58.08	55.53
18	12:50 PM	55.38	57.96	54.44
19	1:00 PM	54.33	57.77	54.23
20	1:10 PM	53.79	57.4	53.9
21	1:20 PM	53.52	57.03	53.63
22	1:30 PM	53.35	56.94	53.68
23	1:40 PM	52.80	56.53	53.15
24	1:50 PM	52.48	56.53	52.98
25	2:00 PM	52.48	55.49	53.08
26	2:10 PM	52.10	55.23	53.06
27	2:20 PM	51.97	54.49	52.57
28	2:30 PM	51.77	54.28	51.48
29	2:40 PM	51.33	54.1	51.86
30	2:50 PM	51.22	53.83	50.92
31	3:00 PM	51	53.42	50.12

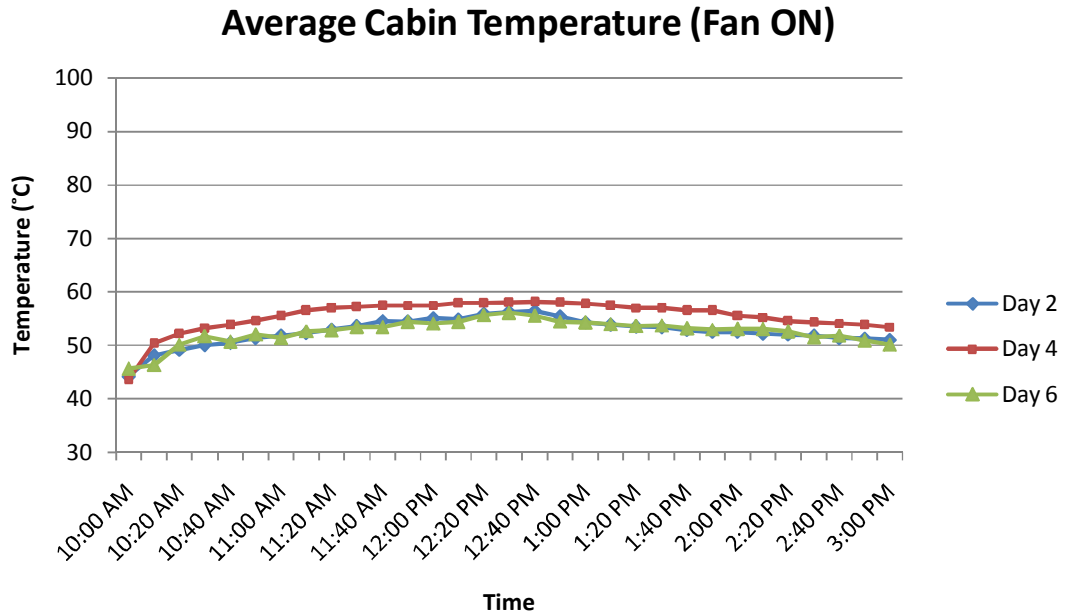


Figure 4.5 Behaviour of change of average cabin temperature (Fans ON)

Figure 4.5 shows the behaviour of the change of average cabin temperature in the car which is almost constant and remains the same during the time and days of experimentation during the process of cross ventilation when the extractor fans are in on state. From fig. 4.4, it can be observed that the variation in the average cabin temperature is about 5°C to 8°C during the span of 5 hours. The maximum cabin temperature rises up to 58°C during the peak of the day when the sun is overhead. The average temperature remains between 55°C and 58°C during the 5 hrs of experimentation. The process of cross ventilation tends to decrease the rise in temperature by about 13°C to 16°C.

Thermal imaging camera readings of the cabin of the car

The following results show the temperature measurement recorded with the FLIR ONE thermal imaging camera at various places in the cabin of the car when the extractor fans are in off as well as in on state.

- **Rear Seat**

It can be seen from the Fig. 4.5 and Fig. 4.6 that during the peak of the day when the Sun is overhead and the extractor fans are switched off, the temperature at the upper portion of the rear seat raises to a very high degree of about 88°C to 90°C which is

very close to the level of our face. The temperature at the middle portion of the rear seat where our back rests also reaches to high levels of about 64°C.

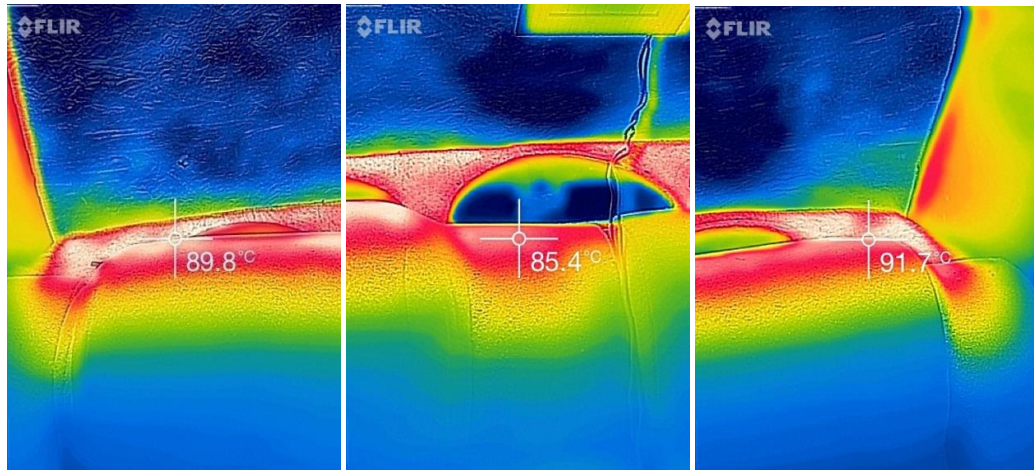


Figure 4.6 Thermal images of upper portion of rear seat

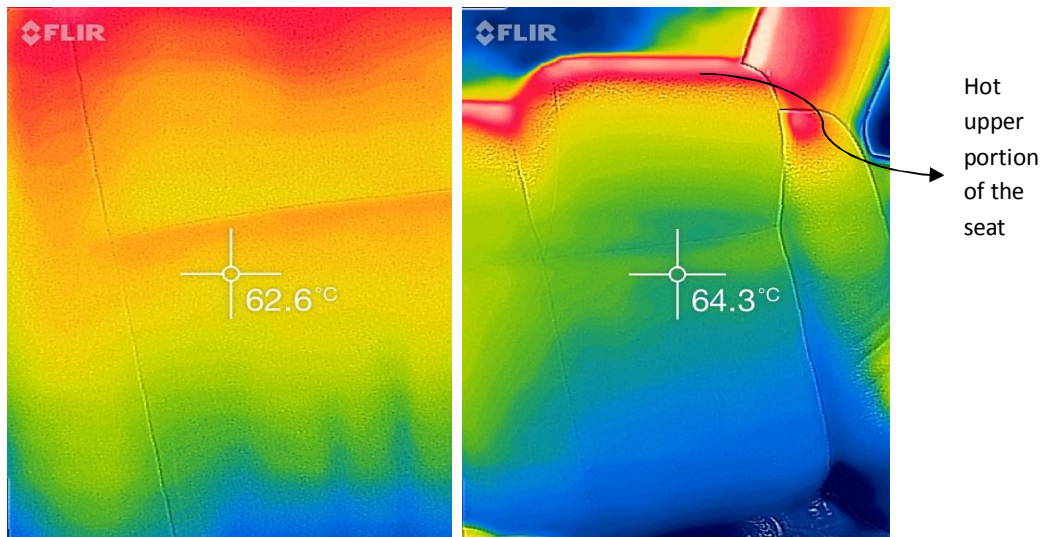


Figure 4.7 Thermal images of middle portion of rear seat

- **Gear lever**

Figure 4.7 shows the temperature reading on the surface of the gear lever taken from the thermal imaging camera when the extractor fans are off.

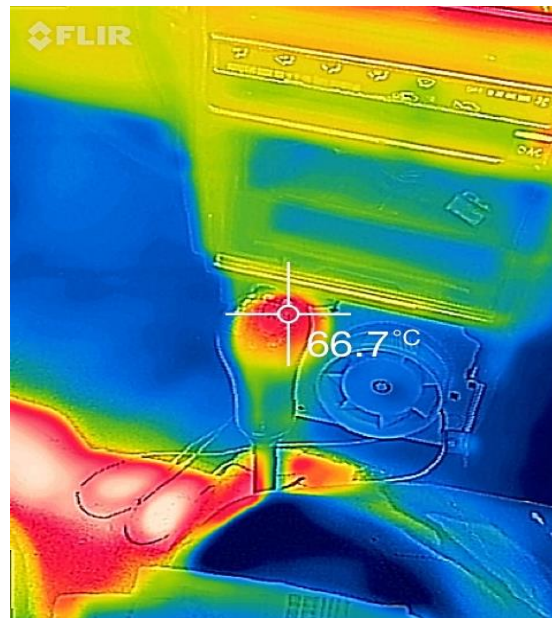


Figure 4.8 Thermal image of the gear lever

- **Seat belt**

It is one of the most important part which come into use before taking hold of the steering wheel, gear lever and the dashboard. Due to safety purposes wearing seatbelt is very important for any person before starting the car. Figure 4.8 shows that the temperature of the seat belt increases to 67.2°C which is quite high for holding it and fixing into the lock.



Figure 4.9 Thermal image of the seat belt

4.3.3 Temperature measurement on the dashboard of the car

The following results show the behaviour of the temperature variation on the dashboard of the car when the extractor fans are in off and on state respectively:

Dashboard temperature when extractor fans are off

Table 4.4 Experimental results of dashboard temperature (Fans OFF)

S No.	Time	Dashboard Temperature(°C) (Fans OFF)	Dashboard Temperature (°C) (Fans OFF)	Dashboard Temperature (°C) (Fans OFF)
		Day 1	Day 3	Day 5
1	10:00 AM	68.2	71.2	68.2
2	10:10 AM	76.1	78.9	75.4
3	10:20 AM	79.9	82.7	77.8
4	10:30 AM	82.5	84.7	80.1
5	10:40 AM	83	85.9	81
6	10:50 AM	85	86.8	81.5
7	11:00 AM	88.4	88.5	83.2
8	11:10 AM	89.6	90.8	82.3
9	11:20 AM	90.9	91.5	82.9
10	11:30 AM	90.8	92.1	82.8
11	11:40 AM	90.8	92.9	82.4
12	11:50 AM	91	93.5	82.8
13	12:00 PM	92.5	94.1	83.1
14	12:10 PM	93.5	94.5	83.8
15	12:20 PM	92.7	94.7	84.8
16	12:30 PM	92.4	95.2	85.1
17	12:40 PM	92.6	94.7	85.1
18	12:50 PM	92.4	94.5	84.9
19	1:00 PM	92.4	94.3	84.4
20	1:10 PM	91.3	93.9	83.7
21	1:20 PM	91	93.5	82.7
22	1:30 PM	86.9	90.7	82.1
23	1:40 PM	83.8	86.6	81.1

24	1:50 PM	79.6	83.4	79.1
25	2:00 PM	78.8	80.8	76.7
26	2:10 PM	75	79.7	74.4
27	2:20 PM	71.3	77.5	73.9
28	2:30 PM	65.7	72.5	69.5
29	2:40 PM	63.3	68.5	63.3
30	2:50 PM	61.1	65.4	60.1
31	3:00 PM	59.4	64.2	58.3

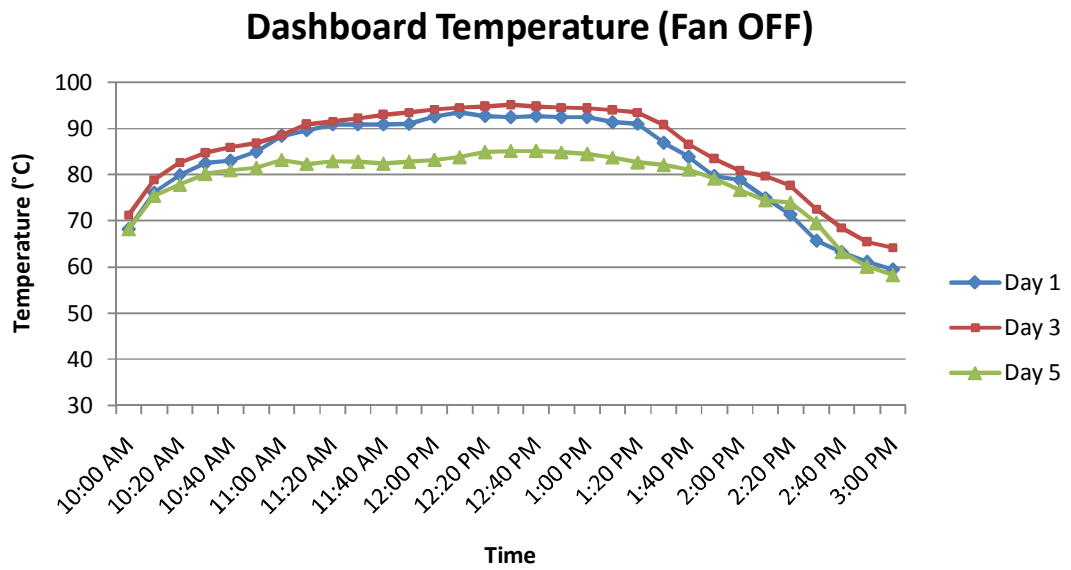


Figure 4.10 Behaviour of change of dashboard temperature (Fans OFF)

Figure 4.10 shows that the behaviour of the change of dashboard temperature remains the same during the days of experimentation. It can be observed that as the time progresses, there is an incremental shift in the dashboard temperature which gradually rises and falls in the initial and final segment of the time and attains its peak value between 12:20 p.m. and 1:10 p.m. The maximum dashboard temperature rises up to 95.2°C at the peak time of the day when the sun is overhead and the extractor fans are in off state. The average dashboard temperature is about 85°C to 90°C during the major time of the experiment. Due to rapid fall of temperature after 2:00 p.m. a steep downfall in graph has been noticed. To reduce high rise in temperature, cross ventilation by the use of two extractor fans were incorporated whose results are shown in the following section.

Thermal imaging camera readings of the dashboard

The following results show the temperature measurement recorded with the FLIR ONE thermal imaging camera on the dashboard of the car when the extractor fans are in off state.

- **For Day 1:**

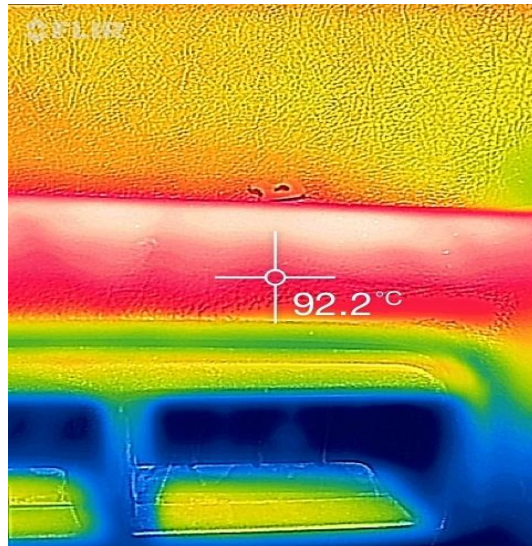


Figure 4.11 Thermal image of the dashboard on day 1

From Fig. 4.11, it can be observed that the temperature of the dashboard rises to a very high degree of about 92.2°C on day 1 during the peak of the day when the Sun is overhead and the extractor fans are switched off.

- **For Day 3:**

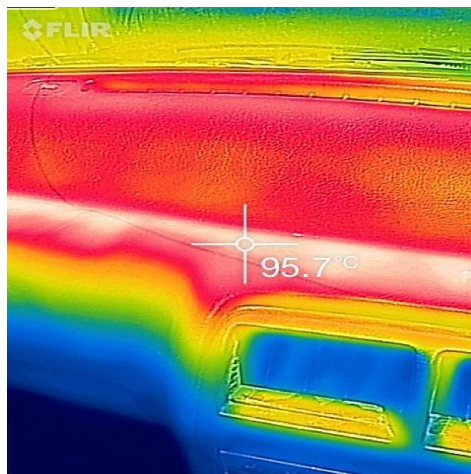


Figure 4.12 Thermal image of the dashboard on day 3

From Fig. 4.12, it can be observed that the temperature of the dashboard rises to a very high degree of about 95.7°C on day 3 during the peak of the day when the Sun is overhead and the extractor fans are switched off. The rise in the dashboard temperature is more on day 3 due to high atmospheric temperature on the third day as compared to the first day.

- **For Day 5:**

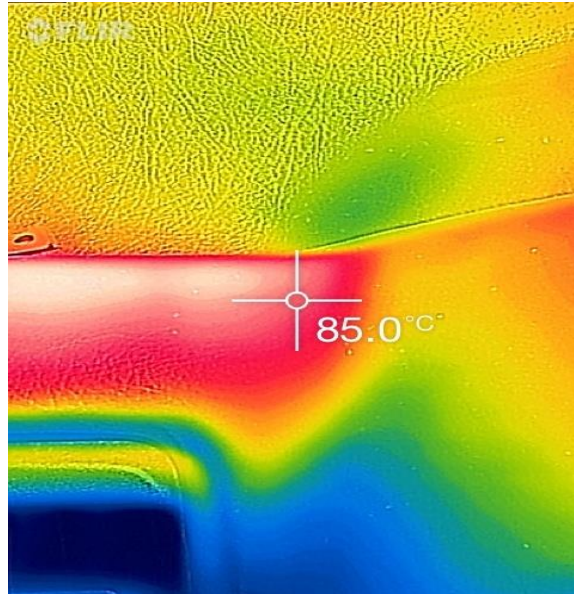


Figure 4.13 Thermal image of the dashboard on day 5

From Fig. 4.13, it can be observed that the temperature of the dashboard rises to a high degree of about 85°C on day 5 during the peak of the day when the Sun is overhead and the extractor fans are switched off. The rise in the dashboard temperature is less on day 5 due to low atmospheric temperature on the fifth day as compared to the previous days.

Dashboard temperature when extractor fans are on

Table 4.5 Experimental results of dashboard temperature (Fans ON)

S No.	Time	Dashboard Temperature(°C) (Fans ON)	Dashboard Temperature (°C) (Fans ON)	Dashboard Temperature (°C) (Fans ON)
		Day 2	Day 4	Day 6
1	10:00 AM	56	62.1	56.4
2	10:10 AM	58.6	63.5	58.8

3	10:20 AM	59.9	65.4	61
4	10:30 AM	61.1	66.6	62.7
5	10:40 AM	61.9	67	62.9
6	10:50 AM	63.2	67.6	64.4
7	11:00 AM	63.1	68.5	64.1
8	11:10 AM	64.7	69.5	66.4
9	11:20 AM	65.7	70.6	67.5
10	11:30 AM	66.8	69.8	67.3
11	11:40 AM	67.5	70.9	68
12	11:50 AM	68.2	69.4	68.2
13	12:00 PM	68.8	71.3	68.8
14	12:10 PM	68.9	71.3	69.5
15	12:20 PM	71	71.3	69.4
16	12:30 PM	71.8	71.4	70.4
17	12:40 PM	71	70.8	69.4
18	12:50 PM	70.2	70.5	68.9
19	1:00 PM	69.2	70.5	67.9
20	1:10 PM	68.5	70.4	67.4
21	1:20 PM	67.3	69.6	66.6
22	1:30 PM	66.8	67.5	67.7
23	1:40 PM	66.1	68.5	67
24	1:50 PM	65.5	66.5	67.2
25	2:00 PM	64.9	65.9	65.4
26	2:10 PM	64.1	66.3	63
27	2:20 PM	63.7	65.9	60.3
28	2:30 PM	63.5	65.1	55.6
29	2:40 PM	63.1	65	54.5
30	2:50 PM	62.4	64.2	53.1
31	3:00 PM	61.7	64.1	52.5

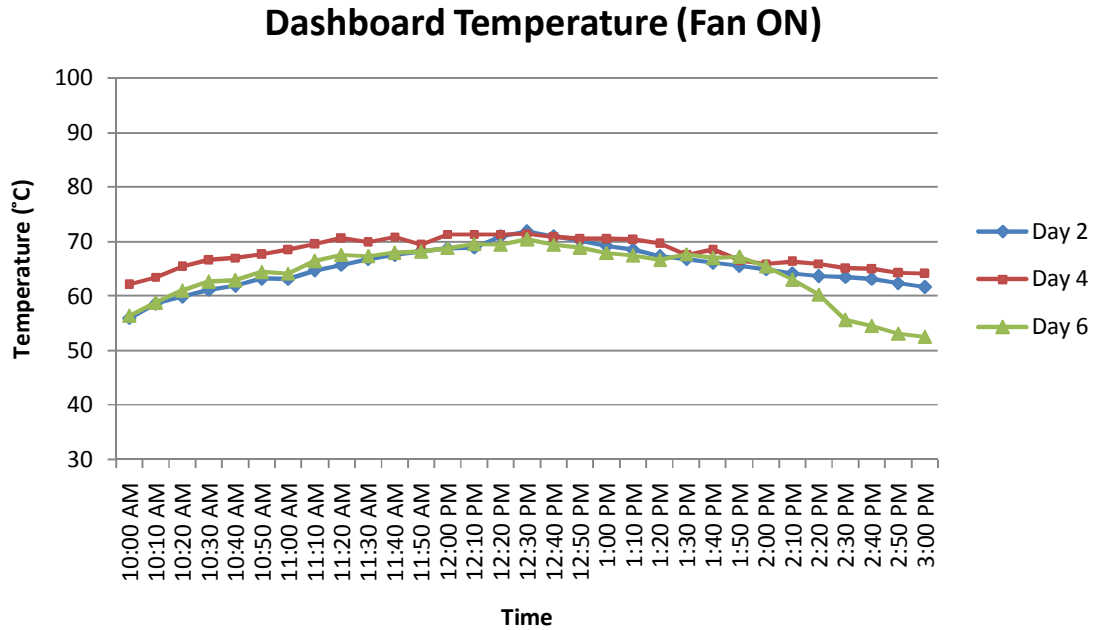


Figure 4.14 Behaviour of change of dashboard temperature (Fans ON)

Figure 4.14 shows the behaviour of the change of dashboard temperature in the car which is almost constant and remains the same during the time and days of the experimentation during the process of cross ventilation when the extractor fans are in on state. It can be observed that the variation in the dashboard temperature is about 10°C to 12°C during the span of 5 hours. The maximum dashboard temperature rises up to 71.8°C at the peak time of the day when the sun is overhead and the extractor fans are in off state. The average dashboard temperature is about 65°C to 70°C during the major time of the experiment. The process of cross ventilation tends to decrease the rise in temperature by about 24°C to 26°C.

Thermal imaging camera readings of the dashboard

The following results show the temperature measurement recorded with the FLIR ONE thermal imaging camera on the dashboard of the car when the extractor fans are in on state.

- **For Day 2:**

From Fig. 4.15, it can be observed that the maximum temperature of the dashboard rises up to only 67.9°C on day 2 during the peak of the day when the Sun is overhead

and the extractor fans are switched on. The process of cross ventilation tends to decrease the rise in temperature by about 25°C.

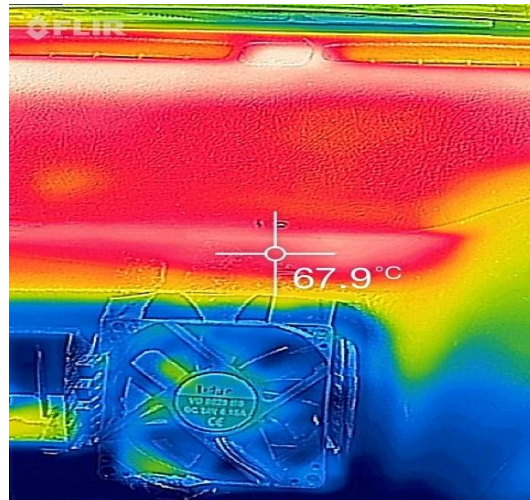


Figure 4.15 Thermal image of the dashboard on day 2

- **For Day 4:**

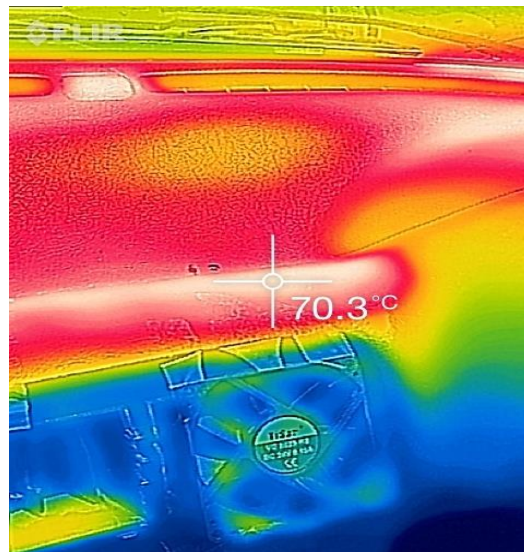


Figure 4.16 Thermal image of the dashboard on day 4

From Fig. 4.16, it can be observed that the maximum temperature of the dashboard rises up to only 70.3°C on day 4 as compared to 95.7°C on day 3 for same atmospheric temperature when the extractor fans are in on state during the peak time of the day. The process of cross ventilation helps in reducing the rise in temperature by about 25°C.

- For Day 6:

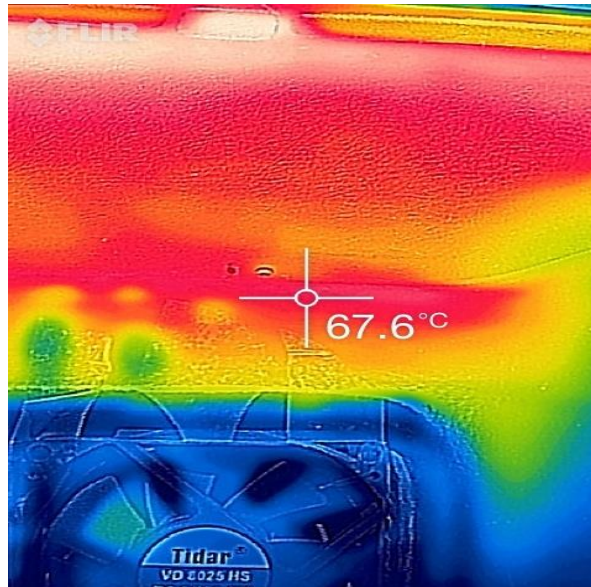


Figure 4.17 Thermal image of the dashboard on day 6

From Fig. 4.17, it can be observed that the maximum temperature of the dashboard rises up to only 67.6°C on day 6 as compared to 85°C on day 5 for same atmospheric temperature when the extractor fans are in on state during the peak time of the day. The process of cross ventilation helps in reducing the rise in temperature by about 17°C.

4.3.4 Temperature measurement on the steering wheel of the car

The following results show the behaviour of the temperature variation on the steering wheel of the car when the extractor fans are in off and on state respectively:

Steering wheel temperature when extractor fans are off

Table 4.6 Experimental results of steering wheel temperature (Fans OFF)

S No.	Time	Steering Wheel Temperature (°C) (Fans OFF)	Steering Wheel Temperature (°C) (Fans OFF)	Steering Wheel Temperature (°C) (Fans OFF)
		Day 1	Day 3	Day 5
1	10:00 AM	62.3	64.2	62.3
2	10:10 AM	68.7	70.1	68.2
3	10:20 AM	73.5	74.9	72
4	10:30 AM	75.9	77.8	73.4

5	10:40 AM	77.1	80.4	75.2
6	10:50 AM	78.3	81.7	75.3
7	11:00 AM	81.2	82.5	75.9
8	11:10 AM	82.6	83.1	76.4
9	11:20 AM	83.9	84.5	76.7
10	11:30 AM	83.8	85.6	76.1
11	11:40 AM	83.8	86.1	76.2
12	11:50 AM	84	86.4	76.8
13	12:00 PM	85.5	86.8	75.9
14	12:10 PM	86.5	87.5	76.1
15	12:20 PM	85.7	87.6	76.2
16	12:30 PM	85.4	87.5	76.8
17	12:40 PM	85.6	87.7	77
18	12:50 PM	85.4	87.5	75
19	1:00 PM	85.4	87.4	74.7
20	1:10 PM	84.3	86.7	74.9
21	1:20 PM	84	85.9	74.1
22	1:30 PM	79.9	83.1	73.5
23	1:40 PM	76.8	80.1	72.7
24	1:50 PM	72.7	77.4	71
25	2:00 PM	71	74.5	68.5
26	2:10 PM	64.2	71.1	65
27	2:20 PM	61.9	67.5	63.3
28	2:30 PM	58.8	64.7	59.9
29	2:40 PM	58.5	63.5	58.5
30	2:50 PM	56.8	61.8	56.3
31	3:00 PM	57	60.5	54.8

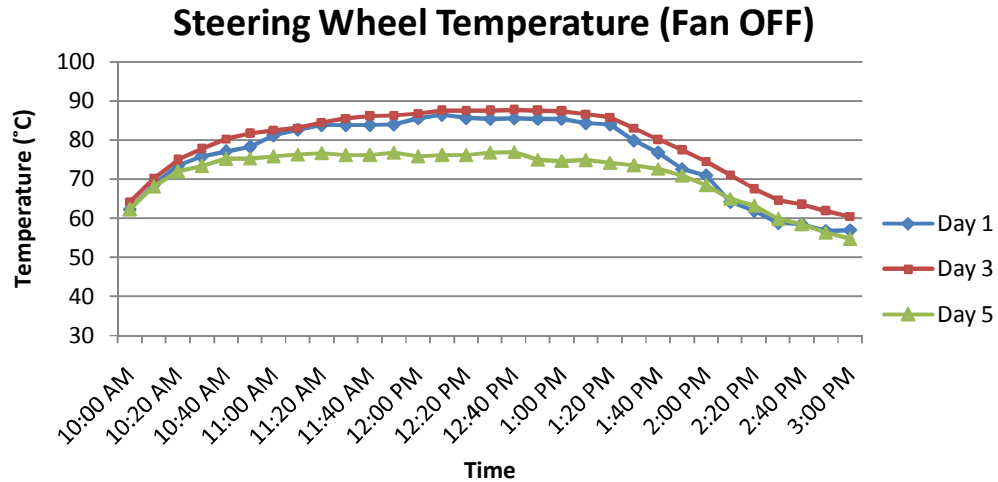


Figure 4.18 Behaviour of change of steering wheel temperature (Fans OFF)

It can be observed from Fig. 4.18 that as the time progresses, there is an incremental shift in the steering wheel temperature which gradually rises and falls in the initial and final segment of the time and attains its peak value between 12:20 p.m. and 1:10 p.m. The maximum steering wheel temperature rises up to 87.7°C at the peak time of the day when the sun is overhead and the extractor fans are in off state. The average steering wheel temperature is about 79°C to 83°C during the major time of the experiment. The figure also shows that the behaviour of the change of steering wheel temperature remains the same during the days of the experimentation. Due to rapid fall of temperature after 2:00 p.m. a steep downfall graph has been noticed. To reduce this high rise in temperature, cross ventilation by the use of two extractor fans was incorporated whose results are shown in the following section.

Thermal imaging camera readings of the steering wheel

The following results show the temperature measurement recorded with the FLIR ONE thermal imaging camera on the steering wheel of the car when the extractor fans are in off state.

- **For Day 1 and Day 3:**

From Fig. 4.19, it can be observed that the temperature of the steering wheel also rises to a very high degree of about 86.2°C during the peak of the day when the Sun is overhead and the extractor fans are switched off.

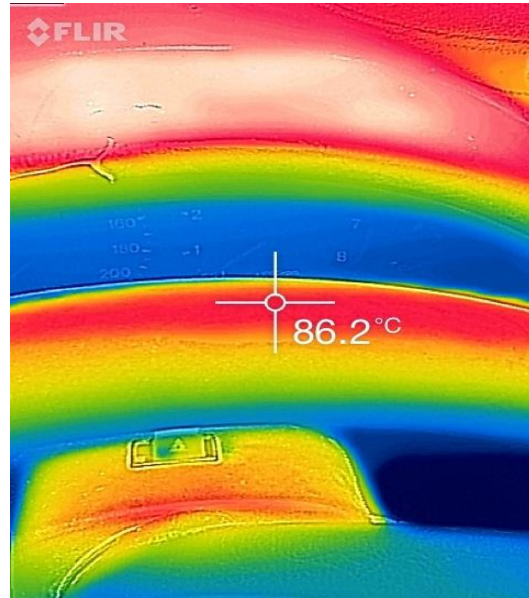


Figure 4.19 Thermal image of the steering wheel on day 1 and day 3

- **For Day 5:**

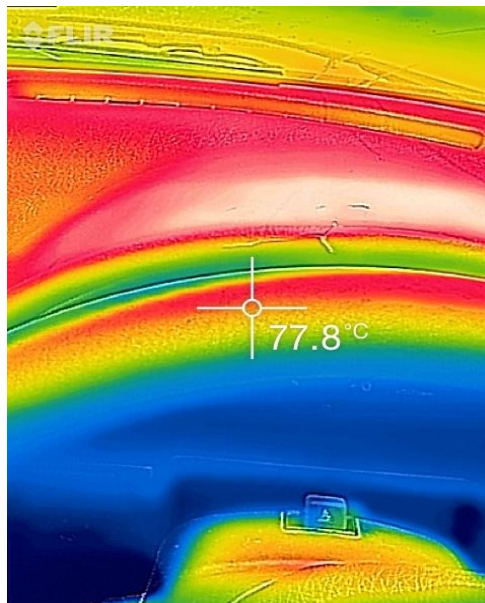


Figure 4.20 Thermal image of steering wheel on day 5

From Fig. 4.20, it can be seen that the temperature of the steering wheel rises to a high degree of about 77.8°C on day 5 during the peak of the day when the Sun is overhead and the extractor fans are switched off. The rise in the steering wheel temperature is less on day 5 due to low atmospheric temperature on the fifth day as compared to the previous days.

Steering wheel temperature when extractor fans are on

Table 4.7 Experimental results of steering wheel temperature (Fans ON)

S No.	Time	Steering Wheel Temperature (°C) (Fans ON)	Steering Wheel Temperature (°C) (Fans ON)	Steering Wheel Temperature (°C) (Fans ON)
		Day 2	Day 4	Day 6
1	10:00 AM	43.2	52.8	44.2
2	10:10 AM	51.5	56.5	49.2
3	10:20 AM	52	58.9	52
4	10:30 AM	53.3	60.4	54.4
5	10:40 AM	55	60.4	53.3
6	10:50 AM	55.7	61.1	54.2
7	11:00 AM	55.9	61.3	54.1
8	11:10 AM	57.5	62	56.8
9	11:20 AM	58.4	62.7	58.1
10	11:30 AM	59.9	62	56.9
11	11:40 AM	60.5	61.8	57.4
12	11:50 AM	59.7	62.6	56.5
13	12:00 PM	61.4	61.5	56.9
14	12:10 PM	60.6	62	56.5
15	12:20 PM	62.1	62.4	58
16	12:30 PM	63.3	63	59.3
17	12:40 PM	63	62.8	58.5
18	12:50 PM	60	62.2	57.8
19	1:00 PM	59.3	61.5	56.8
20	1:10 PM	58.1	61.1	56.8
21	1:20 PM	57.5	61.8	57.8
22	1:30 PM	56.2	60.6	57.3
23	1:40 PM	55.6	60.4	56.5
24	1:50 PM	54	59.6	56.4
25	2:00 PM	53.3	59.8	56.2
26	2:10 PM	52.8	60.2	56.5
27	2:20 PM	51.9	59.3	56.3

28	2:30 PM	52	56.6	55.4
29	2:40 PM	52.2	55.5	52.5
30	2:50 PM	51.3	54.7	50.1
31	3:00 PM	50.7	54.1	49.8

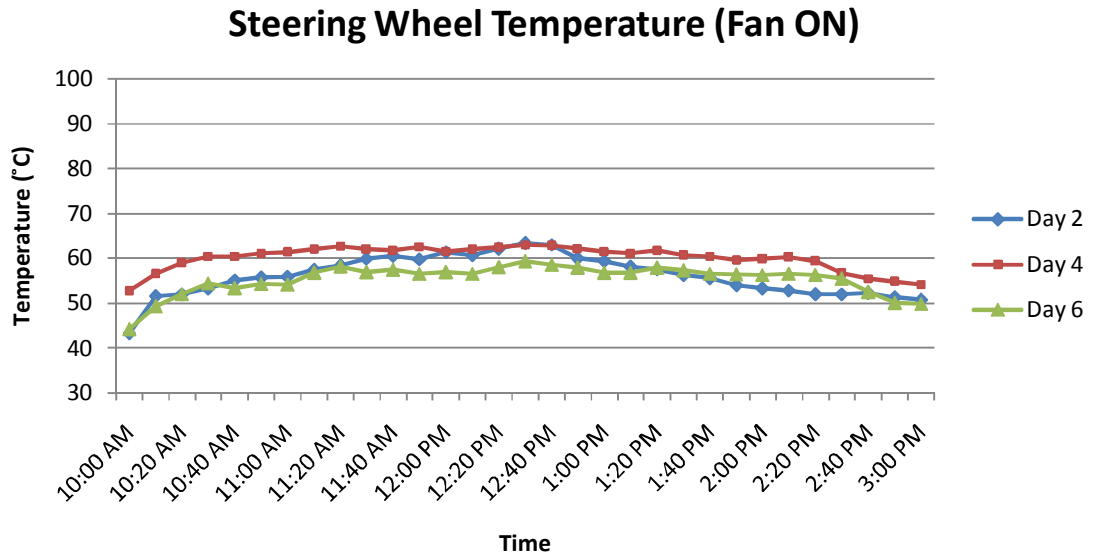


Figure 4.21 Behaviour of change of steering wheel temperature (Fans ON)

From Fig. 4.21, it can be observed that the variation in the steering wheel temperature is about 10°C to 12°C during the span of 5 hours. The figure shows that the behaviour of the change of steering wheel temperature in the car which is almost constant and remains the same during the time and days of the experimentation during the process of cross ventilation when the extractor fans are in on state. The maximum steering wheel temperature rises up to 63.3°C at the peak time of the day when the sun is overhead and the extractor fans are in off state. The average steering wheel temperature is about 56°C to 60°C during the major time of the experiment. The process of cross ventilation tends to decrease the rise in temperature by about 24°C to 26°C.

Thermal imaging camera readings of the steering wheel

The following results show the temperature measurement recorded with the FLIR ONE thermal imaging camera on the steering wheel of the car when the extractor fans are in on state.

- **For Day 2:**

From Fig. 4.22, it can be observed that the maximum temperature of the steering wheel rises up to only 63.1°C on day 2 during the peak of the day when the Sun is overhead and the extractor fans are switched on. The process of cross ventilation tends to decrease the rise in temperature by 25.9°C.

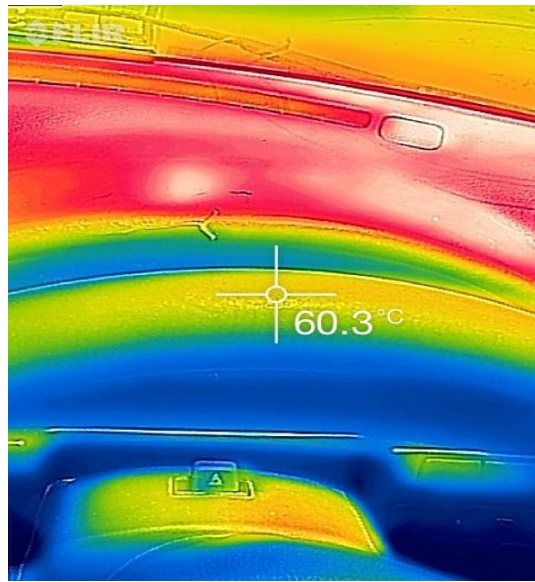


Figure 4.22 Thermal image of steering wheel on day 2

- **For Day 4:**

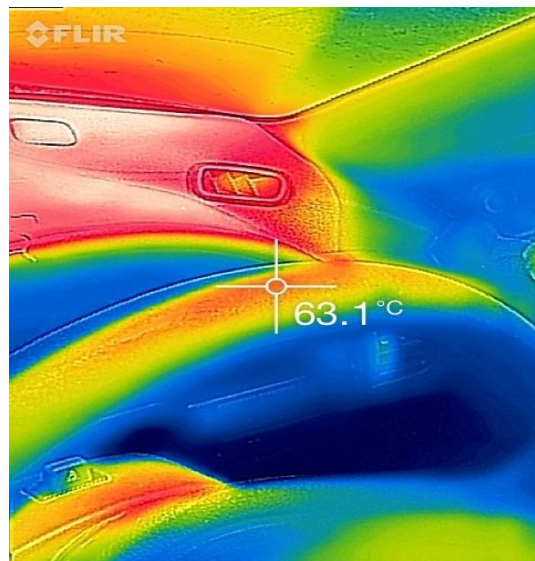


Figure 4.23 Thermal image of steering wheel on day 4

From Fig. 4.23, it can be observed that the maximum temperature of the steering wheel rises up to only 63.1°C on day 4 similar to the case as on day 2 for same atmospheric temperature when the extractor fans are in on state during the peak time of the day. The process of cross ventilation helps in reducing the rise in temperature by almost the same amount as in case of day 2.

- **For Day 6:**

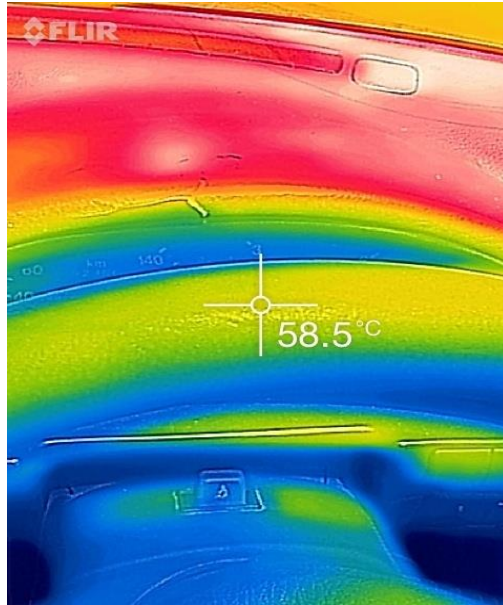


Figure 4.24 Thermal image of steering wheel on day 6

From Fig. 4.24, it can be observed that the maximum temperature of the steering wheel rises up to only 58.5°C on day 6 as compared to 77.8°C on day 5 for same atmospheric temperature when the extractor fans are in on state during the peak time of the day. The process of cross ventilation helps in reducing the rise in temperature by 19.3°C.

4.3.5 Comparison of cabin temperature under different conditions

The following results show the comparison of the average cabin temperature when the extractor fans are in on and off state with the atmospheric temperature:

Table 4.8 Experimental results of comparison of average cabin temperature

S No.	Time	Average Cabin Temperature (°C) (Fans OFF)	Average Cabin Temperature (°C) (Fans ON)	Average Atmospheric Temperature (°C)
1	10:00 AM	50.01	44.46	40.05
2	10:10 AM	55.24	48.25	40.26
3	10:20 AM	59.18	50.45	40.4
4	10:30 AM	61.41	51.60	40.55
5	10:40 AM	62.91	51.65	40.78
6	10:50 AM	63.44	52.68	41.1
7	11:00 AM	64.61	52.86	41.45
8	11:10 AM	65.28	53.8	41.78
9	11:20 AM	66.22	54.23	42.18
10	11:30 AM	66.51	54.74	42.58
11	11:40 AM	66.87	55.09	42.76
12	11:50 AM	67.30	55.41	43.05
13	12:00 PM	67.71	55.55	43.3
14	12:10 PM	67.98	55.72	43.6
15	12:20 PM	68.13	56.45	43.86
16	12:30 PM	68.38	56.76	44.08
17	12:40 PM	68.31	56.66	44.23
18	12:50 PM	68.09	55.92	44.3
19	1:00 PM	68.04	55.44	44.15
20	1:10 PM	67.77	55.03	43.98
21	1:20 PM	67.26	54.73	43.71
22	1:30 PM	66.74	54.65	43.5
23	1:40 PM	65.87	54.16	43.28
24	1:50 PM	63.65	53.99	42.96
25	2:00 PM	62.34	53.68	42.61
26	2:10 PM	59.99	53.46	42.3
27	2:20 PM	57.93	53.01	42
28	2:30 PM	56.02	52.51	41.81
29	2:40 PM	54.53	52.43	41.45
30	2:50 PM	53.32	51.99	41.2
31	3:00 PM	52.67	51.51	40.9

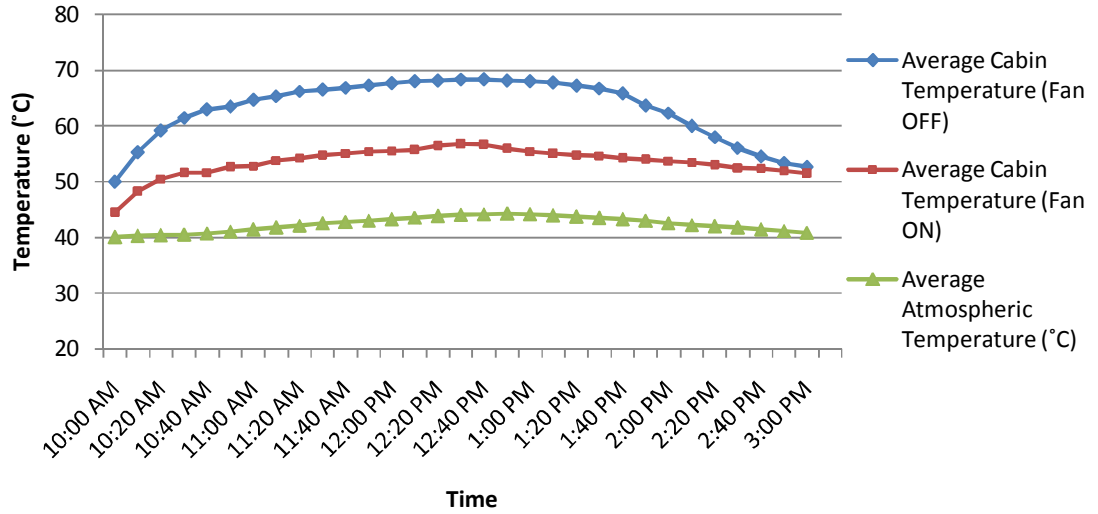


Figure 4.25 Comparison of average cabin temperature with extractor fans in on and off state

Figure 4.25 shows the behaviour of the change of average cabin temperature when the extractor fans are in on and off state and average atmospheric temperature. It can be observed that the variation in the average atmospheric temperature is about 4°C to 5°C throughout the span of 5 hours. As the time progresses, there is an incremental shift in the average cabin temperature when the extractor fans are in on and off state. When the extractor fans were in off state, the temperature difference between the atmospheric air and the cabin of the car was about 23°C to 24°C at the peak time of the day when the Sun is overhead. But later when the extractor fans were in on state, the average cabin temperature reduced by about 13°C and the difference in temperature of the atmosphere and the cabin was reduced by about 50%.

4.3.6 Comparison of dashboard temperature under different conditions

The following results show the comparison of the dashboard temperature when the extractor fans are in on and off state with the atmospheric temperature:

Table 4.9 Experimental results of comparison of average dashboard temperature

S No.	Time	Average Dashboard Temperature (°C) (Fans OFF)	Average Dashboard Temperature (°C) (Fans ON)	Average Atmospheric Temp (°C)
1	10:00 AM	69.2	58.16	40.05
2	10:10 AM	76.8	60.3	40.26
3	10:20 AM	80.13	62.1	40.4
4	10:30 AM	82.43	63.46	40.55
5	10:40 AM	83.3	63.93	40.78
6	10:50 AM	84.43	65.06	41.1
7	11:00 AM	86.7	65.23	41.45
8	11:10 AM	87.56	66.86	41.78
9	11:20 AM	88.43	67.93	42.18
10	11:30 AM	88.56	67.96	42.58
11	11:40 AM	88.7	68.8	42.76
12	11:50 AM	89.1	68.6	43.05
13	12:00 PM	89.9	69.63	43.3
14	12:10 PM	90.6	69.9	43.6
15	12:20 PM	90.73	70.56	43.86
16	12:30 PM	90.9	71.2	44.08
17	12:40 PM	90.8	70.4	44.23
18	12:50 PM	90.6	69.86	44.3
19	1:00 PM	90.36	69.2	44.15
20	1:10 PM	89.63	68.76	43.98
21	1:20 PM	89.06	67.83	43.71
22	1:30 PM	86.56	67.33	43.5
23	1:40 PM	83.83	67.2	43.28
24	1:50 PM	80.7	66.4	42.96
25	2:00 PM	78.76	65.4	42.61
26	2:10 PM	76.36	64.46	42.3
27	2:20 PM	74.23	63.3	42
28	2:30 PM	69.23	61.4	41.81
29	2:40 PM	65.03	60.86	41.45

30	2:50 PM	62.2	59.9	41.2
31	3:00 PM	60.63	59.43	40.9

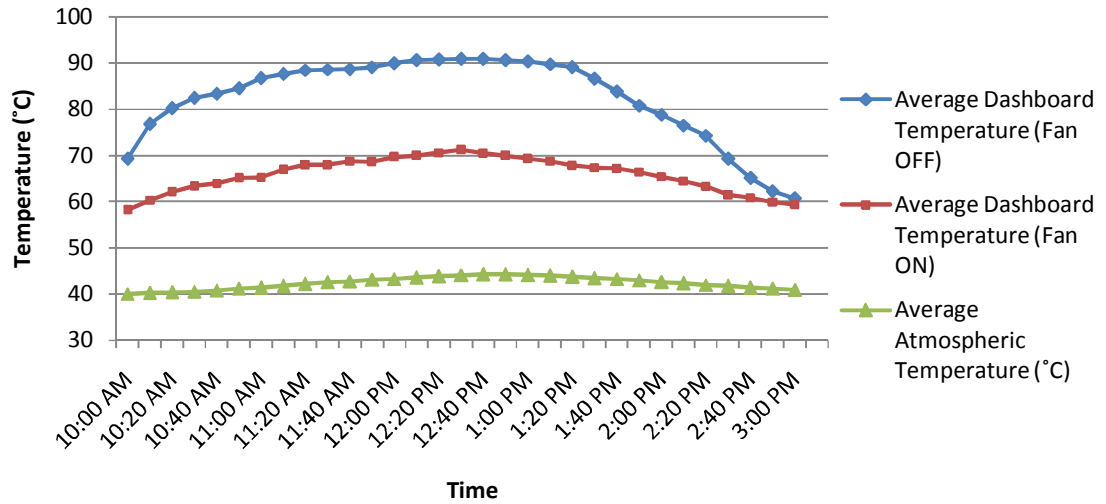


Figure 4.26 Comparison of average dashboard temperature with extractor fans in on and off state

Figure 4.26 shows the behaviour of the change of average dashboard temperature when the extractor fans are in on and off state with average atmospheric temperature. It can be observed that the variation in the average atmospheric temperature is about 4°C to 5°C throughout the span of 5 hours. As the time progresses, there is an incremental shift in the average dashboard temperature when the extractor fans are in on and off state. When the extractor fans were in off state, the temperature difference between the atmospheric air and the dashboard of the car was about 45°C to 47°C at the peak time of the day when the Sun is overhead. But later when the extractor fans were in on state, the average dashboard temperature reduced by about 20°C to 21°C and the difference in temperature of the atmosphere and the cabin was reduced by about 45%.

4.3.7 Comparison of steering wheel temperature under different conditions

The following results show the comparison of the steering wheel temperature when the extractor fans are in on and off state with the atmospheric temperature:

Table 4.10 Experimental results of comparison of average steering wheel temperature

S No.	Time	Average Steering Wheel Temperature (°C) (Fans OFF)	Average Steering Wheel Temperature (°C) (Fans ON)	Average Atmospheric Temp (°C)
1	10:00 AM	62.93	46.73	40.05
2	10:10 AM	69	52.4	40.26
3	10:20 AM	73.46	54.3	40.4
4	10:30 AM	75.7	56.03	40.55
5	10:40 AM	77.56	56.23	40.78
6	10:50 AM	78.43	57	41.1
7	11:00 AM	79.86	57.1	41.45
8	11:10 AM	80.7	58.76	41.78
9	11:20 AM	81.7	59.73	42.18
10	11:30 AM	81.83	59.6	42.58
11	11:40 AM	82.03	59.9	42.76
12	11:50 AM	82.4	59.6	43.05
13	12:00 PM	82.73	59.93	43.3
14	12:10 PM	83.36	59.7	43.6
15	12:20 PM	83.16	60.83	43.86
16	12:30 PM	83.23	61.86	44.08
17	12:40 PM	83.43	61.43	44.23
18	12:50 PM	82.63	60	44.3
19	1:00 PM	82.5	59.2	44.15
20	1:10 PM	81.96	58.66	43.98
21	1:20 PM	81.33	59.03	43.71
22	1:30 PM	78.83	58.03	43.5
23	1:40 PM	76.53	57.5	43.28

24	1:50 PM	73.7	56.66	42.96
25	2:00 PM	71.33	56.43	42.61
26	2:10 PM	66.76	56.5	42.3
27	2:20 PM	64.23	55.83	42
28	2:30 PM	61.13	54.66	41.81
29	2:40 PM	60.16	53.4	41.45
30	2:50 PM	58.3	52.03	41.2
31	3:00 PM	57.43	51.53	40.9

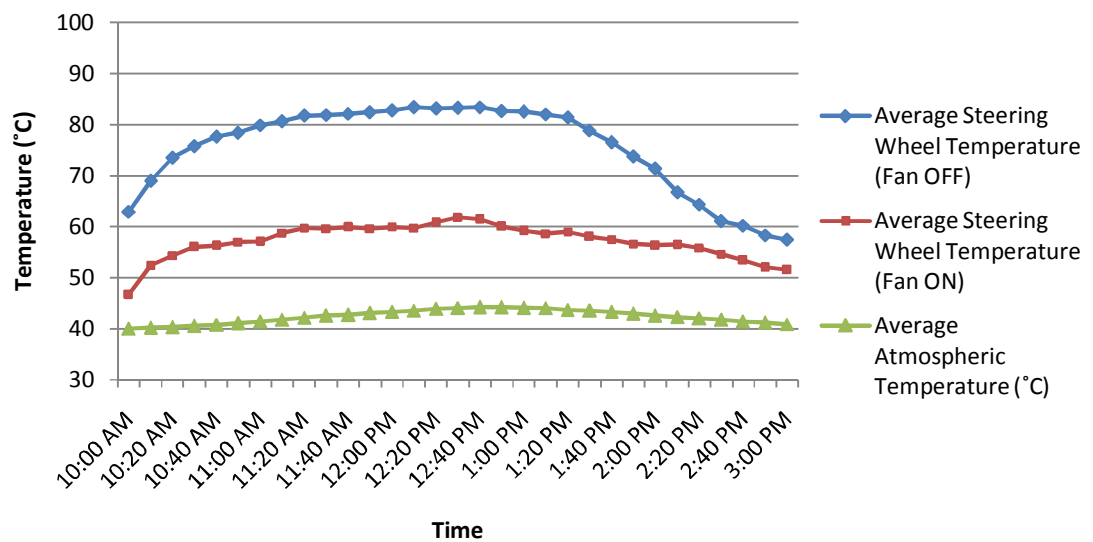


Figure 4.27 Comparison of average steering wheel temperature with extractor fans in on and off state

From fig. 4.27, it can be observed that the variation in the average atmospheric temperature is about 4°C to 5°C throughout the span of 5 hours. The figure shows the behaviour of the change of average steering wheel temperature when the extractor fans are in on and off state and average atmospheric temperature. As the time progresses, there is an incremental shift in the average steering wheel temperature when the extractor fans are in on and off state. When the extractor fans were in off state, the temperature difference between the atmospheric air and the steering wheel of the car was about 38°C to 40°C at the peak time of the day when the Sun is overhead. But later when the extractor fans were in on state, the average steering

wheel temperature reduced by about 20°C to 22°C and the difference in temperature of the atmosphere and the cabin was reduced by about 55%.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

Experiments were performed in a Maruti Esteem car using two extractor fans and LM-35 temperature sensors by maintaining a cross ventilation of air in the car cabin.

The thesis concludes with the following remarks:

- A car was parked under direct sunlight so as to observe amount of temperature rising in the vehicle by placing temperature sensors at thirteen different places in the car cabin. It was observed that there was very high temperature (71°C) in the cabin and it is reduced to 54 °C after using the ventilation fans.
- The experimental results obtained with the help of thermal sensors are in good agreement with the temperature recorded by the thermal imaging camera.
- Provision of cross ventilating fans inside the car reduces the peak temperature of 95.7°C to 70.3°C at the dashboard and 86.2°C to 65°C at the steering wheel.
- The instantaneous rise temperature for short duration is reduced to appreciate value of 11 °C to 13 °C when ventilation fans were used in parked car.
- A significant decrease in air conditioning cooling loads is observed as the 15 minutes cooling shows an improvement of 7°C inside the cabin.

5.2 Scope of Future Work

Based on the work conducted in this thesis, the following are the possible areas where work can be done in the future:

- Varying the speed of extractor fans which can lead to use of cheaper fans and operate on less power.
- Possibilities can be explored for the solar panel and battery set-up placed on the roof of the car to avoid discharging of car main battery when the fans are in operation for long duration.

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