

Study of Passenger Comfort in Vehicle Cabin

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by

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July, 2015


CERTIFICATE

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Dedicated to
My parents and friends

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Abstract

Thermal Comfort in Passenger Vehicle is of major concern for car manufacturers and customers. One of the defining factors of thermal comfort is air velocity. Conventional fan used in vehicle for circulation of conditioned air does not provide desired air velocity to rear passengers. Fan at its highest speed does produce a lot of noise inside the vehicle cabin which hampers noise comfort as well. Thermal and Noise comfort are two vital factors contributing a safe drive.

The main objective of this work is to improve thermal comfort for rear passengers inside the vehicle cabin and by doing so improving noise comfort level as well. In the present work, low noise axial fans are embedded in headrest whose direction can be controlled independently by rear passengers. Modelling of car seat and fan assembly is done and computer simulated results are used to validate the experimental results.

Key words: Thermal comfort; Thermal sensation; Noise comfort; Air velocity; Air temperature.

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Acronyms

ASHRAE= American Society of Heating, Refrigerating and Air Conditioning Engineers

MRT= Mean Radiant Temperature

HVAC= Heating, Ventilating and Air Conditioning

SUV= Sports Utility Vehicle

MUV= Multi Utility Vehicle

PMV= Predicted Mean Vote

PPD= Predicted Percentage Dissatisfied

EHT= Equivalent Homogenous Temperature

CFD= Computational Fluid Dynamics

CIL= Clear Insulated Laminated Tint

GIL= Green Insulated laminated Tint

A.C.= Air Conditioner

PCB= Printed Circuit Board

Chapter 1

Introduction

1.1 Introduction

In modern world, vehicles are supposed to be people's main means of transportation. People spend much of their time in vehicles during a day. Either riding or driving is considered as our part of life. So passengers comfort in vehicle cabin is considered very important. In last few decades scientists are really pushing the limits in the field of thermal comfort in vehicles and have made a lot of breakthroughs. Thermal comfort, traffic safety as well as health of passengers in vehicle cabin are all dependent upon the working and efficiency of air conditioning system in vehicle. Passenger's thermal comfort has been the critical concern throughout the development of automobile as thermal comfort affects the automobile's driver arousal level and ability to concentrate. Nowadays thermal comfort does play an important role in decision making of the customers, and that is why automotive companies do take this reason into account in its automobile development.

1.1.1 Background and motivation

The reason why enormous effort needs to be put in improving the vehicle thermal environment and comfort is due to significant role it plays in human's life. Passengers cannot stand up the burning hot summer or freezing cold winter without proper conditioning of air in cabin. Especially for kids and old people to survive in a cabin which may reach temperature up to 90 degrees is a bit too risky if vehicle is not air conditioned properly. Lakhs of people have lost their lives and it has been found that in many cases driver's arousal level and concentration ability were not up to the mark which highlights the fact that thermal environment must be well designed and there is a great scope in improving it. On the other hand some regulations have been set to meet the demand of energy conservation and emission reduction. Hence research in field of thermal comfort not only improves thermal environment but also reduces fuel consumption as well.

1.1.2 Thermal Comfort

ASHRAE standards define thermal comfort as that state of mind which expresses satisfaction with the thermal environment [1]. Thermal comfort in vehicles represents a subjective sensation of heat balance that occurs in the human body when environmental parameters as well as personal factors are considered. Figure 1.1 shows factors affecting thermal comfort.

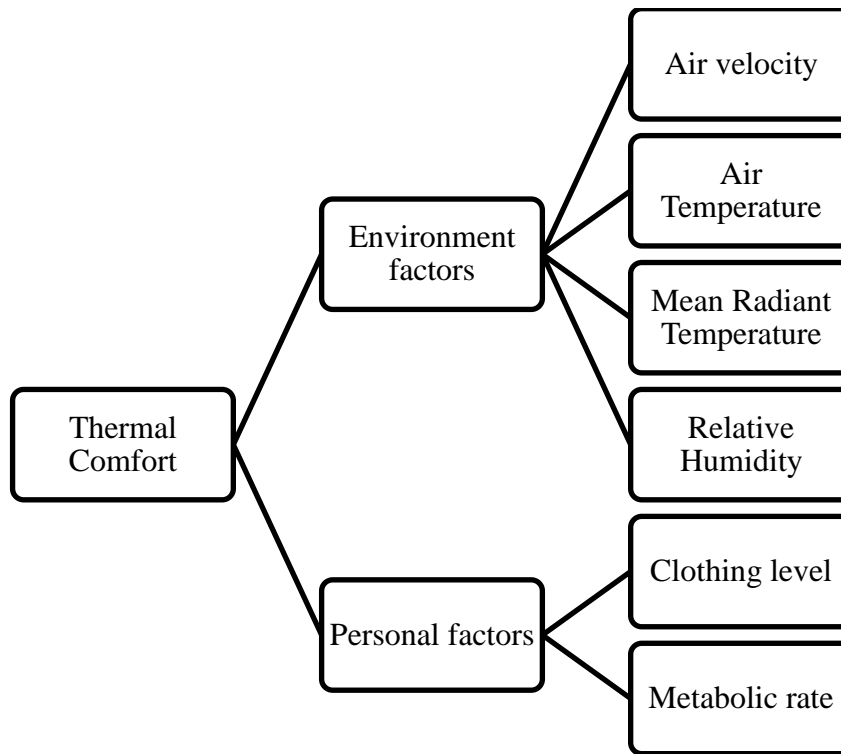


Figure 1.1: Factors affecting thermal comfort

Air Velocity:

International standard ASHRAE 55 define air velocity with respect to thermal comfort as the average speed of the air to which the body is exposed, with respect to location and time. The maximum air velocity allowed inside a vehicle is found to be a function of the air temperature that is determined by the convection heat exchange between the human body and environment. Measurements should be carried out approximately 3-5 minutes due to air fluctuations to obtain a reasonable average value. Air flow sensation is subjective which varies according to the person's sensitivity (some parts of the body are more sensitive, e.g. nape). Volume of air coming out from air vents is limited inside the vehicle cabin due to its reduced volume and hence can be directed

to smaller sections (as opposed to buildings). The direction of hot air should be toward the bottom half of the occupant's body and the cool air should be directed toward the upper half. Many researchers have found out that in a warm environment, higher air flow could provide a thermal comfort.

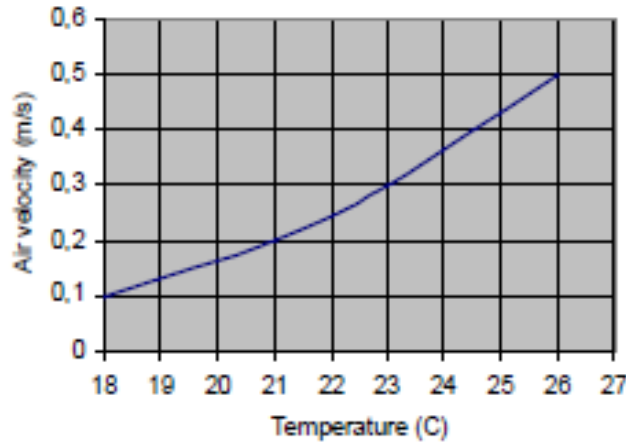


Figure 1.2: Air flow vs Temperature curve [1]

Figure 1.2 shows the correlation between the air velocity limit and the inside air temperature. As it can be seen in this figure the limits of air velocity values increase at high air temperature values.

Air Temperature:

The air temperature is the average temperature of air surrounding the occupants, with respect to location and time [2]. According to ASHRAE 55 standard, the spatial average takes into account the ankle, waist and head levels, which vary for seated or standing occupants. Dry bulb thermometer is the instrument which measures air temperature and that is why air temperature is also termed as dry bulb temperature. What should be optimum temperature inside vehicle cabin is a function of season time. Air temperature zones inside the vehicle cabin are not homogenous due to localized solar flux, and radiation heat load which makes it even more challenging to study air temperature pattern inside the vehicle cabin.

Moreover, air temperature in vehicle cabin also varies with “class” of vehicle depending upon the size of vehicle and how luxurious it is. For example a large vehicle which has leather upholstery may exhibit entirely different air temperatures than a small economy vehicle during

same driving conditions in warm up conditions. Thermal comfort is supposed to be in the range of 22-26 °C and thermal neutrality is maintained in this range [3].

Mean Radiant Temperature:

The amount of heat transferred from a surface is related to mean radiant temperature and material's ability to absorb or emit heat or its emissivity is the major factor concerning mean radiant temperature [2]. It is also dependent upon the temperature and emissivity of surrounding surface. And one of the critical factors is view factor. The mean radiant temperature (MRT) is the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space [1]. MRT represents the mean temperature of all the objects surrounding the body. MRT will be positive when surrounding objects are warmer than the average skin temperature and negative when they are colder. MRT governs human energy balance and human body heat losses, especially on hot sunny days [1].

Relative Humidity:

ASHRAE Standard 55 defines relative humidity as the ratio of the partial pressure of water vapor in a gaseous mixture of air and water vapor to the saturated vapor pressure of water at a prescribed temperature [3]. It needs to be measured at only one position in vehicle cabin as water vapor pressure is uniform in cabin. Optimum relative humidity is around 50% regarding thermal comfort sensation [1]. Humidity does not play a crucial role in deciding thermal comfort but relative air humidity is closely related to inside air temperature which does play a significant role in obtaining thermal comfort. Figure 1.3 shows correlation between temperature and humidity.

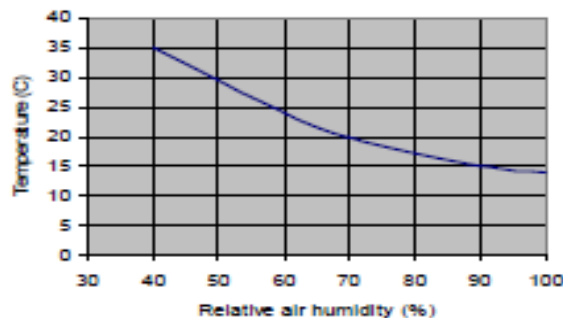


Figure 1.3: Correlation between temperature and relative humidity [1]

Metabolic Rate:

The ASHRAE 55-2010 Standard defines metabolic rate as the level of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism. Metabolic rate is expressed in met units. Different people have different metabolic rates that can fluctuate due to activity level and environmental conditions [2]. Food and drink habits may have an influence on metabolic rates, which indirectly influences thermal preferences. These effects may change depending on food and drink intake. Body shape is another factor that affects thermal comfort. Heat dissipation depends on body surface area. A tall and skinny person has a larger surface-to-volume ratio, can dissipate heat more easily, and can tolerate higher temperatures more than a person with a rounded body shape [2].

Clothing Insulation:

The amount of clothing level worn by an occupant also has a significant effect on thermal comfort as it can influence the heat loss and therefore the thermal balance. Skin temperature of different body parts is also different regardless of clothing level. Figure 1.4 shows relation between skin temperatures of different body parts and inside air temperature in closed space.

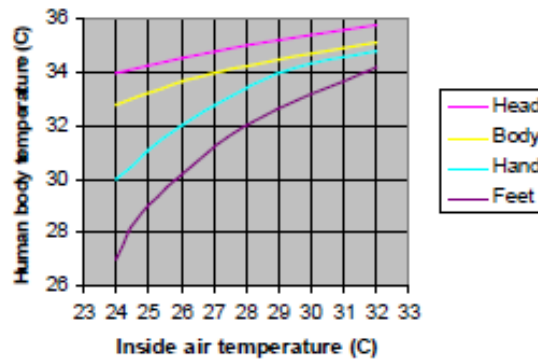


Figure 1.4: Skin temperature of different body parts versus inside air temperature [1]

1.2 Reasons to study thermal comfort

Production of automobiles is increasing day by day and with that installation of air conditioning unit (HVAC) in automobiles as well. So penetration of air conditioner in automobiles is increasing with an exponential trend. The sole and foremost important purpose of air conditioning unit is to achieve and maintain thermal comfort for all the passengers even in extreme climate conditions, and to guarantee good visibility, providing an effective defrosting

and defogging. Figure 1.5 shows the increasing trend of HVAC installation in automobiles throughout the world.

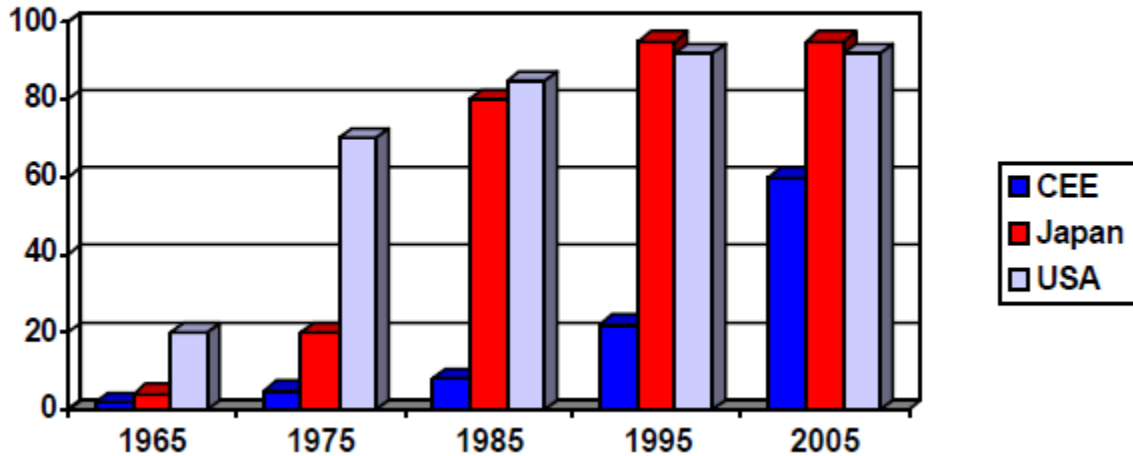


Figure 1.5: Percentage of vehicles equipped with an HVAC system [4]

In today's world approximately 93% of vehicles are equipped with an air conditioning unit [1]. By looking at this data it can be said with surety that air conditioner is already considered essential for vehicles and efforts must be put on in this field to find out whether the aim of HVAC is fulfilled and if not than what are the reasons behind it. And it has been found out that with installation of HVAC, tailpipe emissions are almost doubled [1]. So there is a greater concern regarding environment as well to study thermal comfort in vehicles.

1.3 Reasons to study thermal comfort in India

Take Asia, as an example for the number of vehicles equipped with air conditioning units.

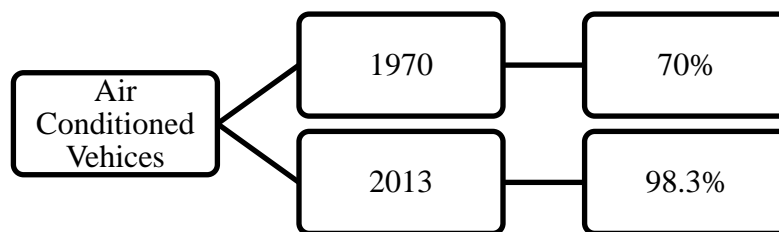


Figure 1.6: Increase in air conditioned vehicles in Asia [2]

Figure 1.6 shows the increase in air conditioned vehicles in Asia. Due to the long summer season in India and most parts of the country are facing extreme hot and humid environment. Hence more cars are produced with HVAC installed in them.

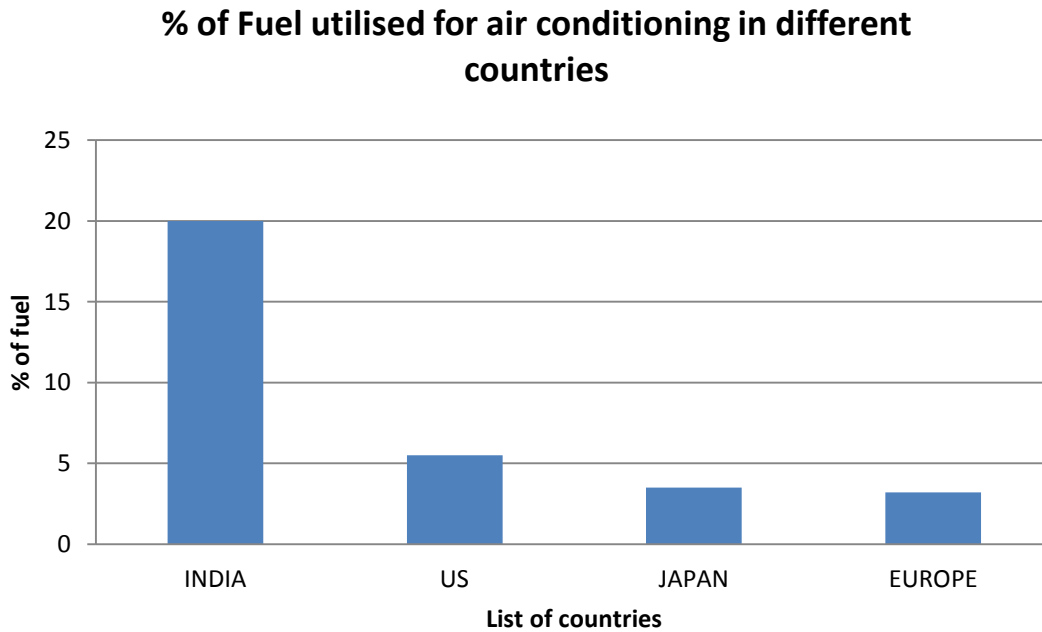


Figure 1.7: % of fuel utilized for air conditioning [5]

Figure 1.7 shows % of fuel used for air conditioning in automobiles across different countries in the world. In India's hot and humid climate, operation of vehicle air conditioners can account for up to 20 percent of fuel consumption, compared to about 3.2 percent in Europe, 3.5 percent in Japan, and 5.5 percent in the U.S. [5]. That's why special effort should be put in India to study thermal comfort as huge chunk of fuel is being used for air conditioning.

There is a tremendous growth in automobile production in India as well. India is the 5th largest producer of automobiles in terms of cars [6]. India is producing approximately 3 million cars per year. It means a large amount of fuel is being spent on air conditioning as there are a lot of cars running on Indian roads and 20% of that fuel is being utilized for air conditioning. Right now there are approximately 40 million cars in India [6].

85% of trips worldwide have an average distance of 18 km. This amounts to 15-30 minute of duration. So the first 15-20 minutes is most crucial period in terms of thermal comfort for the occupants [4].

Vertical temperature difference at the rear seats should not be more than 5°C [6]. But it has been found in most cases that vertical temperature difference reaches up to 10°C which is not beneficial for obtaining thermal comfort for rear passengers. 34% of total petrol used in India is just for running cars and 20% of it is being used for air conditioning. 13% of total diesel used in India is for cars and 20% of it is being used for air conditioning [6].

Consumption of Fuel in Passenger Car

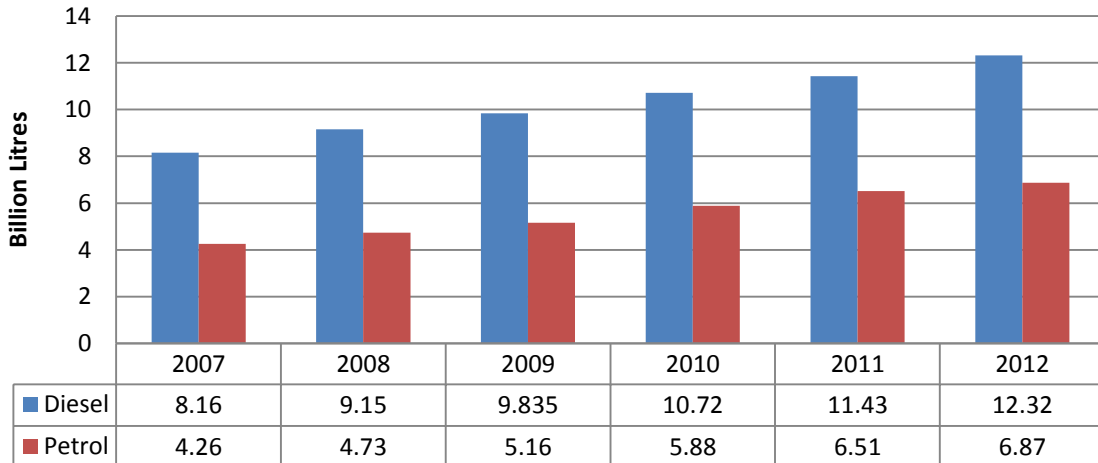


Figure 1.8: Consumption of fuel with respect to year [6]

Figure 1.8 shows the amount of fuel which is being used to run the cars in India. And to calculate amount of fuel being used just to air condition the vehicle, 20% of this amount is suggested [5].

Consumption of Fuel for Air Conditioning

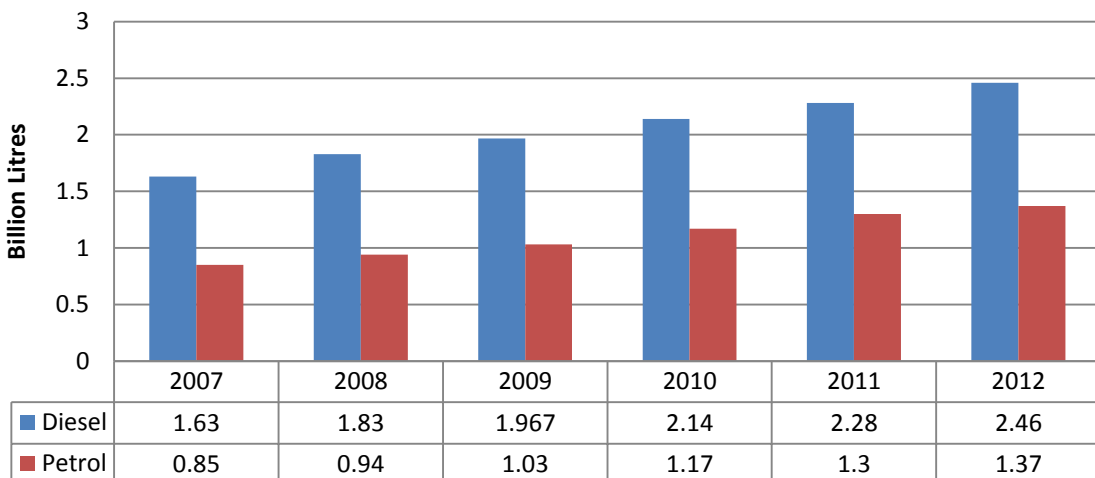


Figure 1.9: Consumption of fuel for air conditioning with respect to year in India [6]

Figure 1.9 shows consumption of fuel for air conditioning in automobiles in different years in India.

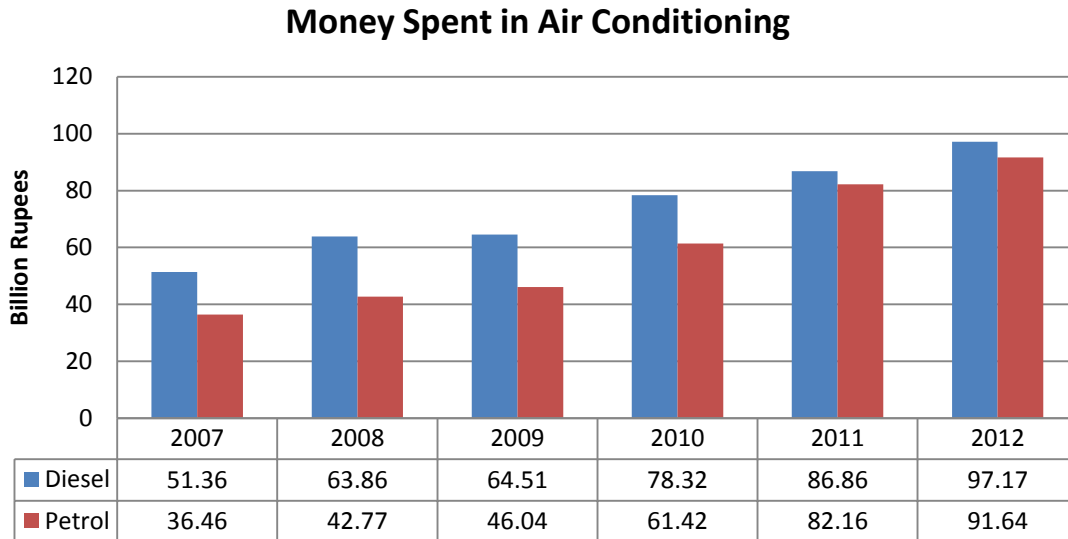


Figure 1.10: Money spent in air conditioning with respect to year [6]

Figure 1.10 shows total amount of money spent just for air conditioning of the vehicle in different years in India. This amount of money is being spent on air conditioning so as to achieve the sole purpose of achieving thermal comfort of all occupants inside the vehicle cabin but still there are some serious doubts hanging around it. So there is a strong reason in India to get into this field and by doing so look for furthermore improvements.

1.4 Area of research

The main purpose of controlling vehicle cabin temperature is being fulfilled by HVAC but to achieve thermal comfort for all passengers is altogether a different task. Two crucial factors affecting thermal comfort are Air velocity and Air temperature. Air velocity inside the cabin should be up to level so that all passengers should have comfort sensation. But in doing so there should not be that much of noise created in air ducts and vehicle cabin so that noise discomfort occurs. Rear passengers do face a problem in having an optimum air velocity and hence thermal comfort of rear passengers is always difficult to achieve as well as to maintain. Hence to provide better air velocity, ducts are provided for rear passengers that acquire a lot of cabin space and also affect the aesthetics of vehicle cabin. This also leads to increase in price of the automobile.

Many vehicles do have separate air conditioning units for rear passengers to provide better air velocity and conditioned air as well which increases the vehicle cost as well. If air velocity and air circulation inside the vehicle cabin is increased and still maintaining noise comfort as it can hampers driver's concentration and by doing so does not increase the price of automobile and can achieve thermal comfort of rear passengers in lesser time than it will be really helpful in saving a lot of money as well as improving thermal comfort in lesser time.

So the sole purpose of research is to provide better air velocity and air circulation for rear passengers at lesser noise level in comparison to conventional design and achieving their thermal comfort in lesser time because 85% of trips have average duration of 15-30 min [4] and in doing this does not increase the price of an automobile.

1.5 Organization of Thesis

Seven chapters are included in this Thesis. Overview of the information included in the various chapters is as follows:

First chapter includes the introduction part which includes explanation of thermal comfort and problems in achieving it inside vehicle cabin. And also why there is need to study thermal comfort especially in India.

Literature review regarding thermal comfort, factors affecting thermal comfort, how to calculate it, and how to achieve it is included in second chapter. Literature review summary and problem formulation is also included in this chapter.

Methodology is explained in third chapter which briefly describes steps followed in present work.

Fourth chapter is modelling and simulation in which part model of required components is developed and then simulation results are gathered.

Fifth chapter is Validation through experimental setup in which different equipment used in present work is mentioned.

Results and discussion contributes to sixth chapter in which results are obtained for different cases and brief discussion is then represented.

Chapter seven includes Conclusions and future scope which contributes to various conclusions of present work and its future scope as well.

Chapter 2

Literature Review and Problem Formulation

2.1 Literature review

Musat *et. al.* [1] examined different thermal comfort parameters and various models to study thermal comfort inside the vehicles. Standard air temperature inside car cabin varies according to class to which it belongs i.e. hatchback, sedan, SUV and MUV. ASHRAE standards 55 prescribe 3°C vertical air temperature difference between head and ankle level. Air velocity inside vehicle is a function of air temperature. Air flowing through open windows increases thermal discomfort. Because of reduced volume airflow can only be directed towards smaller sections inside the vehicle cabin. Considering thermal comfort cool air should be directed towards upper half of passenger's body and heated air should be directed towards bottom half. Humidity plays a minor role in thermal comfort and optimum relative humidity is about 50%. Fanger's thermal comfort model suggests that thermal comfort can be predicted if all six environmental factors are known. Thermal comfort can be analyzed by Predicted mean vote (PMV) and discomfort by Predicted percentage dissatisfied (PPD). The value of the PMV index has a range from -3 to +3, corresponding to human sensations from cold to hot respectively, where the null value of the PMV index represents neutral sensation. Analysis of thermal comfort using thermal manikin gives best solution for thermal control and it can also be used to calculate clothing and chair insulation.

Amit *et. al.* [2] studied different vent shapes and its effect retaining same duct geometry in every case for thermal comfort of passengers. Effect of vent shapes on velocity at vent outlet, overall flow distribution from ducts and pressure drop across ducts is studied. Fluent is used to solve convective heat transfer as it is decoupled from other two modes. Conduction and radiation modes are analyzed in Radtherm taking input as results of convective heat transfer. Car cabin was modeled in Catia. In this work it is concluded that among different vent shapes circular vent shapes give better results by giving thermal comfort for passengers and better airflow distribution inside the cabin considering same duct geometry and opening area. There is total

improvement from 0.5 to 2 in case of thermal sensation of passengers for circular vents with same opening area. Also, compared with vent shapes, the circular vent leads to a 5% reduction in temperature at chest level of manikin.

Victor et. al. [4] focused on human temperature regulating system, its functioning, adaptability and the consequences of thermal information on sensation and comfort. It has been found that core temperature of body is 37°C and it varies between 36°C during night and 39°C during heavy exercises. Thermal climate in cabs is also studied in this work. It is found that penetration of HVAC in European market is increasing at an exponential rate as 90% of vehicles are equipped with air conditioning units. Studies shows that 85% of trips have average distance less than 18 km and with time duration of 15 to 30 minutes. The vertical temperature difference should not be greater than 3°C but in few studies it has been proven that in case of cold head and warm feet person can accept much more than this difference. Even if passenger is thermally neutral or there is no heat exchange between body and environment but passenger may still feel discomfort due to unwanted local cooling or heating on some parts of body.

NRDC et. al. [5] has proved that in India, vehicle air conditioners can account up to 20% of fuel consumption as compared to about 3.2% in Europe, 3.5% in Japan and 5.5% in US. Therefore it is vital to study thermal comfort in India.

Mariana et. al. [7] studied distribution of air flow and temperature inside passenger compartment based on body's energy balance using Fiala's manikin which provides all the thermo-physiological effects of the human body model by THESEUS-FE software Air flow simulation is done in ANSYS fluent. The influence of inhomogeneous air velocity and air temperature from air conditioning system creates a kind of climate that may vary considerably in space and time. Concluded results were that thermal comfort is reached better where air flow rate is bigger, but keeping same air temperature.

Nielsen [8] stated some facts regarding petrol and diesel consumption in India and future predictions as well. 34% of total petrol used in India is just for running cars and 20% of it is being used for air conditioning. 13% of total diesel used in India is for cars and 20% of it is being used for air conditioning.

Lustbader [9] presented that by improving the ways by which conditioned air is delivered is an effective way to improve thermal comfort at little energy cost, resulting in reduced fuel usage. Seats in vehicles are well suited for efficient delivery of conditioned air due to their large area of

with and close proximity to the passenger. A seat acts as a thermal insulator that leads to increase in skin temperature and reduces evaporation of sweat that results in less cooling. Ventilations in a seat has low energy costs and eliminates this insulating effect while increasing evaporative cooling thus in this work ventilated seat is developed and hence proved that the ventilated seat decreases steady state seat back temperature by 3.5°C and increases thermal comfort especially at passengers back and by doing so cooling capacity of HVAC can be reduced by 4% which results in reduction of car air conditioner fuel use by 3%.

Fiser *et. al.* [10] focused on the amount of air supplied by air conditioning unit into a car cabin which is one of main parameter for correct simulation and prediction of car cabin heat load and this amount of air is not based on HVAC settings but depends on actual operating conditions. It has been found out that supply flow rate is strongly dependent on speed of car when fan speed is set at second level.

Madhavi *et. al.* [11] presented field study in warm humid climates in India and concluded that thermal comfort is successfully obtained using fans and air movement preference varied with temperature. It is also concluded that humidity has a little effect on air movement preference.

Dragan [12] suggested that due to temporal and spatial variation of boundary conditions and state variables in the vehicle cabin heating, ventilating and air-conditioning (HVAC) does not have to be designed to provide a uniform environment because of individual differences regarding to physiological and psychological responses including clothing insulation, activity, air temperature and air movement preference. Therefore the system should be able to generate preferred local environmental conditions even on individual body part level. Results prove that values proposed by standards could be too restrictive and preferable conditions are biased towards higher air velocities.

Tabacu *et. al.* [13] studied that the environmental conditions in the vehicle cabin is very inhomogeneous. The varying radiation from the sun and the effect of inhomogeneous air velocity and air temperature from the vehicle's ventilation or air conditioning system creates a climate that may vary considerably in time and space.

Alok *et. al.* [14] stated that vehicle cabin is complex man-machine interface and two main goals of heating ventilation and air conditioning System is to provide thermal comfort and save energy. Thermal Comfort varies person to person and is a subjective feeling therefore it is very hard to model mathematically. Thermal comfort depends on many variables such as temperature,

relative humidity, radiation and air velocity. Fuzzy logics are used to design mathematical model of car. Fuzzy controller is designed for cabin to control the cabin temperature. A simplified mathematical model is considered where air temperature and the air velocity inside car cabin are the only two variables. The temperature is used as the feedback signal in fuzzy controller. The major goal of controller is to provide thermal comfort while minimizing energy consumption. Evaporator cooling capacity was selected as criterion for energy consumption.

Charlie *et. al.* [15] developed a virtual thermal comfort engineering model to predict the passenger cabin environment and thermal comfort. This study also includes the effect of different solar incidence angles and solar radiation. It has been proved that the proposed model is capable to find out air temperature and thermal comfort inside the vehicle cabin. Equivalent Homogenous Temperature (EHT) is used to quantify thermal comfort in inhomogeneous thermal environments.

Huang *et. al.* [16] proposed an “Airflow Management” system to control the airflow in the passenger cabin in order to achieve a regional steady-state temperature. With this new concept, each passenger in a different area of the vehicle cabin can be satisfied with respect to their unique temperature demands. Flow of air is controlled by air inlets and outlets installing fans for the modulation of airflow directions and rates. Cabin is divided into four regions having different temperatures to meet different personal demands.

Kamar *et. al.* [17] used computational fluid dynamics (CFD) numerical method to monitor the effect of different glazing types affecting the air-temperature field inside the vehicle cabin under the steady-state conditions. Different glazings are applied on front and rear windscreens. Two types of glazing are used viz clear insulated laminated tint (CIL) with a shading coefficient of 0.78 and green insulated laminate tint (GIL) with a shading coefficient of 0.5. It has been found that the temperature of the air around the driver is slightly lower than the air around the rear passenger for a specified glazing material. The use of GIL glazing material on both the front and rear windscreens reduces the air temperature inside vehicle cabin and thus provides better thermal environment to the occupants. Level higher than the waist of the occupants experiences swirling air flow conditions in vehicle cabin. This study concluded that the use of glazing materials on both the front and rear windscreen has no significant effects on the air-flow condition inside the vehicle cabin.

Chien et. al. [18] devised a numerical model to calculate the thermal comfort of a vehicle passenger and compare the numerical model's results with experimental results in a warm cabin after the A.C. had been turned on. Model's accuracy is verified by performing different experiments. A 3-D thermal model of fluid flow and heat transfer is developed to simulate a vehicle with a passenger. It has been shown that after the A.C. is turned on, the flow field becomes very complex and average temperature reduces quickly. The flow field and temperature in the passenger cabin slowly started to stabilize after A.C. has been turned on for 10 minutes. After turning on A.C. for 20 minutes the PMV value indicates that only the feet are uncomfortable. Comparing the numerical analysis with experimental results, the predicted temperature distribution of the air in the vehicle cabin is in close proximity with obtained results experimentally.

Kaynakli et. al. [19] explained a combined theoretical and experimental study of thermal comfort during the soaking time or heating period inside vehicle cabin. Temperature, humidity and air velocity are measured at different locations inside the vehicle cabin so as to monitor the effects of thermal conditions on human body. The human body is divided into 16 segments, and temperature variation is observed both theoretically and experimentally. Heat and mass transfer between the human body and the interior environment of vehicle is simulated by a computational model during transient conditions of soaking period and predictions are compared with the experimental data.

Farzaneh et. al. [20] studied that a temperature feedback controller cannot best achieve the thermal comfort. This is because thermal comfort is influenced by many variables such as, temperature, air velocity, relative humidity, activity level, environmental radiation and clothing insulation. In this work Fanger's predicted mean value (PMV) index is used as feedback to controller. Thermal models of HVAC system and vehicle cabin are developed. Two fuzzy controllers one with temperature as its feedback and the other PMV index as its feedback are designed. Result indicates that the PMV feedback controller is better than the temperature feedback controller. Result proves that thermal comfort level is further increased while energy consumption is decreased.

W.1 <https://www.google.co.in/search?q=rear+ac+vents&biw=1366&bih=599&tbm=isch&tbid=0&source=univ&sa=X&ei=7GBpVbaWEs2ruQSC34GABw&ved=0CBwQsAQ&dpr=1#imgrc=>, 26 May/2015/12.12 pm has shown different design and provisions of rear fans and

ducts provided in vehicle. Different vehicles are shown with different design and problems associated with those design are also highlighted.

W.2 <https://www.cardekho.com/new-cars+rear-ac-vents>, 26 May/2015/12.27 pm.

W.3 <https://shop.flir.com/dp/B00K0PXF6>, 26 May/2015/12.40 pm.

2.2 Literature gaps and problem formulation

Automotive companies adopt a lot of different methods to achieve thermal comfort for rear passengers in vehicle cabin. Providing rear air vents and installing separate air conditioning are two methods which car manufacturers adopt in achieving the above stated aim. Figure 2.1 shows the placement of rear air vents with ducts in rear cabin in between two front seats.



Figure 2.1: Placement of rear air vents in rear cabin of vehicle [W.1]

The rear air vents provided with air ducts can be of different designs viz rectangular, circular, and elliptical shape. Different car manufacturers have opted for different shapes as per their designs. Figure 2.2 shows different designs of rear air vents placed in rear cabin.



Figure 2.2: Different designs of rear air vents [W.1]

Rear air vents and ducts provided in between front seats acquire cabin space and therefore design changes are also need to be done for this sole purpose. Theses rear ducts are provided to transfer the cool air of main air conditioning unit from dashboard to rear vents. There is no provision of extra fan in this rear duct to amplify air. Very few high end car/SUV's have fan in rear duct. The position of rear ducts is also not suitable as per the requirement. Height of exit grill is very low, which is not capable enough to throw air on face of rear passengers seating on door side i.e. behind front seats. Blood circulation in human body is maximum in upper half especially face and head. Feeling of being comfortable starts from environment around head and face. Hence air ducts in middle of front seats is not a perfect solution to achieve thermal comfort of rear passengers. These ducts and rear vents increase the cost of vehicle. Figure 2.3 shows that lot of cabin space is acquired which results in reduced leg space for rear passengers.



Figure 2.3: Reduction in leg space for rear passengers (center) [W.2]

To overcome the above stated problems rear air vents are provided in different positions in vehicle cabin. Figure 2.1 and 2.2 shows the rear air vents in between front seats. Figure 2.4 shows rear air vents provided in side pillars of the vehicle.



Figure 2.4: Rear vents in side pillars of car [W.1]

But this leads to changes in design of vehicle which is costlier approach. Design of side pillars become more complex due to the provision of ducts and transfer pipes up-to C pillars. Maintenance of vehicle is also difficult as to correct any fault in rear vents or pipes in pillars.

Other popular technology used to achieve thermal comfort for rear passengers is to provide separate air conditioning unit in roof of car which will throw conditioned air from different air vents provided in the air conditioning unit. Figure 2.5 shows separate air conditioning unit provided in roof of vehicle.



Figure 2.5: Separate rear air conditioning unit [W.1]

This separate air conditioning unit costs approximately Rs. 20000 to Rs. 25000 and also increases fuel consumption of vehicle. Hence it leads to increase in buying as well as running cost for the customer.

There should be an efficient way of circulating conditioned air in rear cabin of vehicle at a reasonable cost. Design should be simple to make, operate and maintain during its service life. Another alternate of the concerned problem is to increase the air circulation within the cabin. All the passenger vehicles are equipped with only one large fan unit in dashboard assembly. Large fan attached with main air conditioning unit is the only source of air circulation in the vehicle cabin from front to rear. The situation becomes worst for the passengers sitting in rear third row of SUV's and MUV's. To increase air circulation, fan high speed is only alternate in every vehicle. Fan operation at maximum speed increase noise level inside car cabin and decrease cooling rate of air conditioning unit. Increase in noise level due to fan speed and turbulent air may distract the attention of driver which can be a serious problem while driving. It is also observed that passengers/driver increase volume of music system to make it more audible. High fan noise, turbulent air and increased volume level of music system is an important safety concern.

A very little work was published related to increase in air velocity coming out from dashboard vents and recirculation of this amount of air to rear cabin at a faster rate so that thermal comfort of rear passengers can be achieved little faster. In the previous studies more efforts were concentrated on how to control air temperature with the help of fuzzy logics, intelligent air conditioning and to simulate air conditioning with the help of different software so that correct results can be predicted without bearing the cost of experimental setup. Different air vent shapes and their effects have also been studied and circular vents were found to be better in terms of air

flow distribution and achieving thermal comfort for passengers as well. Thermal manikins and Fanger model are believed to be reliable in calculating thermal comfort. Ventilated seats are also a good medium to transfer conditioned air to occupants and thermal comfort of occupants can be achieved in a better way.

85 % of trips have average distance of less than 18 km and average duration of 15 to 30 minutes [4]. So, first 10-15 minutes are very crucial in terms of air conditioning. No work has been done in this field to improve the cabin thermal conditions in the stated time period so that occupant's thermal comfort can be achieved a little faster and with less noise. Thermal comfort of rear passengers should not be delayed due to less air flow in rear cabin. Providing large air flow in rear cabin by increasing fan speed leads to more noise inside vehicle cabin which affects driver's ability to concentrate that leads to accidents. At high fan speed air flow coming out from central vents is directed towards center passenger in rear cabin but air flow coming out from side vents strikes front passengers hence leading to less air flow to rear side passengers.

Aim of the present work is to provide more air flow in rear cabin at low noise so that rear passenger's thermal comfort can be achieved faster and noise comfort of driver as well as all occupants inside vehicle cabin is more. Improved thermal and noise comfort will enhance the driver's ability to concentrate on road while driving.

Chapter 3

Methodology

3.1 Introduction

In the present work fans are installed in central air outlet vents of particular dimensions which will fit into vents so that air velocity in rear cabin increases. Also fan assembly is installed in headrests so that more airflow is directed towards rear passengers. Noise comfort is achieved with the help of these fans as at less fan speed e.g. 2, 3 air velocity is more than or equal to air velocity at fan speed 4. Hence by doing so more air flow is directed towards rear passengers at less noise level. Noise reduction in cabin is achieved with a difference between fan speed 4 and 2. But this difference will be very less affected by installed fans as all are silent fans and do not contribute much in terms of noise. Initially car modeling is done in PTC Creo and then air velocity and thermal analysis is done in ANSYS Fluent. Then air velocity and noise readings are taken at different fan speeds using anemometer and sound level meter respectively. PCB installation of 13 LM 35 temperature sensors is done inside car cabin. Temperature monitoring inside the car cabin is done at different fan speeds without any modifications. Then low noise axial flow fans are installed at central air vents and head rests of front seats facing rear passengers. Modelling and analysis steps are repeated for the same. Air velocity, noise and temperature readings for installed set up are taken and comparisons are done.

3.2 Steps executed

Step 1: Parameters examined in existing model

- Study of cabin temperature at different A.C. blower speed.
- Study of air velocity at different A.C. blower speed.
- Study of noise at different A.C. blower speed.

Step 2: Modelling and simulation

- Modelling of vehicle cabin as per possible realistic conditions based on initial data.

- Analysis of air velocity at different A.C. blower speed to verify the pattern of air circulation based upon the input parameter from preliminary experiments.

Step 3: Experimentation

- Validation of air velocity distribution as per simulated results in the cabin.
- Placement of thirteen temperature sensors at different positions in front and rear cabin.
- Study of temperature variation at thirteen prescribed locations at different positions for different fan speeds.
- Study of cooling efficiency by installing two auxiliary fans at central air vents.
- Study of cooling efficiency of air conditioning unit by installing two auxiliary fan units behind headrest of front seats.
- Study of cabin noise under proposed conditions.

Chapter 4

Modelling and Simulation

4.1 Modelling

Model of car has been generated using modelling software named as PTC Creo and its analysis is done in ANSYS Fluent. Actual dimensions of car have been considered in generating its part model. Figure 4.1 shows the car model designed in creo. Boundary conditions for the analysis are obtained from preliminary experimentation of existing vehicle.

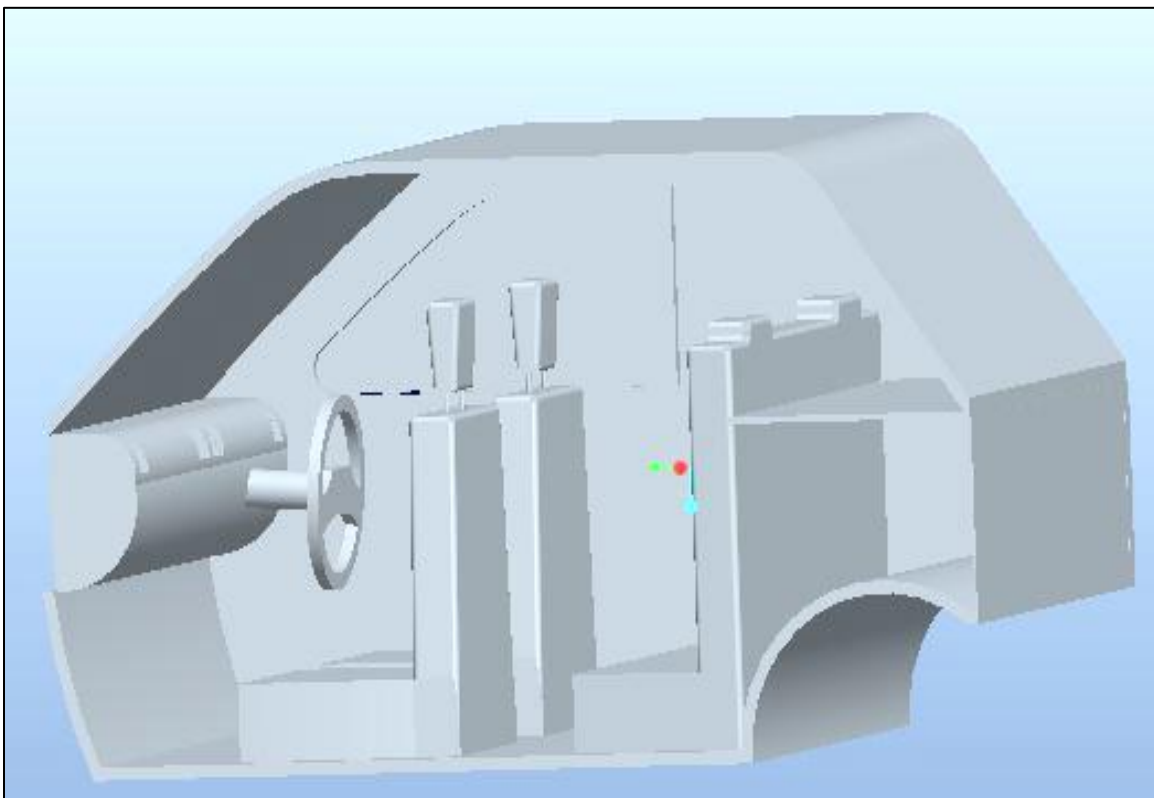


Figure 4.1: Model of car designed in creo

Two fans are installed in central vents of air outlets in dashboard and two fans are installed in front two headrests facing the rear passengers. Air velocity of headrest fan is 4 m/s, hence air

velocity at rear corner passengers is approximately 1 m/s. Model of headrest has been developed in PTC Creo. Figure 4.2 shows headrest model designed in creo.

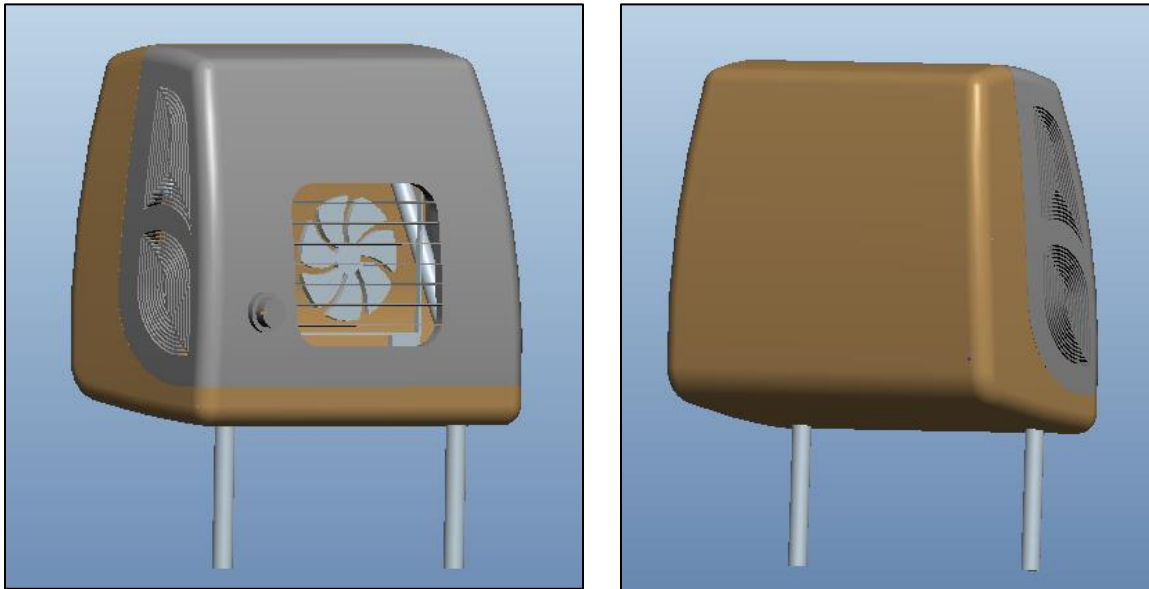


Figure 4.2: Headrest model

Fan assembly is installed in headrest facing rear passengers. Side grills are provided at both sides of headrest so that enough amount of air can be sucked in. Fins are provided in front grills so that air flow can be maneuvered in desired direction.

For analysis in ANSYS Fluent inlet velocities are needed to be specified in each case where boundary conditions are changing. Figure 4.3 shows all inlet and outlet positions inside car cabin.

Inlet 1= Side vent to the left of front passenger

Inlet 2= Central vent to the right of inlet 1

Inlet 3= Central vent to the right of inlet 2

Inlet 4= Side vent to the right of driver

Inlet 5=Fan assembled in front passenger's seat headrest

Inlet 6=Fan assembled in driver's seat headrest

Outlet= Rear windshield

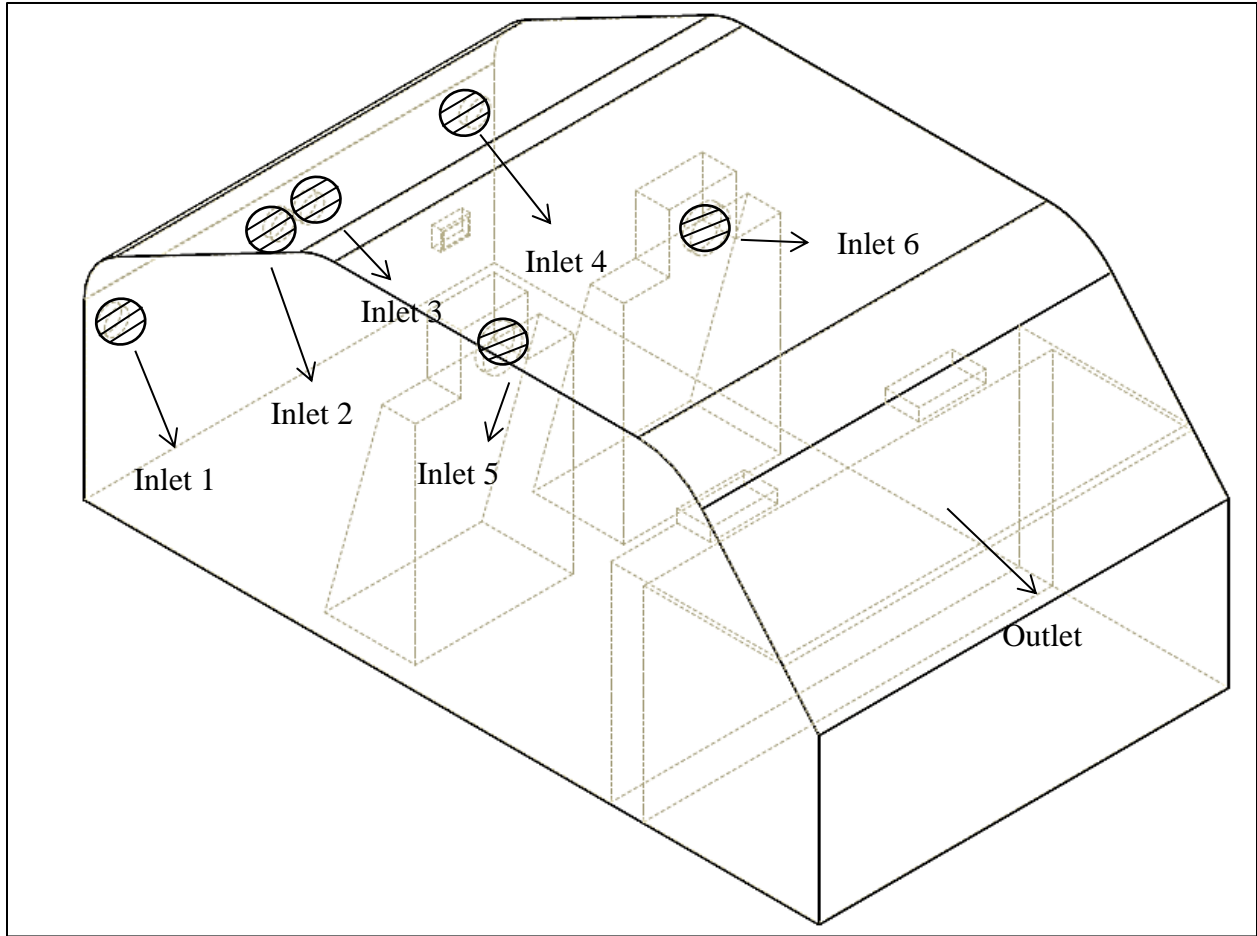


Figure 4.3: Car view showing different inlet positions

4.2 Analysis

Analysis of different blower speeds is performed in ANSYS Fluent. All different cases have been studied and images of those are shown with side and front views so analysis can be understood easily. Boundary conditions of inlet air velocity are taken same as mentioned in Table 4.1 and 4.2 for the respective blower and fan speed.

Air velocities are different in different cases and have been mentioned in each case. Three cases are considered at each blower speed and analysis of each case has been shown with prescribed inlet velocities as boundary conditions.

Car model is imported in ANSYS Fluent to analyze air velocity at different blower speeds inside car cabin. All readings of air velocity are measured with Anemometer. Table 4.1 shows air velocities at different blower speeds of central vents.

Table 4.1: Air velocities at different A.C. blower speeds

A.C. Blower speed	Air velocity(m/s) in conventional case
1	2
2	2.7
3	3.7
4	4.6

Low noise axial flow fans are installed in central vents. Fins of central air vents are removed so that low noise axial flow fans can be installed easily. Table 4.2 shows the improved air velocities.

Table 4.2: Air velocities with installed fans (front) at different A.C. blower speed

A.C. Blower speed	Air velocity (m/s) with auxiliary fans
1	3.2
2	3.7
3	4.4
4	4.8

Case 1: A.C. blower speed 1

Case 1.1: A.C. blower Speed 1: Conventional case

(Inlet 1: 2 m/s, inlet 2: 1.8 m/s, inlet 3: 1.8 m/s, inlet 4: 1.8 m/s)

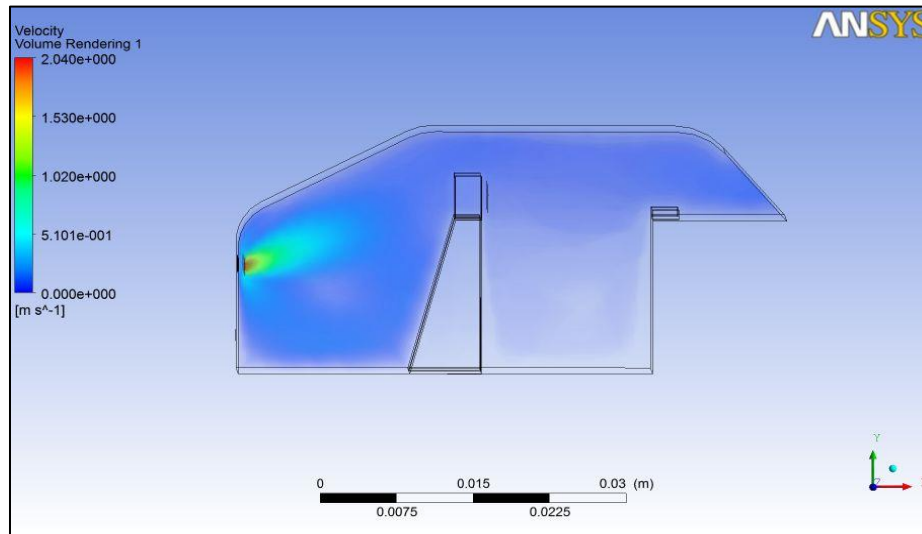


Figure 4.4: Side view at A.C. blower speed 1

Figure 4.4 shows the side view of A.C. blower speed 1. Very less amount of air is provided in rear cabin due to less air velocity at this particular fan speed.

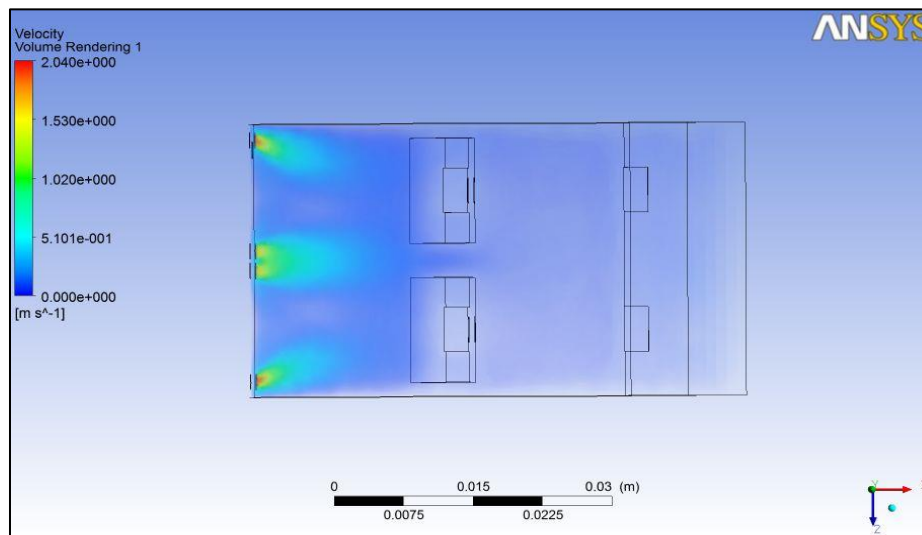


Figure 4.5: Top view of A.C. blower speed 1

Figure 4.5 shows the top view of A.C. blower speed 1. Air velocity in between front seats is around 0.4 m/s and near rear central passenger is around 0.1 m/s.

Case 1.2: A.C. blower speed 1: Improved case (2 front fans attached)

(Inlet 1: 2 m/s, inlet 2: 3.2 m/s, inlet 3:3.2 m/s, inlet 4: 2m/s)

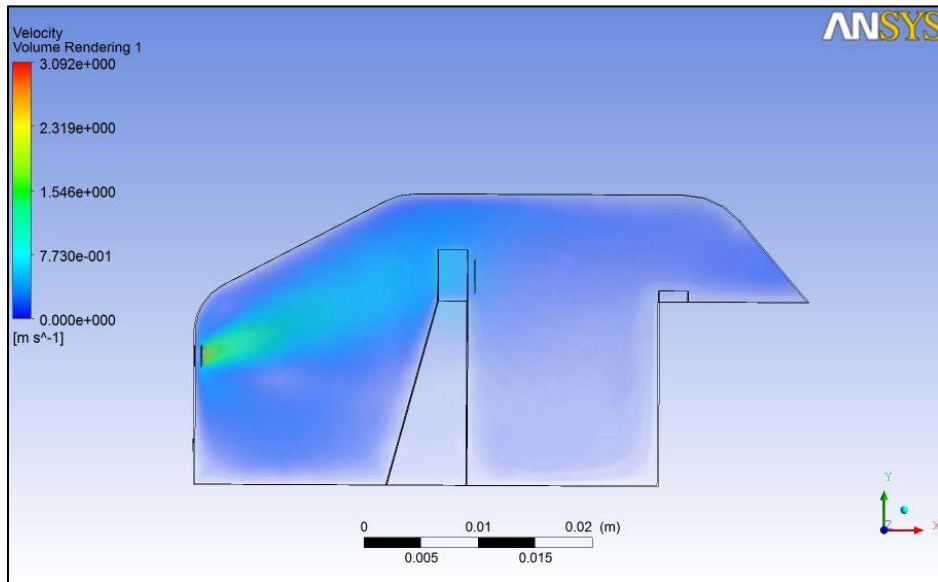


Figure 4.6: Side view of A.C. blower speed 1 with installed fans (front)

Figure 4.6 shows side view of A.C. blower speed 1 with installed fans only in central air outlet vents. Air velocity in front cabin is increased and air speed is more in rear cabin as compared to conventional case.

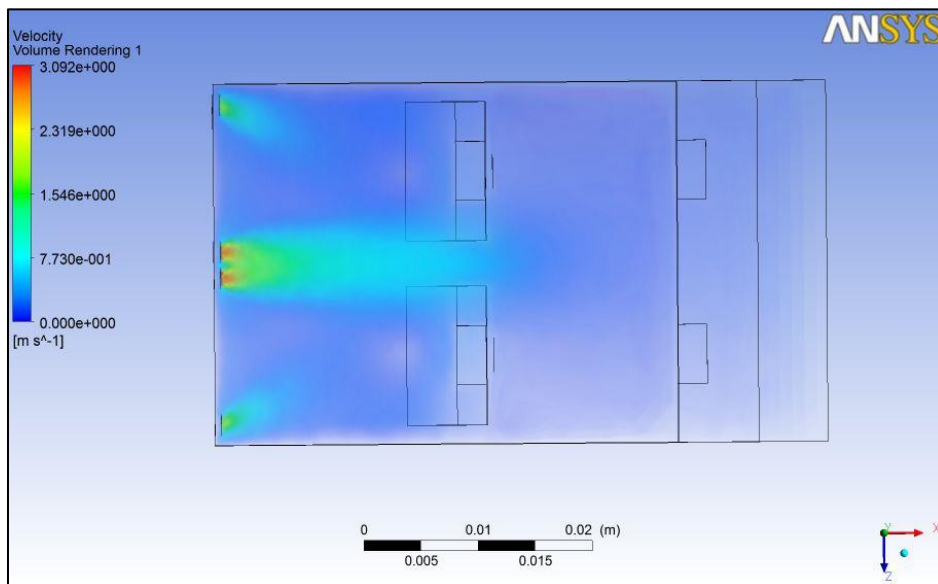


Figure 4.7: Top view of A.C. blower speed 1 with installed fans (front)

Figure 4.7 shows top view of A.C. blower speed 1 with installed fans only at central air outlet vents. Air velocity in between front seats is around 0.7 m/s.

Case 1.3: A.C. blower speed 1: Improved case (all 4 fans attached)

(Inlet 1: 2 m/s, inlet 2: 3.2 m/s, inlet 3:3.2 m/s, inlet 4: 2m/s inlet 5: 3.5 m/s, inlet 6: 3.5 m/s)

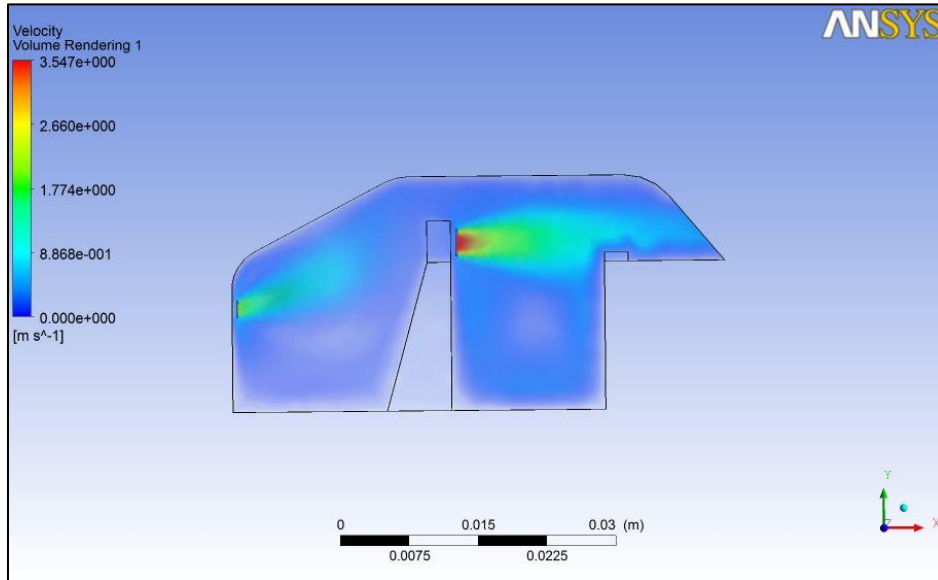


Figure 4.8: Side view of A.C. blower speed 1 with installed fans (all four)

Figure 4.8 shows side view of A.C. blower speed 1 with all four fans attached. Air velocity in front as well as rear cabin has increased drastically.

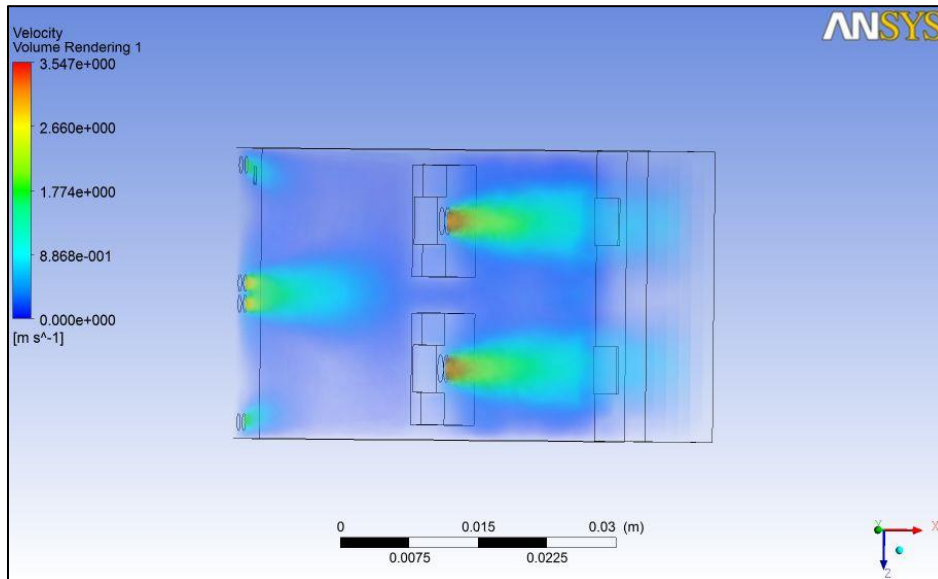


Figure 4.9: Side view of A.C. blower speed 1 with installed fans (all four)

Figure 4.9 shows top view of A.C. blower speed 1 with all four fans attached. Air velocity in between front two seats is 0.7 m/s but in rear cabin air velocity is around 0.8-0.9 m/s for both rear side passengers.

Case 2: A.C. blower speed 2

Case 2.1: A.C. blower Speed 2: Conventional case

(Inlet 1: 2.7 m/s, inlet 2: 2.7 m/s, inlet 3: 2.7 m/s, inlet 4: 2.7 m/s)

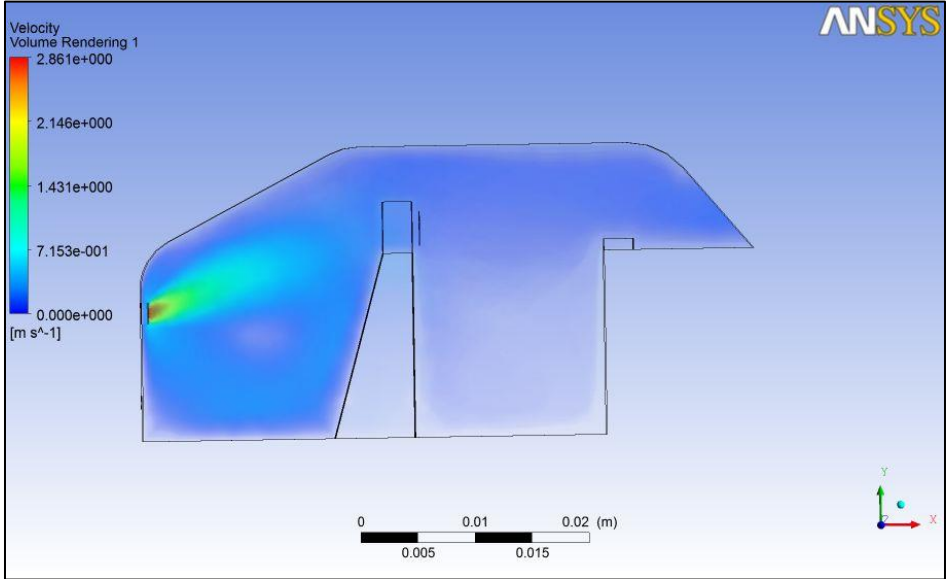


Figure4.10: Side view of A.C. blower speed 2

Figure 4.10 shows side view of A.C. blower speed 2. Air velocity has increased in front as well as rear cabin in comparison to fan speed 1.

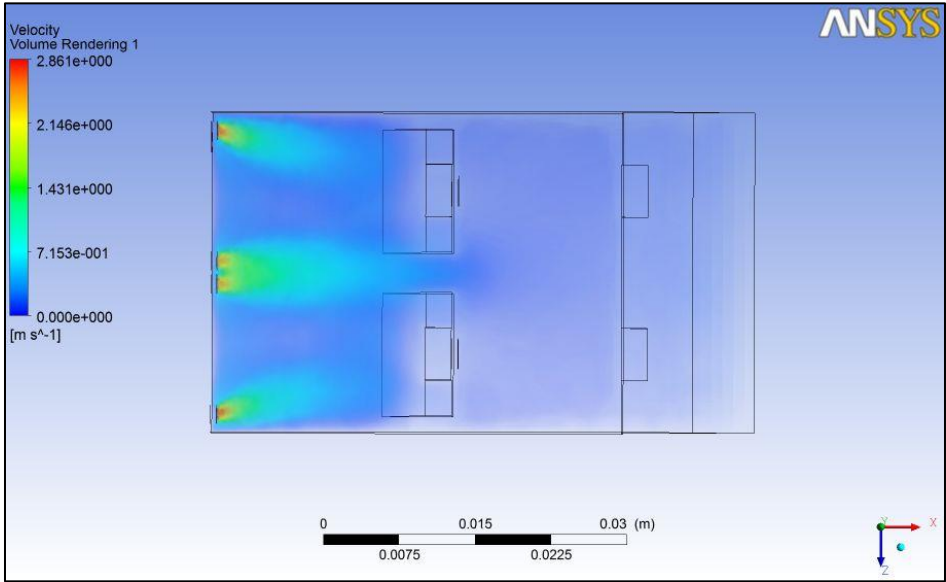


Figure 4.11: Top view of A.C. blower speed 2

Figure 4.11 shows top view of A.C. blower speed 2. Air velocity in between front two seats is around 0.7 m/s and in rear cabin is around 0.15 m/s and near back seat is around 0.25 m/s.

Case 2.2: A.C. blower speed 2: Improved case (2 front fans attached)

(Inlet 1: 2.7 m/s, inlet 2: 3.7 m/s, inlet 3:3.7 m/s, inlet 4: 2.7 m/s)

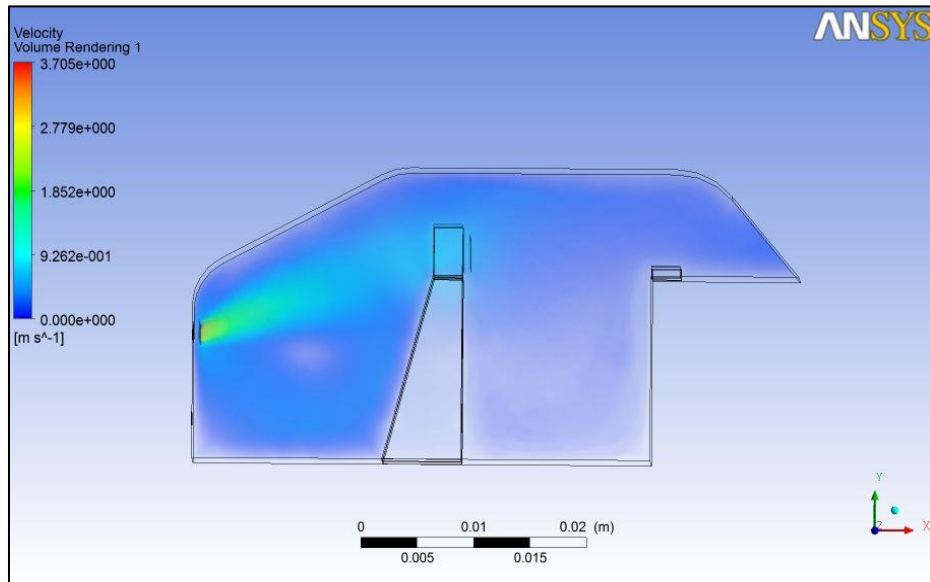


Figure 4.12: Side view of A.C. blower speed 2 with installed fans (front)

Figure 4.12 shows top view of A.C. blower speed 2 with installed central air outlet vents. Air velocity is increased in both front and rear cabin in comparison to conventional case.

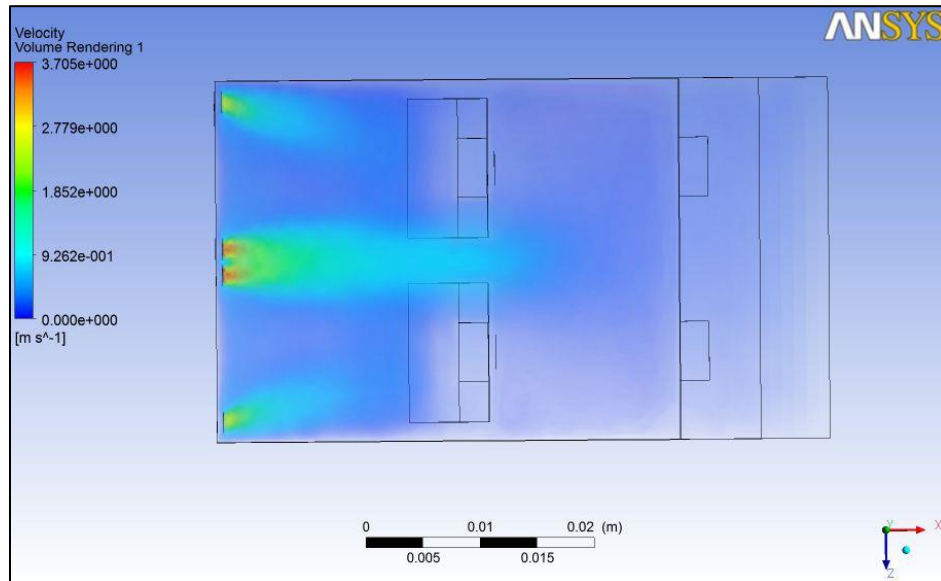


Figure 4.13: Top view of A.C. blower speed 2 with installed fans (front)

Figure 4.13 shows top view of A.C. blower speed 2 with installed central air outlet vents. Air velocity in between front seats is around 0.9 m/s and near back seat is around 0.30 m/s.

Case 2.3: A.C. blower speed 2: Improved case (all 4 fans attached)

(Inlet 1: 2.7 m/s, inlet 2: 3.7 m/s, inlet 3:3.7 m/s, inlet 4: 2.7m/s inlet 5: 3.5 m/s, inlet 6: 3.5 m/s)

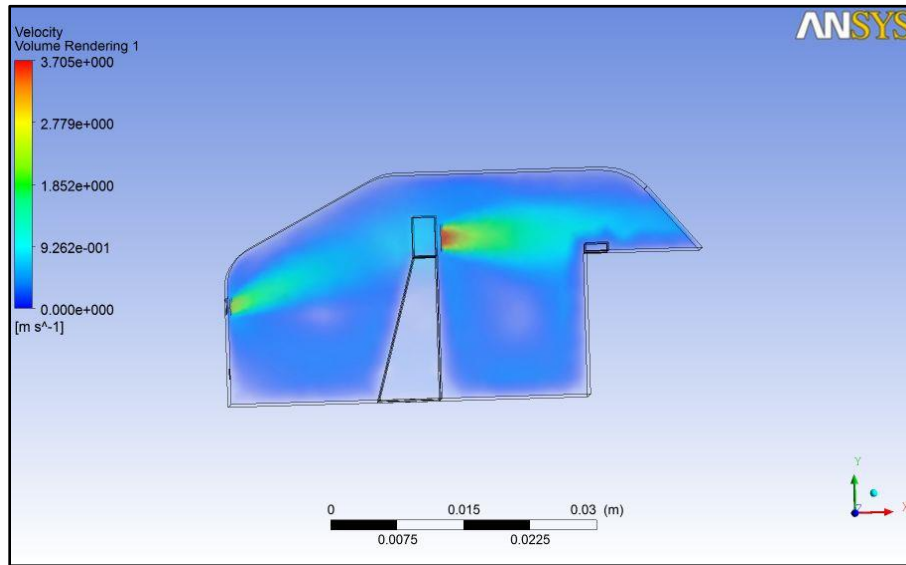


Figure 4.14: Side view of A.C. blower speed 2 with installed fans (all 4 fans attached)

Figure 4.14 shows side view of A.C. blower speed 2 with all four fans attached. Air velocity has increased in both front and rear cabin in comparison to conventional case.

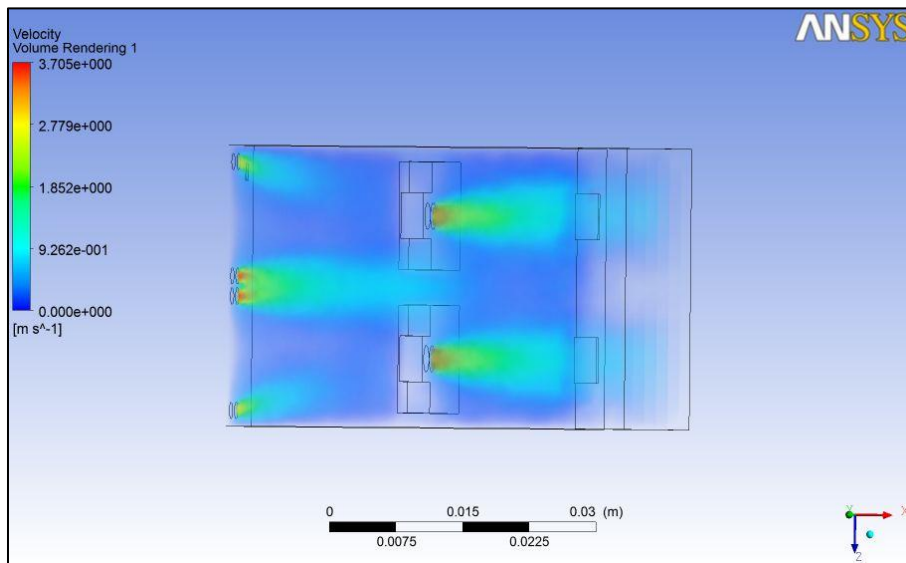


Figure 4.15: Top view of A.C. blower speed 2 with installed fans (all 4 fans attached)

Figure 4.15 shows top view of A.C. blower speed 2 with all four fans attached. Air velocity between front two seats is around 0.9 m/s and near back seat is around 1 m/s for both rear side passengers.

Case 3: A.C. blower speed 3

Case 3.1: A.C. blower speed 3: Conventional case

(Inlet 1: 3.7 m/s, inlet 2: 3.7 m/s, inlet 3: 3.7 m/s, inlet 4: 3.7 m/s)

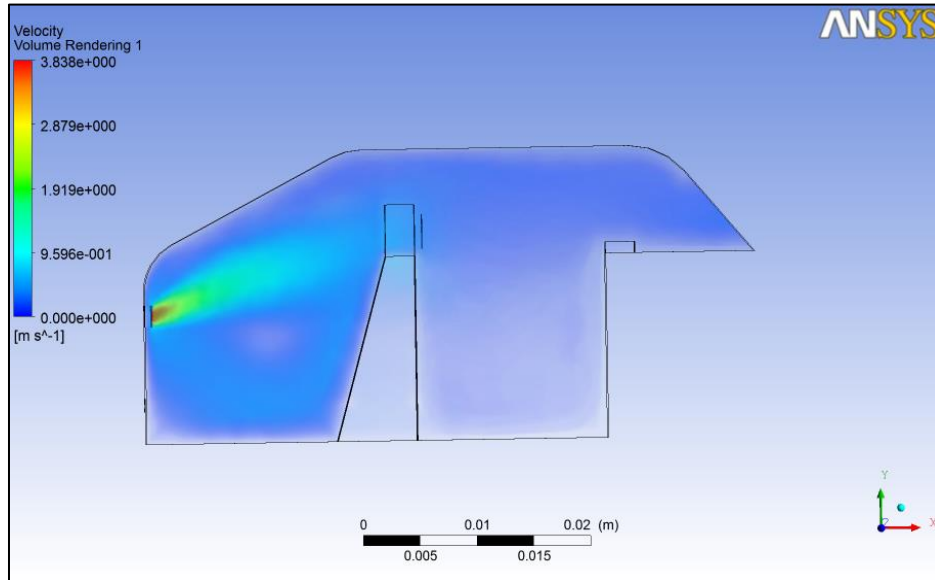


Figure 4.16: Side view of A.C. blower speed 3

Figure 4.16 shows side view of A.C. blower speed 3. Air velocity has increased in both front and rear cabin in comparison to fan speed 2.

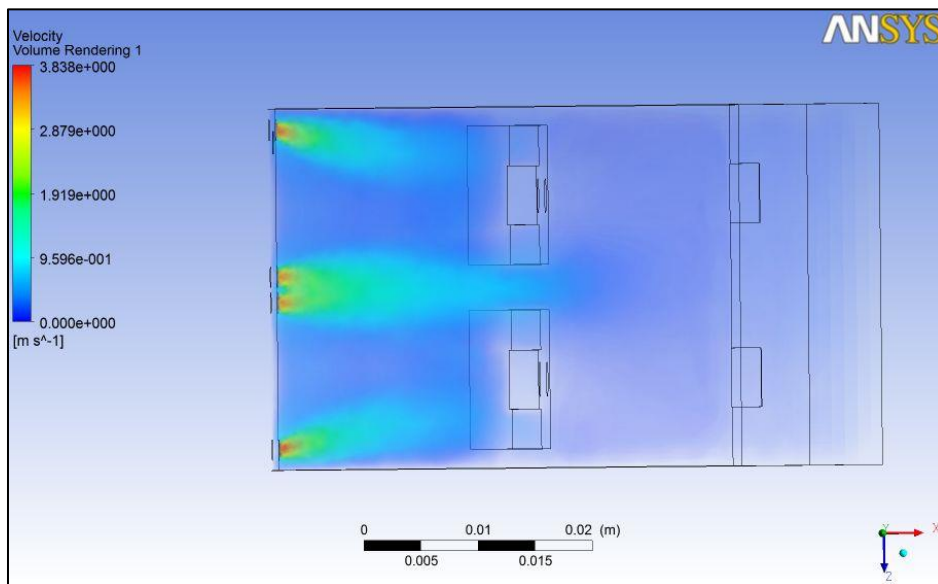


Figure 4.17: Top view of A.C. blower speed 3

Figure 4.17 shows top view of A.C. blower speed 3. Air velocity in between front two seats is around 0.7 m/s and in rear cabin is around 0.30 m/s.

Case 3.2: A.C. blower speed 3: Improved case (2 front fans attached)

(Inlet 1: 3.7 m/s, inlet 2: 4.4 m/s, inlet 3: 4.4 m/s, inlet 4: 3.7 m/s)

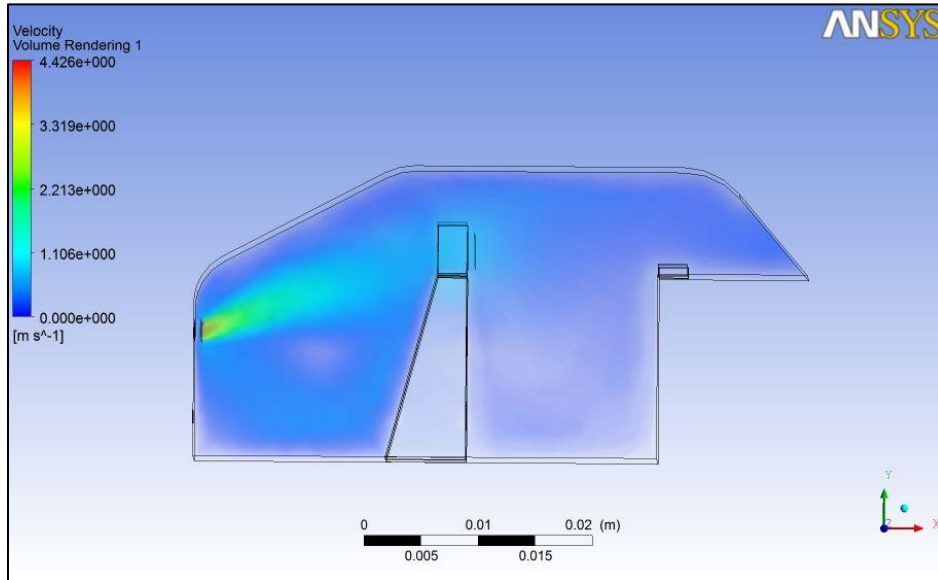


Figure 4.18: Side view of A.C. blower speed 3 with installed fans (front)

Figure 4.18 shows side view of A.C. blower speed 3 with fans attached at central air outlet vents. Air velocity has increased with comparison to conventional case.

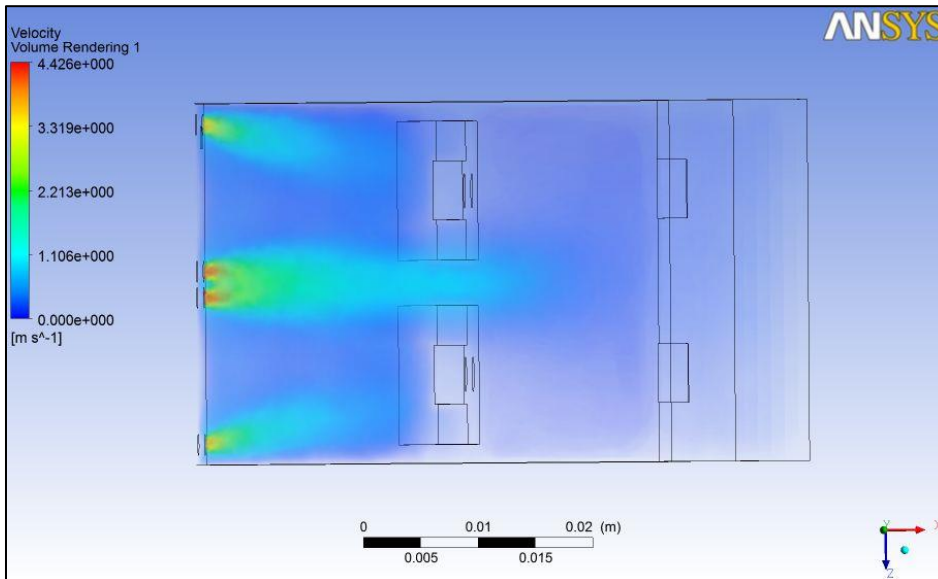


Figure 4.19: Top view of A.C. blower speed 3 with installed fans (front)

Figure 4.19 shows top view of A.C. blower speed 3 fans attached in central air outlet vents. Air velocity in between front seats is around 1 m/s and near back seat is around 0.4 m/s.

Case 3.3: A.C. blower speed 3: Improved case (all four fans attached)

(Inlet 1: 3.7 m/s, inlet 2: 4.4 m/s, inlet 3: 4.4 m/s, inlet 4: 3.7 m/s, inlet 5: 3.5 m/s, inlet 6: 3.5 m/s)

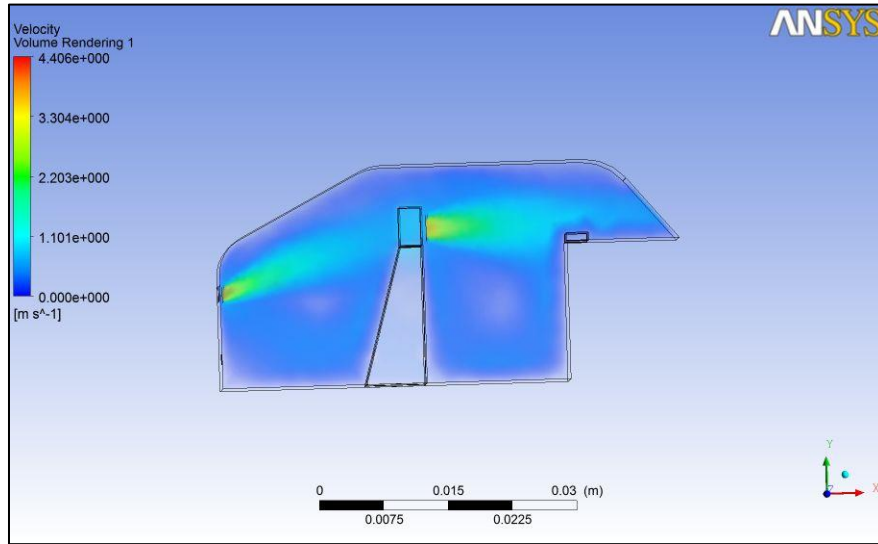


Figure 4.20: Side view of A.C. blower speed 3 with installed fans (all four fans attached)

Figure 4.20 shows side view of A.C. blower speed 3 with all four fans attached.

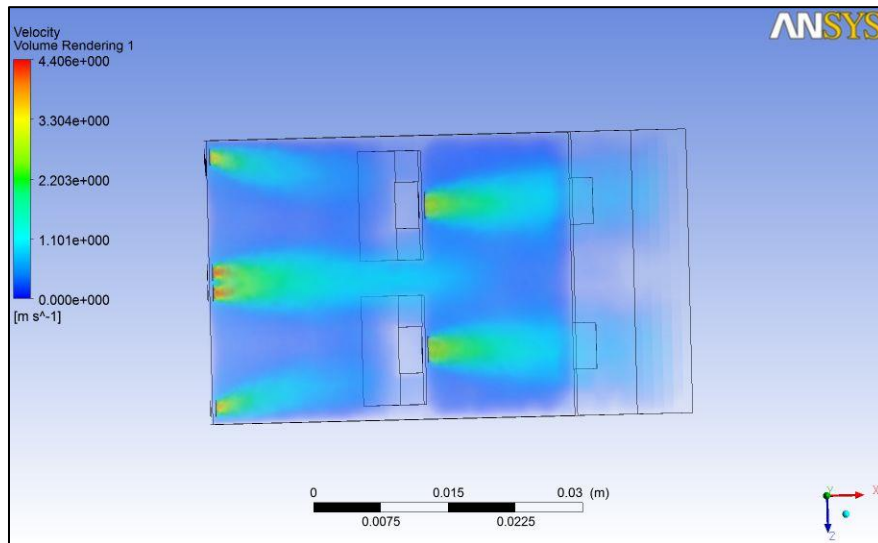


Figure 4.21: Top view of A.C. blower speed 3 with installed fans (all four fans attached)

Figure 4.21 shows top view of A.C. blower speed 3 with all four fans attached. Air velocity between front seats is around 1 m/s and near back seat is around 1.10 m/s for both rear side passengers.

Case 4: A.C. blower speed 4

Case 4.1: A.C. blower speed 4: Normal case

(Inlet 1: 4.7 m/s, inlet 2: 4.7 m/s, inlet 3: 4.7 m/s, inlet 4: 4.7 m/s)

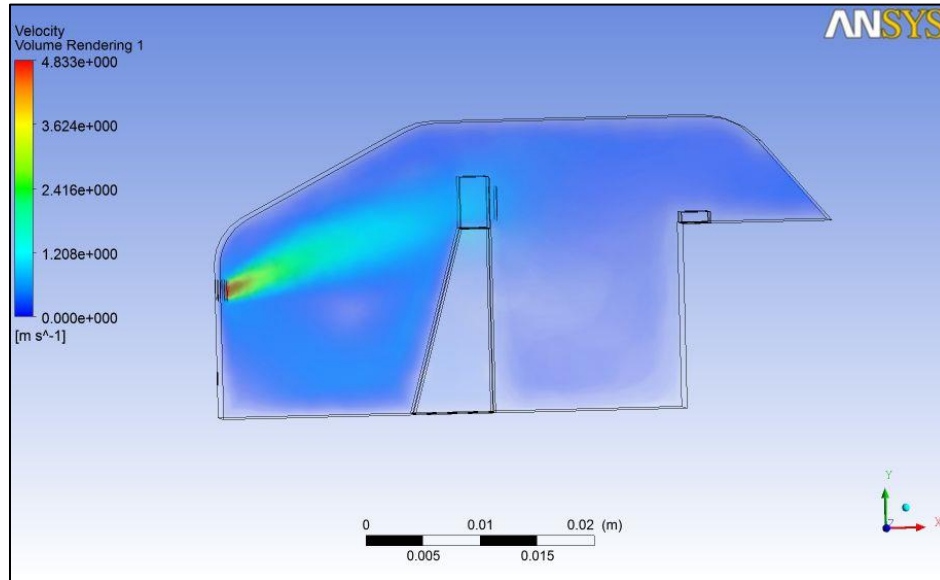


Figure 4.22: Side view of A.C. blower speed 4

Figure 4.22 shows side view of A.C. blower speed 4. Air velocity has increased in comparison to fan speed 3 in both front and rear cabin.

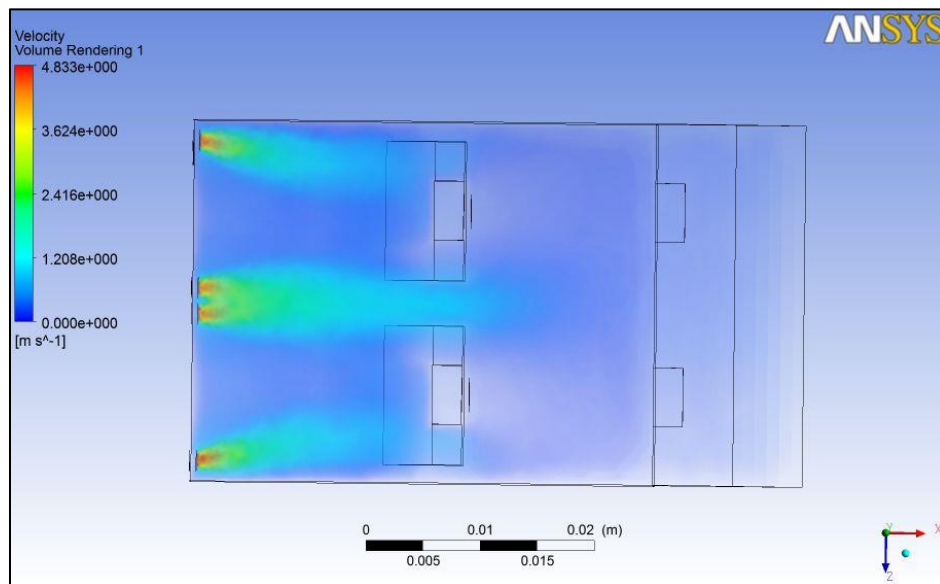


Figure 4.23: Top view of A.C. blower speed 4

Figure 4.23 shows top view of A.C. blower speed 4. Air velocity in between front two seats is around 1.20 m/s and near back seat is around 0.5 m/s.

Case 4.2: A.C. blower speed 4: Improved case (2 front fans attached)

(Inlet 1: 4.7 m/s, inlet 2: 4.7 m/s, inlet 3: 4.7 m/s, inlet 4: 4.7 m/s)

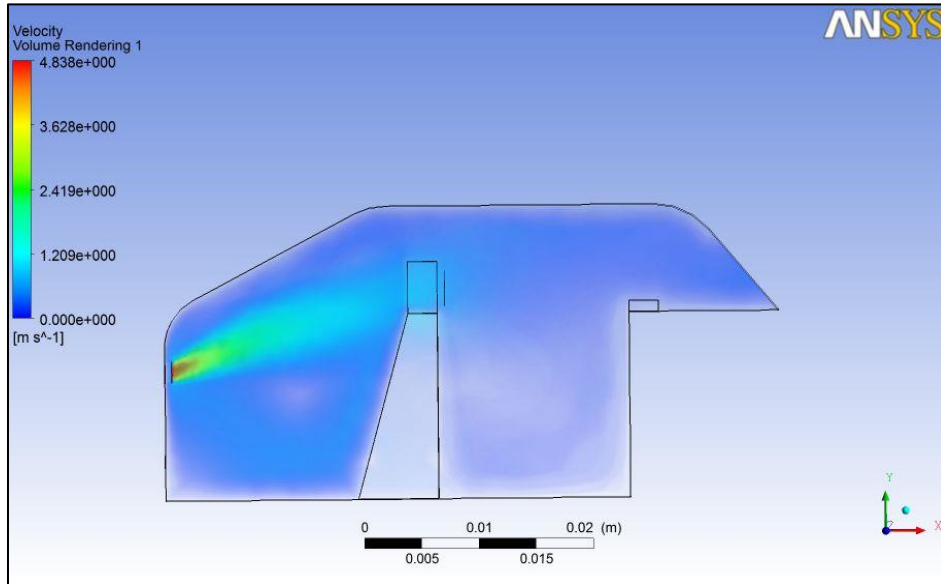


Figure 4.24: Side view of A.C. blower speed 4 with installed fans (front)

Figure 4.24 shows side view of A.C. blower speed 4 with fans attached at central air outlet vents. No increase in air velocity in both front and rear cabin.

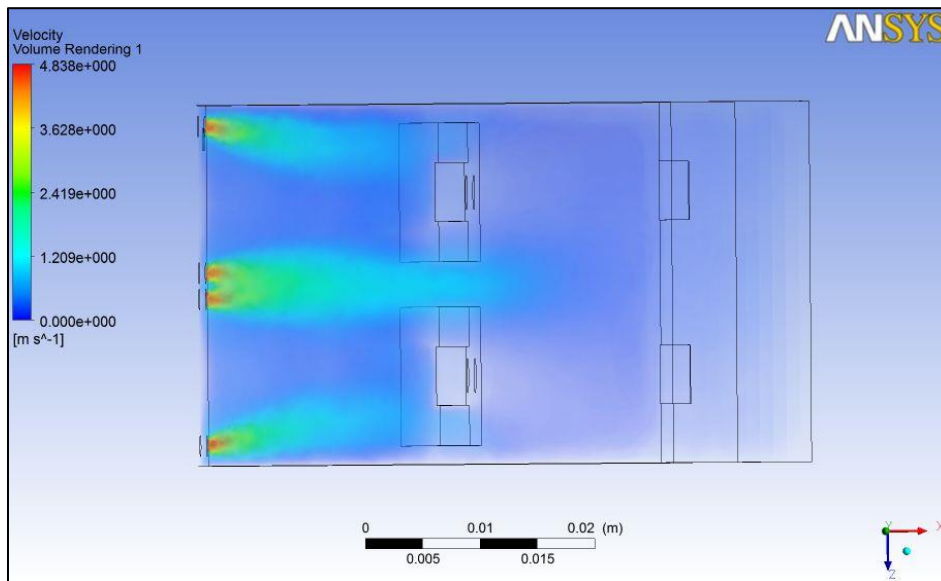


Figure 4.25: Top view of Fan speed 4 with installed fans (front)

Figure 4.25 shows top view of A.C. blower speed 4 with fans attached at central air outlet vents. No increase in air velocity in both front and rear cabin.

Case 4.3: A.C. blower speed 4: Improved case (all four fans attached)

(Inlet 1: 4.7 m/s, inlet 2: 4.7 m/s, inlet 3: 4.7 m/s, inlet 4: 4.7 m/s, inlet 5: 3.5 m/s, inlet 6: 3.5 m/s)

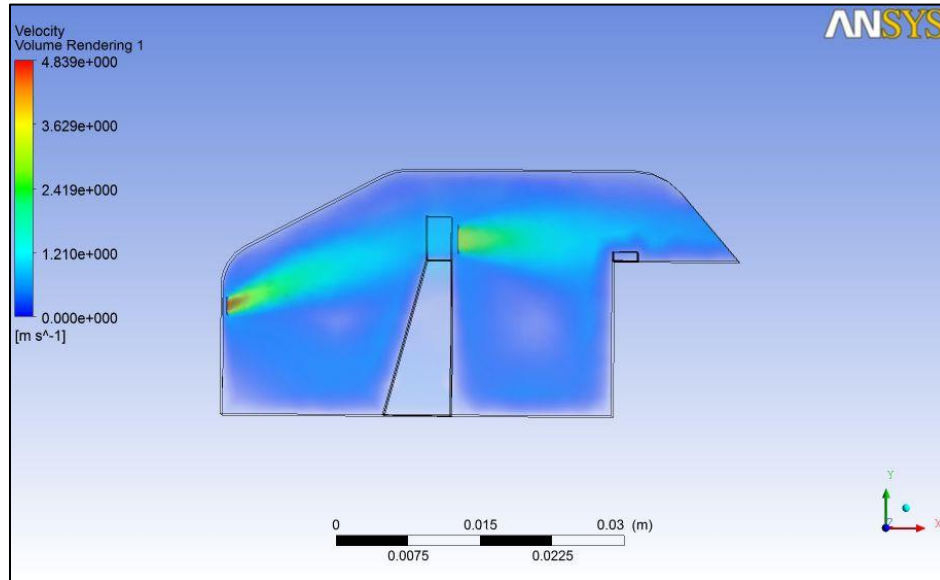


Figure 4.26: Side view of A.C. blower speed 4 with installed fans (all four fans attached)

Figure 4.26 shows side view of A.C. blower speed 4 with all four fans attached. No increase in air velocity in front cabin but there is increase in rear cabin.

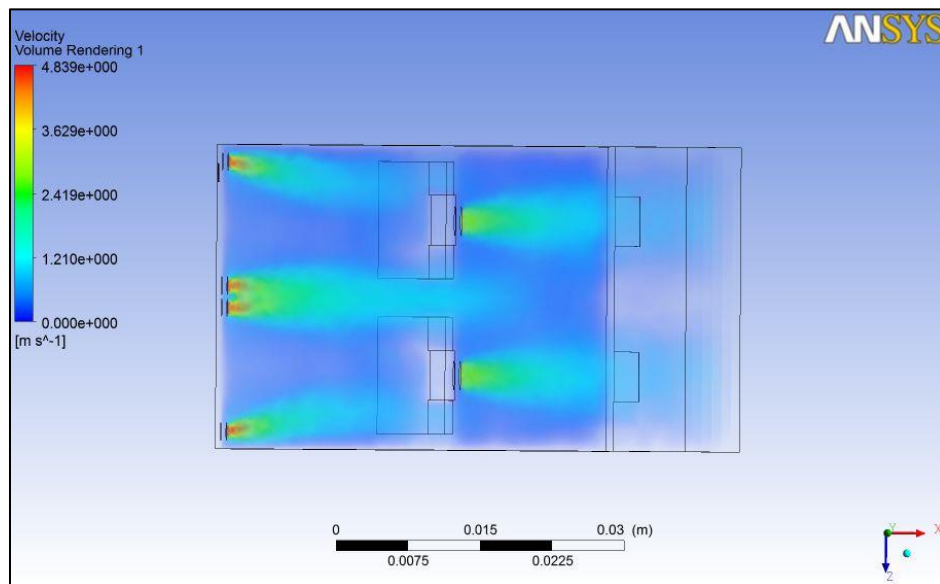


Figure 4.27: Top view of A.C. blower speed 4 with installed fans (all four fans attached)

Figure 4.27 shows top view of A.C. blower speed 4 with fans attached at central air outlet vents. Air velocity in between front seats is 1.2 m/s and around 1.25 m/s near back seat.

Observation from analysis: Air velocities are improved at each A.C. blower speed after installing fans. With installed setup air velocity at A.C. blower speed 3 is equivalent to air velocity at A.C. blower speed 4 in conventional case and same case goes with A.C. blower speed 2 with installed setup and A.C. blower speed 3 in conventional case. Air velocity at rear passengers is improved by 1 m/s after installing fans in headrest and central air outlet vents in comparison to conventional case.

Chapter 5

Experimental Setup

5.1 Introduction

Equipment used in present work:

- Vehicle
- Printed Circuit Board of temperature sensors
- Low noise axial flow fans
- Anemometer
- Sound level meter
- Thermal imaging camera

5.1.1 Vehicle

Esteem VX 1996 model has been purchased for thesis work. Figure 5.1 shows rear and front view of purchased vehicle.



Figure 5.1: Rear and front view of vehicle

5.1.2 Temperature sensor module

A printed circuit board (PCB) with 13 temperature sensors has been developed to take the temperature readings inside car cabin. PIC micro-controller has been used to integrate these sensors. RS232 port is used to drive this controller. 3V-5V power supply is required to operate this controller therefore USB to serial convertor has been used to connect this PCB with laptop. 9V adaptor has been used to power all the components in PCB. Figure 5.2 shows developed PCB of sensors.

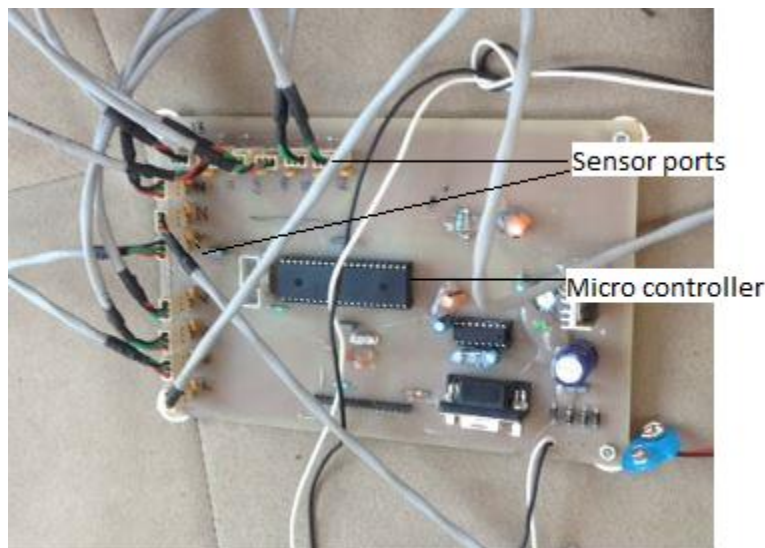


Figure 5.2: PCB of sensors

LM 35 sensors have been used to monitor temperature of air inside vehicle cabin at various locations. LM 35 sensors were chosen as they are highly accurate with an accuracy of $\pm 1/4$ °C and are calibrated in °C (degree Centigrade). They can monitor wide range of temperature from -55°C to 150°C. LM 35 gives a linear output with a scale factor of 10mV/°C. For example if the output voltage is 326mV then the temperature is 32.6°C. It has a wide operating voltage from 4V to 30V.

5.1.3 Low noise axial flow fans

Four fans are used in present work. Two fans are installed in center air outlet vents in dashboard. Intel core 2 duo fans are used to improve air velocity coming out from outlet vents. Features of this fan are as follows:

- Fan diameter: 84 mm.
- Fan speed is 1500 rpm.

- Pulse Width Modulated fan (PWM) with seven blades.
- Operation voltage 12 volts DC.
- Operation current 0.2 ampere.
- Weighs approximately 120 grams.

Figure 5.3 shows installed fans in center outlet vents. These fans are operated at each blower speed of car and in every case air velocity of incoming air has been increased.

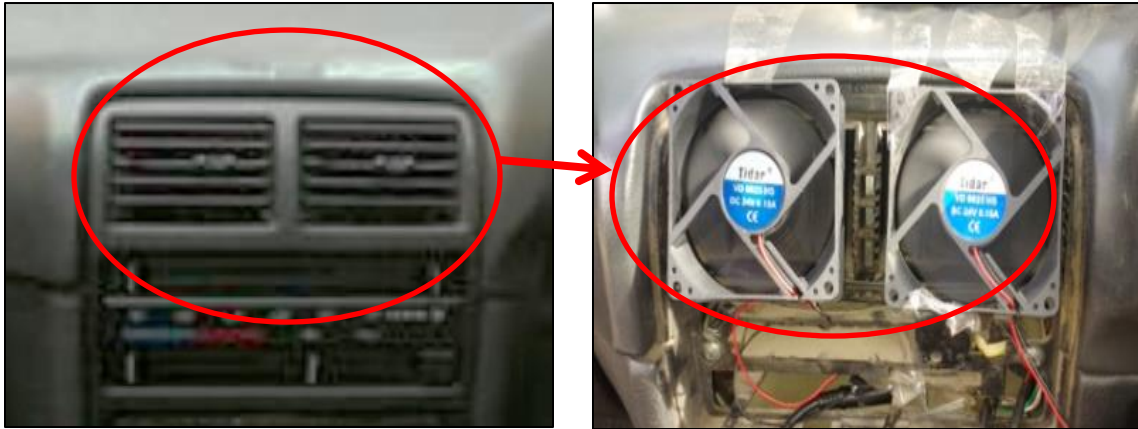


Figure 5.3: Fans installed in center outlet air vents in dashboard

Two fans are assembled in front two headrest facing rear passenger. These fans have different dimensions and specifications in comparison with two fans installed in dashboard vents. Figure 5.4 shows fans installed in head rest at front two seats.



Figure 5.4: Fans installed in head rest

Fan specifications:

- Fan's size: 120x120x38 mm.
- Operation speed 1800 rpm.

- Operates at DC 220/240 volts.
- Operation current 0.14 ampere.

5.1.4 Anemometer

Air flow meter: (LUTRON AM 4201 DIGITAL ANEMOMETER) Figure 5.5 shows the anemometer used in present work.

Features

- The portable anemometer provides fast accurate readings with digital readability and the convenience of a remote sensor separately.
- Multi-functions for air flow measurement: m/s, km/h, ft/min, knots. Table 5.1 shows the general specifications of Lutron 4201 anemometer.
- Low-friction ball-bearing design resulting in accuracy at both high and low velocities. Table 5.2 shows the electrical specifications of Lutron 4201 anemometer.
- Conventional twisted vane arms, always a source of unreliability have been eliminated.

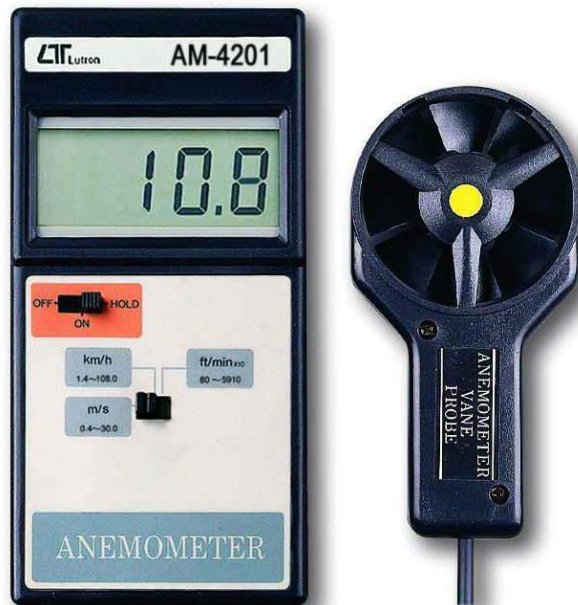


Figure 5.5: Anemometer

Table 5.1: General specifications of Lutron AM 4201anemometer

Display	18mm (0.7") LCD
Measurement	m/s (meters per second), km/h (kilometers per hour), ft/min (feet/per minute), knots (nautical miles per hour), Temp.- °C, °F (AM-4202 only). Data hold.

Table 5.2: Electrical specifications of Lutron AM 4201anemometer

Measurement	Range	Resolution	Accuracy
m/s	0.4-30.0 m/s	0.1 m/s	± (2%)

5.1.5 Sound level meter and Noise measurement

(CESVA SC 310 Sound Level Meter)

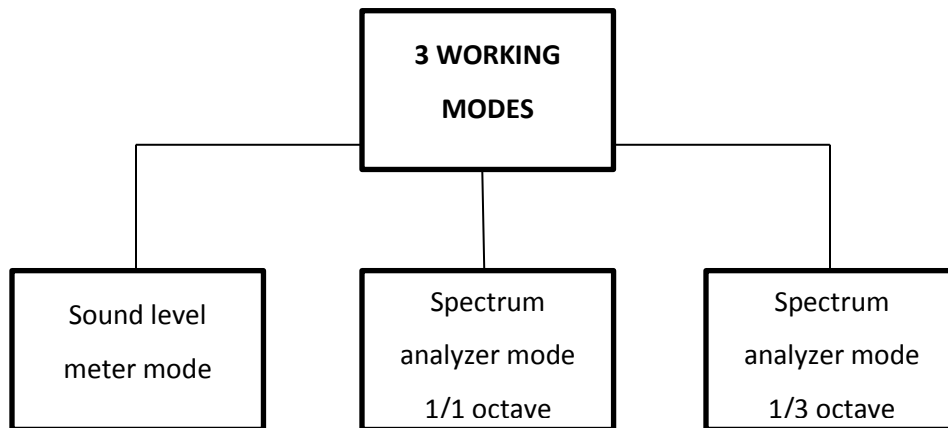


Figure 5.6: Different working modes of sound meter

The SC 310 is a powerful, user friendly instrument. It can work as an integrating sound level meter class 1 according to IEC 61672, 60651, 60804, ANSI S1.4. It is also a real type spectrum analyzer. Figure 5.6 shows different working modes of sound meter.

It has a single range, there is no need to make any scale adjustments. It also measures all functions simultaneously. These functions are the ones needed to calculate the basic noise evaluation figures of most of the countries in the world.

The SC 310's graphic screen as shown in Figure 5.7 provides graphical and numerical representations of the functions measured. It has an extensive internal memory to record all the measured data. The amount of stored functions is configurable.

Features:

- Integrating sound level meter class 1 according to IEC and ANSI.
- Real time spectrum analyzer.
- Mass storage of data in memory.
- Direct printing.
- Circular memory available.
- One single range 23-137 dbA (no range setting).
- Measures all parameter simultaneously with A, C and Z frequency weightings.
- Back-lit graphic screen and soft touch keyboard for easy use.



Figure 5.7: Sound level meter

5.1.6 Thermal image camera

(Flir One Thermal Imager)

Flir One thermal image camera is used to capture thermal images in which it gives temperature distribution as well as specifies temperature at a given point. It is not available in Indian market and was imported from USA for the implementation of present work. It is used to determine temperature values of various surfaces (human body) and vehicle components (dashboard, steering wheel) inside the car cabin. Specifications of Flir one camera are mentioned below:

- Scene range temperature: 0°C to 100°C.
- Sensitivity: able to detect temperature differences as small as 0.1°C.
- Visible camera: VGA
- Operated with iphone 5/5s using freeware Flir application.
- It uses storage memory of iphone on which it is installed. It does not have its own memory.
- It has a built in battery of 1400 mAh. It does not use iphone battery for its functioning.

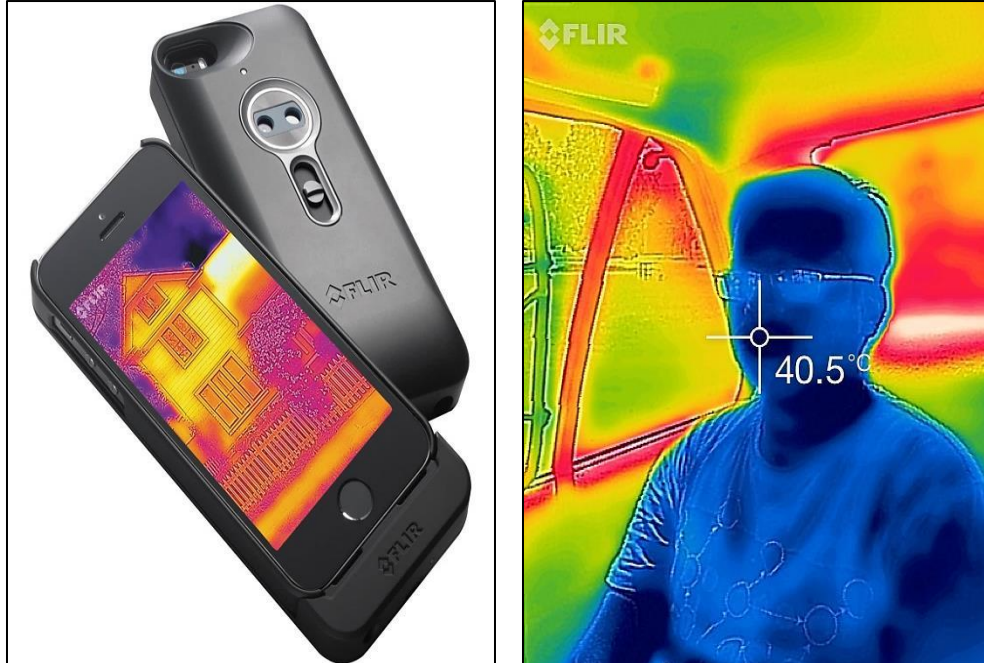


Figure 5.8: Flir one thermal image camera and sample image [W.3]

Figure 5.8 shows the flir one thermal image camera, its installation on iphone and sample image taken by this camera in this work.

5.2 Arrangement of PCB and 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 center 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: Back of front driver headrest

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

Sensor 9: Back of front passenger headrest

Sensor 10: Driver face

Sensor 11: Front passenger chest

Sensor 12: Driver chest

Sensor 13: Front passenger chest

Figure 5.9 shows the sensor arrangement in modeled vehicle cabin. All 13 sensors are placed in their respective positions.

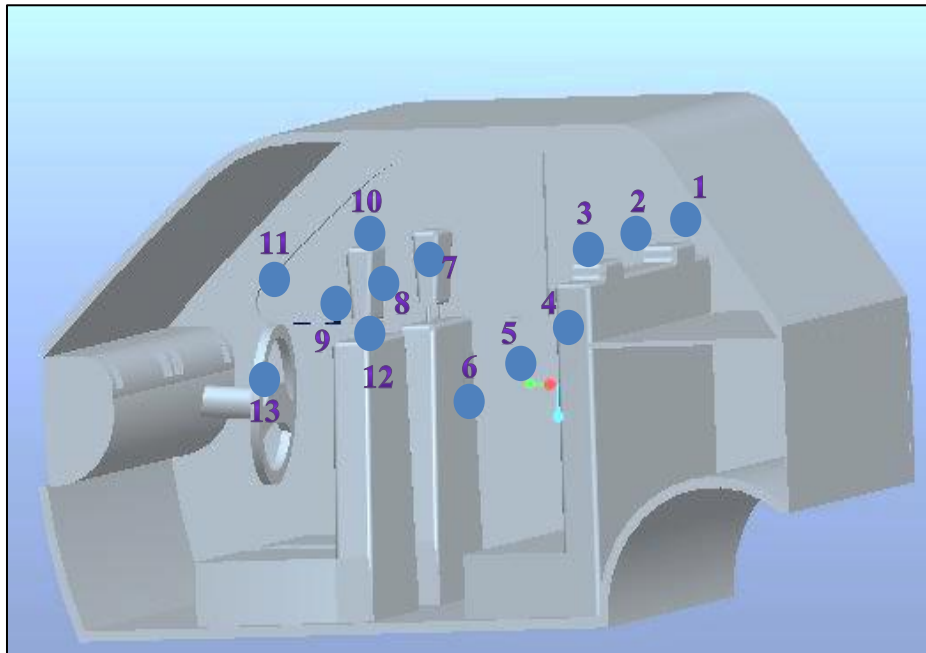


Figure 5.9: Placement of sensors in creo

Figure 5.10 shows the actual sensor arrangement in vehicle cabin. All 13 sensors are placed in their respective positions.



Figure 5.10: Placement of sensors and PCB

5.2.1 Temperature measurement

Output data is in the form of excel sheet. Readings are taken with step size of 2 seconds during the interval of 10 minutes for each case. Figure 5.11 shows Laptop connection to PCB with USB and RS232 serial port. The present study deals with cooling problem when cabin is hot due to parking in direct sunlight. For this situation experiments were conducted on A.C. blower speed 2, 3 and 4 only.



Figure 5.11: Laptop connection with PCB with USB and RS232 serial port

5.2.2 Noise measurement

Noise readings are taken in three cases. Noise readings taken are having units of dbA.

Case 1: A.C. blower speed with different fan speeds.

Case 2: A.C. blower speed with different fan speeds and front two fan and headrest fans installed.

Chapter 6

Results and Discussions

6.1 Air velocity measurement

Air velocity readings are taken at 6 locations and are validated with already calculated simulated results. 6 locations mentioned are explained below:

Location 1: Driver face

Location 2: Gap between two front headrests

Location 3: Front passenger face

Location 4: Rear right side passenger face

Location 5: Rear center passenger face

Location 6: Rear left side passenger face

Figure 6.1 shows all the above stated location used for air velocity measurement.

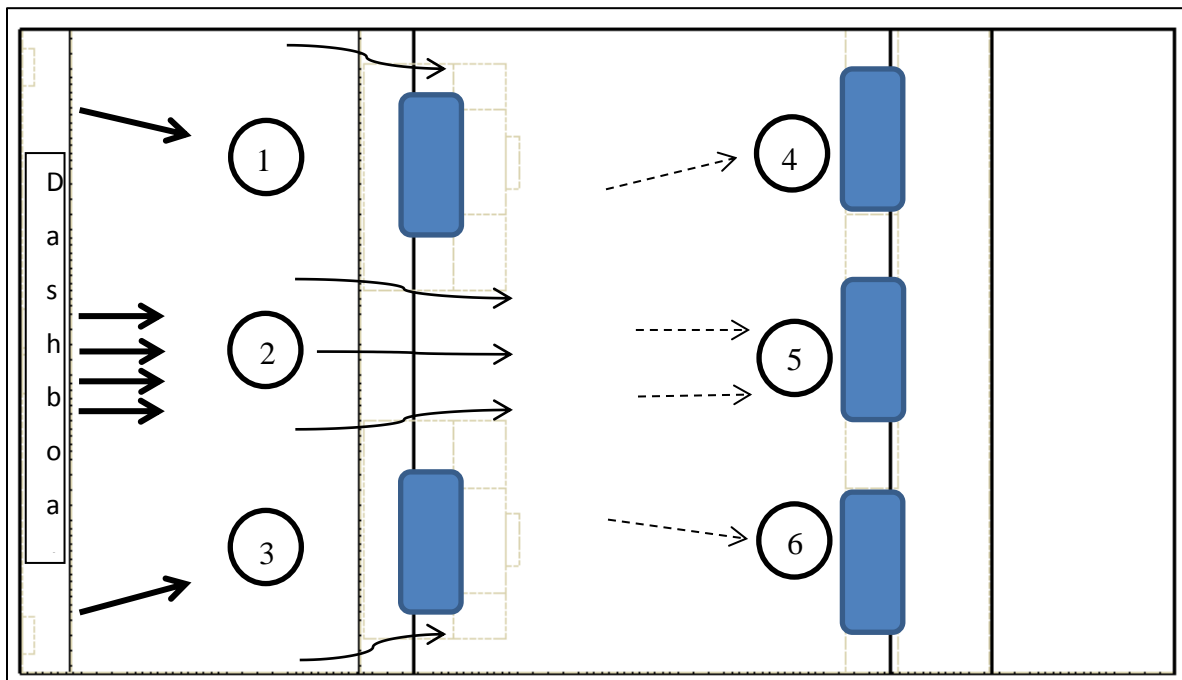


Figure 6.1: 6 locations used for air velocity measurement

6.1.1 Conventional case

Table 6.1 shows the air velocity measurements taken at prescribed six locations at different A.C. blower speed in conventional case.

Table 6.1: Air velocity at different locations in conventional case

A.C. blower speed	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
2	0.7	0.8	0.7	0.1	0.1	0.1
3	1.1	1.2	1.1	0.1	0.25	0.1
4	1.9	2.0	1.9	0.2	0.5	0.2

These results are validated with the help of simulated results which are shown below.

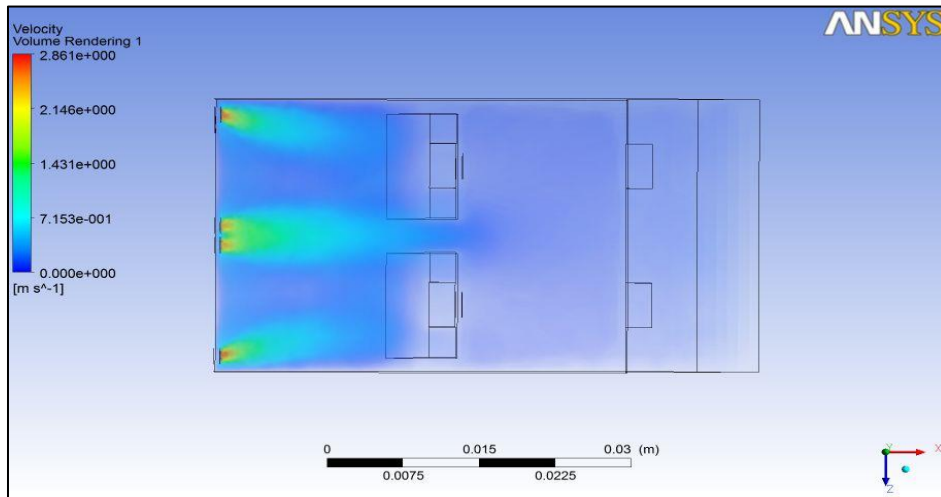


Figure 6.2: A.C. blower speed 2 (conventional)

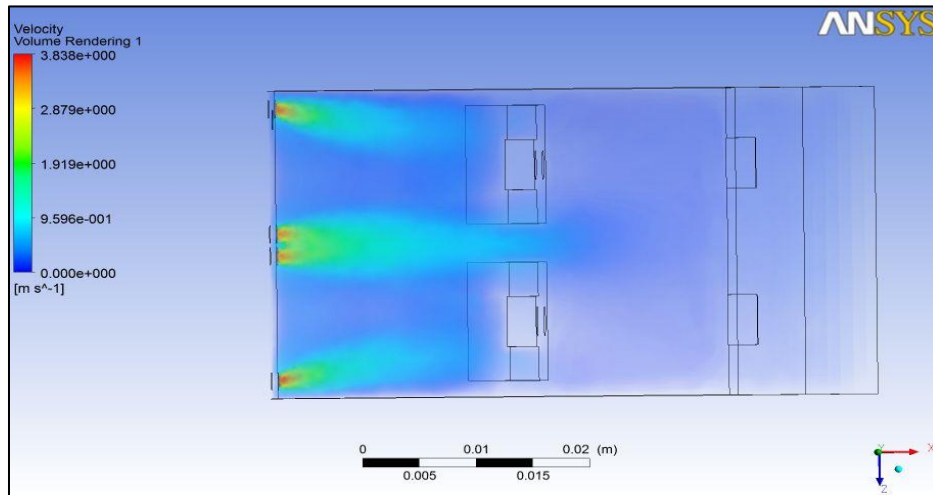


Figure 6.3: A.C. blower speed 3 (conventional)

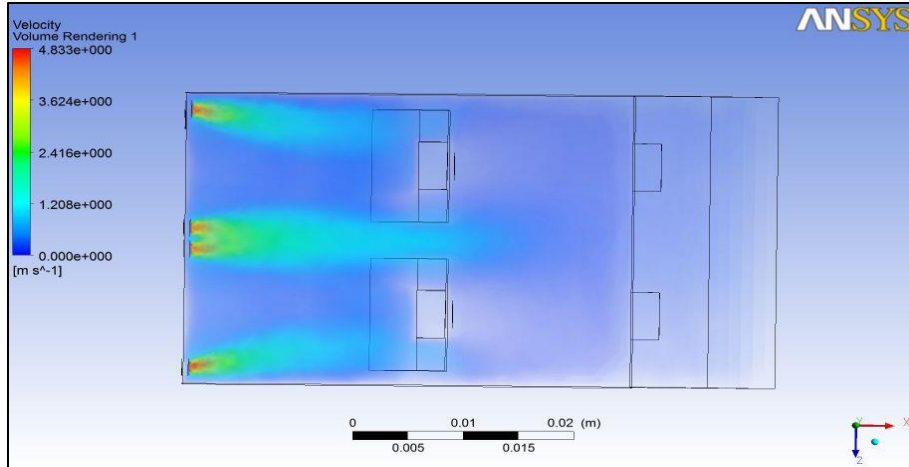


Figure 6.4: A.C. blower speed 4 (conventional)

Experimental readings taken at different A.C. blower speed in conventional case are validated with simulated results. All readings are in close proximity to simulated results.

6.1.2 Auxiliary front two fans installed

Table 6.2 shows the air velocity measurements taken at prescribed six locations at different A.C. blower speed in improved case (2 fans installed).

Table 6.2: Air velocity at different locations in improved case (2 fans installed)

A.C. blower speed	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
2	0.7	0.9	0.7	0.1	0.15	0.1
3	1.1	1.3	1.1	0.1	0.3	0.1
4	1.9	2.1	1.9	0.2	0.6	0.2

These results are validated with the help of simulated results which are shown below.

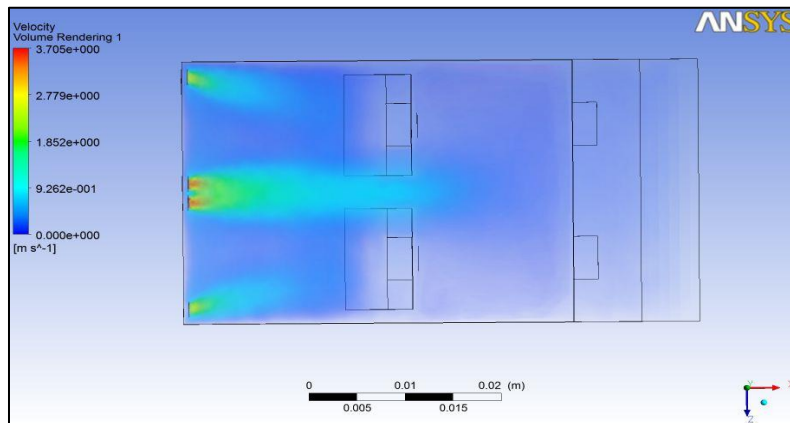


Figure 6.5: A.C. blower speed 2 (improved 2 fans installed)

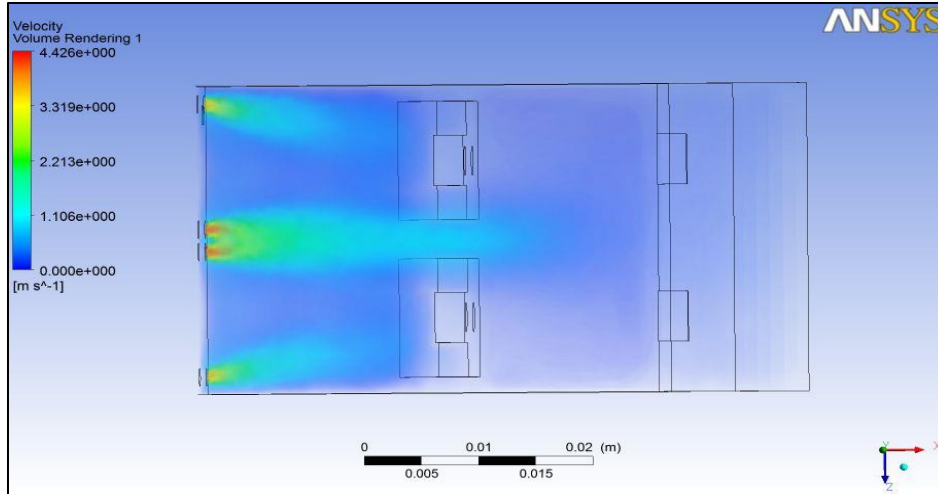


Figure 6.6: A.C. blower speed 3 (improved 2 fans installed)

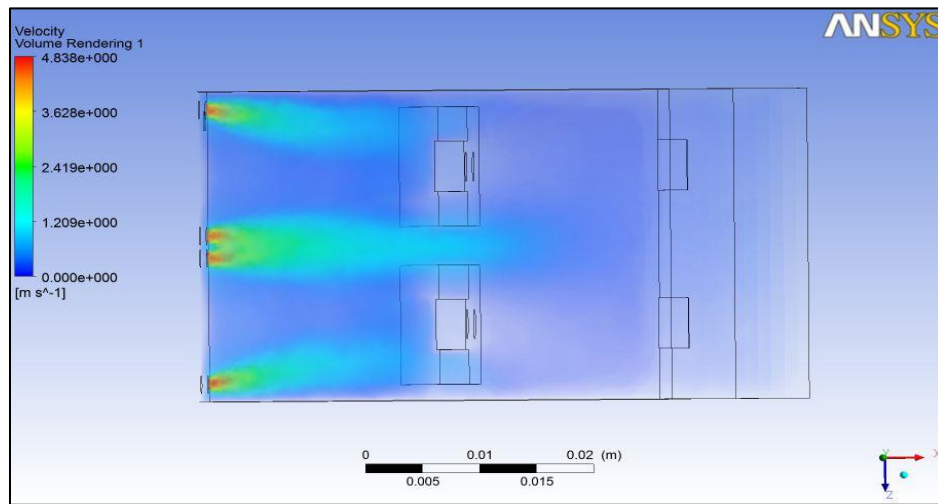


Figure 6.7: A.C. blower speed 4 (improved 2 fans installed)

Experimental readings taken at different A.C. blower speed in conventional case are validated with simulated results. All readings are in close proximity to simulated results.

6.1.3 Auxiliary front two fans and headrest fans installed

Table 6.3 shows the air velocity measurements taken at prescribed six locations at different A.C. blower speed in improved case (4 fans installed).

Table 6.3: Air velocity at different locations in improved case (4 fans installed)

A.C. blower speed	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
2	0.7	0.9	0.7	1.2	0.15	1.2
3	1.1	1.3	1.1	1.2	0.3	1.2
4	1.9	2.1	1.9	1.2	0.6	1.2

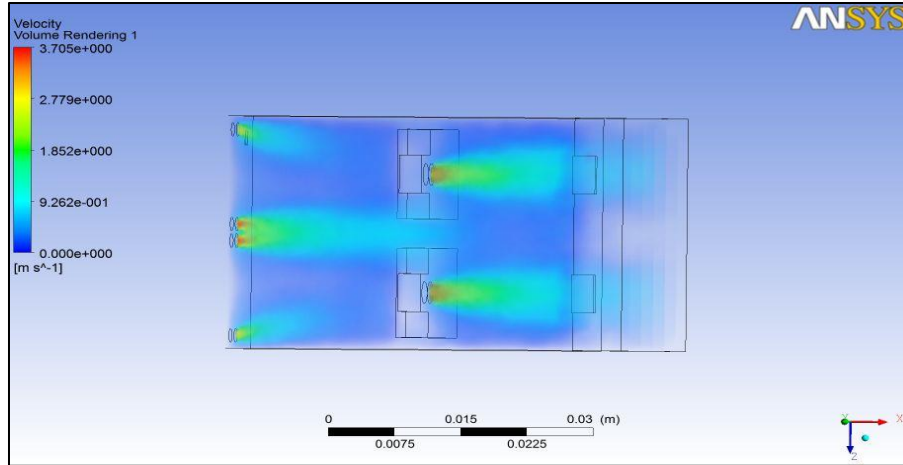


Figure 6.8: A.C. blower speed 2 (improved 4 fans installed)

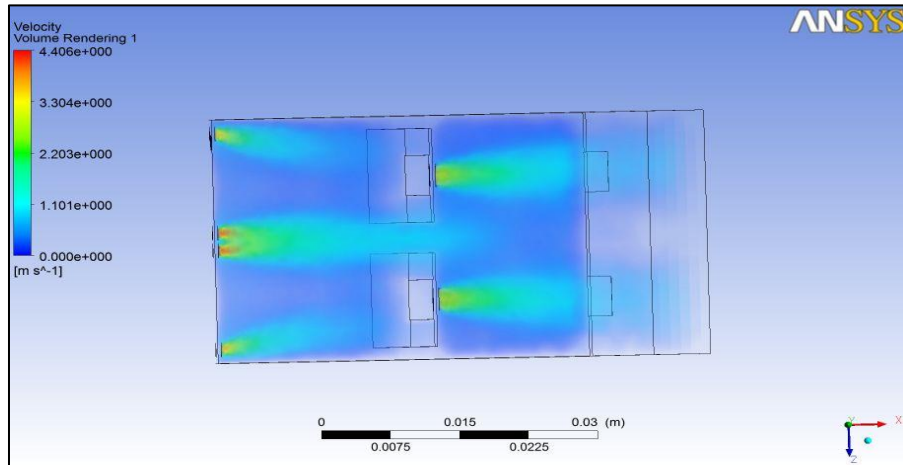


Figure 6.9: A.C. blower speed 3 (improved 4 fans installed)

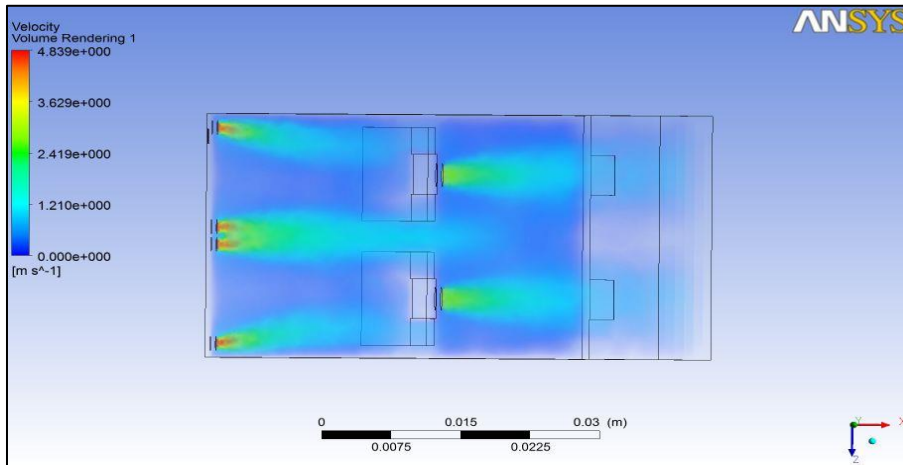


Figure 6.10: A.C. blower speed 4 (improved 4 fans installed)

Experimental readings taken at different A.C. blower speed in conventional case are validated with simulated results. All readings are in close proximity to simulated results.

6.2 Temperature measurement

Temperature readings are taken with the help of sensors at different blower and fan speeds. Each case with different boundary conditions is measured. Readings are taken on different days and different day time. Experimental investigation and simulated results of the air velocity with auxiliary fans are indicating the improvement in air circulation with reduced noise. For temperature measurement *improved case* refers to the situation when headrest fans and auxiliary fans on dashboard are operating simultaneously.

In actual case, sampling time (**Feedback**) for each observation is 2 seconds and total time of observation is 10 minutes hence there are 300 readings for 13 sensors. For demonstration purpose every table represents feedback after 30 sec and total time is 10 minutes but graph plotted is from original 300 observations. Table 6.4 represents readings of A.C. blower speed 2 in conventional case.

6.2.1 Temperature readings at A.C. blower speed 2 and improved case

Layout of all 13 sensors placed in vehicle cabin is described in figure 5.9.

Table 6.4: Temperature readings at A.C. blower speed 2 (conventional)

Feedback	TEMP1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	49.6	46.5	48.9	47.9	45.8	47.8	44.7	47	46.9	47.1	46.6	42.6	43.5
15	47	44.3	47.5	45	42.8	46.5	43.5	45.8	46.2	45	44.9	41.5	42.4
30	45.3	42.1	46.5	42.9	40.3	45.7	42	43.5	44.9	42.8	43.2	39.6	40.9
45	43.4	40.4	44.5	42.1	38.6	45.2	40.7	42.4	42.6	41.4	41.8	38.5	39.4
60	42.5	39.5	43.4	41.2	37.5	43.5	39.8	41.1	42	40	40.8	37.3	38.7
75	41.3	38.5	42.7	40.3	36.7	43.1	39	40.4	41.6	39.5	40	36.6	37.6
90	40.9	38.1	41.7	40.1	35.9	42.6	38.5	40.1	40.6	39.3	39	36.2	37.1
105	40.7	37.2	41.3	39.7	35.5	42.2	38.1	39.8	40.6	38.7	38.7	35.8	36.9
120	40.2	36.7	40.9	39.6	35.2	41.8	37.5	39.4	39.8	38.5	38	35.4	36
135	39.8	36.3	40.1	38.5	34.6	42	37.1	39.3	38.9	37.5	37.4	34.7	35.3
150	39.4	36.1	40.2	38.3	34.3	41.5	36.7	38.6	38.8	37.6	36.8	34.4	35.2
165	39.2	35.5	39.8	38.5	34	41.4	36.4	38.4	38.4	36.7	36.3	33.8	34.5
180	39.3	35.2	39.4	38.1	33.4	41.3	35.8	38.4	38.1	36.3	35.6	33.2	33.7
195	38.6	34.7	38.9	38.3	32.6	40.9	35.4	38.2	37.6	35.8	35	32.7	33.2
210	38.9	34.4	39	38.2	32.2	40.4	35.1	38	37	35.5	34.6	31.9	32.8
225	38.5	34.2	38.3	38.4	32.2	40.8	34.5	37.5	36.4	35.1	34.4	31.7	32.4
240	38.3	33.8	38.5	38.3	31.7	41	34.4	37.2	36.5	34.8	33.8	31.3	31.7
255	38.3	33.8	38.4	38.2	31.8	40.3	34.1	36.9	36.5	34.2	33.6	31	31.3
270	38.2	33.5	38.3	37.7	31.3	40.7	33.8	36.8	36	33.7	33.2	30.8	31
285	38.2	33.3	38.1	37.8	31.3	40.6	33.7	36.5	35.8	33.7	33.3	30.5	30.7
300	38	33.1	37.7	37.9	31.2	40.1	33.6	36.5	35.8	33.6	33.2	30.7	30.9

Table 6.5 represents readings of A.C. blower speed 2 with installed fans.

Table 6.5: Temperature readings at A.C. blower speed 2 with installed fans (improved)

Feedback	TEMP1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	52.6	50.2	51.2	50.1	50.3	50.7	48.4	50.5	50.4	51.6	50.7	48.2	47.3
15	50.5	48.3	50.1	48.3	49.3	47.6	47.4	49.7	49.5	49.7	47.8	46.6	45.8
30	48.1	45.8	46.4	46.2	46.3	43.7	46	46.7	46.7	47.9	43.9	44	43.3
45	46.3	44	44.7	43.7	45	42	45	45.5	45	46.1	41	41.1	40.9
60	44.9	42.2	42.7	43.3	43.3	39.6	44	43.5	43.4	44.4	38.9	39.6	39.5
75	44.3	41.3	41.4	41.8	42.1	38.8	43.2	42	42.5	43.4	37.6	38.3	37.5
90	44.2	40.7	40.5	41.9	41.8	38.3	42.5	41.7	42	42.5	37	37.5	36.4
105	43.2	40.1	39.7	40.4	40.9	38.1	41.9	40.5	41.2	42.2	36	36.7	35.5
120	42.7	39.8	39	41.1	40.6	37.4	41.3	40	40.7	41.1	35.2	36.1	34.4
135	41.9	39.2	38.6	39.9	39.5	36.7	40.9	39.5	39.9	40.9	34.7	35.3	33.8
150	41.9	38.7	38	40	39.7	36.4	40.6	39	39.7	40.7	34.6	35.2	33.1
165	41.7	38.7	37.4	39.7	39.3	36.5	40.3	38.8	39.7	40.3	34.1	34.5	32.6
180	40.9	38.3	37.4	38.9	38.9	35.8	40	38.4	38.9	39.9	33.4	34.3	32.5
195	40.8	38.2	37	38.9	38.7	35.7	39.8	38	38.6	39.2	33.7	34	31.8
210	40.7	37.8	36.5	38.4	38.3	35.1	39.3	37.9	38	39.3	33.2	33.4	31.4
225	39.9	37	36.3	38.1	38	35.2	39	37.6	38.1	38.5	32.8	33.1	30.9
240	39.8	36.9	36.3	37.8	37.7	35.1	38.7	37.5	38	38.6	32.3	32.8	30.6
255	39.6	36.5	36.1	37.3	37.3	34.5	38.4	36.9	37.7	37.8	32	32.4	30.6
270	39.2	36.3	35.6	37.3	37	34.2	37.9	36.6	37.3	37.8	32.1	32.1	30.1
285	39.2	36.1	35.4	37.1	36.7	34.1	37.9	36.7	37.3	36.8	31.8	31.8	29.8
300	38.7	35.8	35	36.7	36.6	33.6	37.5	36	36.6	37	31.2	31.5	29.6

Figure 6.11 shows the face temperature of rear side passenger at the starting (0 min) and end of interval (10 min) at A.C. blower speed 2.

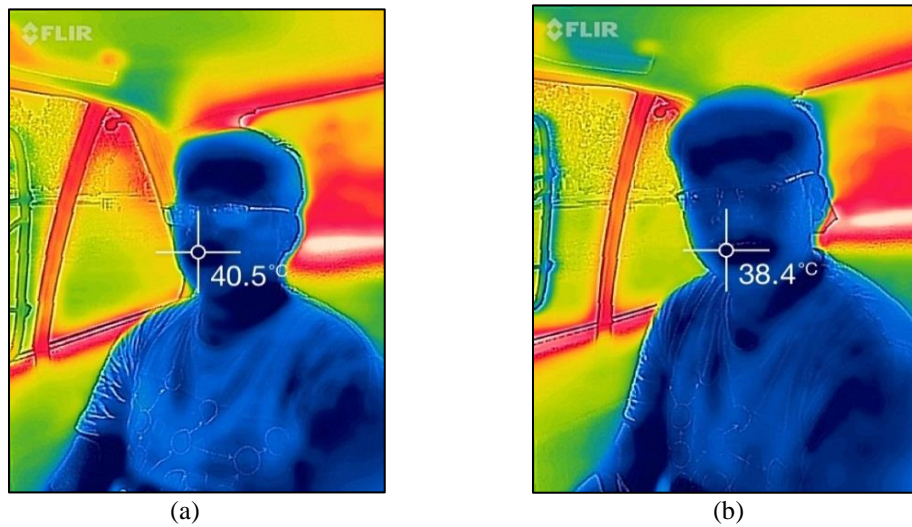


Figure 6.11: Face temp. of rear side passenger at A.C. blower speed 2 after 10 min (a) normal case (b) improved case

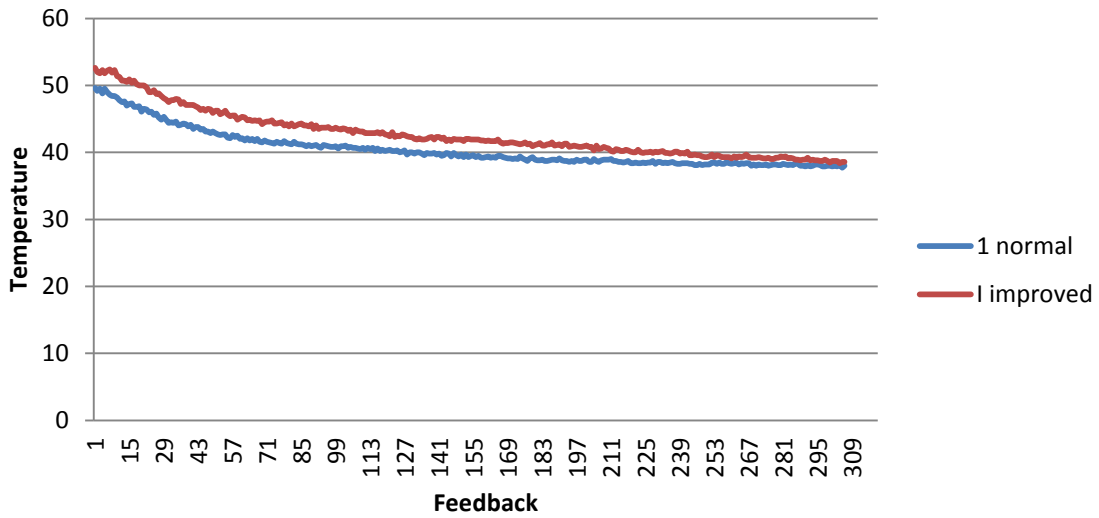


Figure 6.12: Improvement in sensor 1 at A.C. blower speed 2

Figure 6.12 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows improvement in sensor 1.

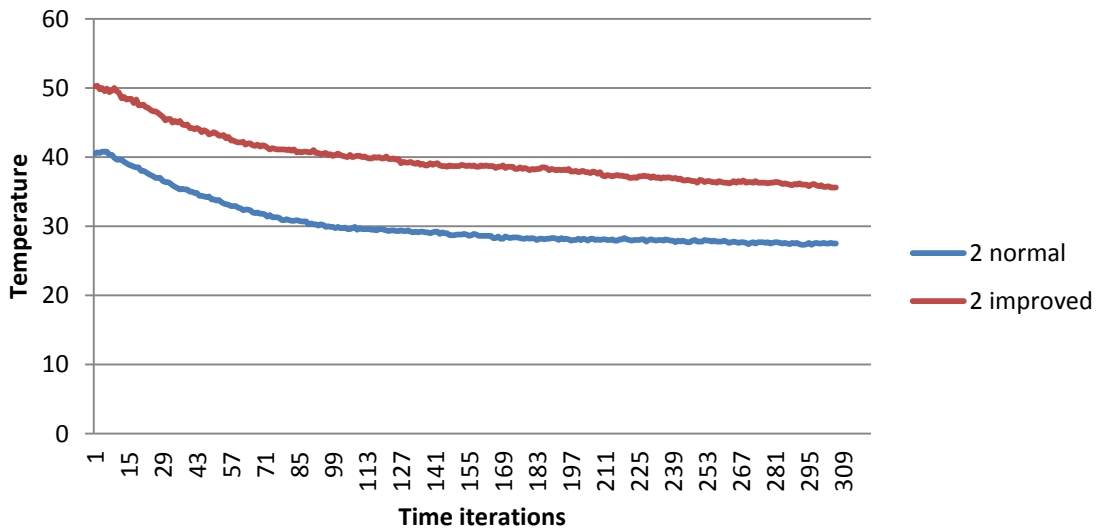


Figure 6.13: Improvement in sensor 2 at A.C. blower speed 2

Figure 6.13 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 1.

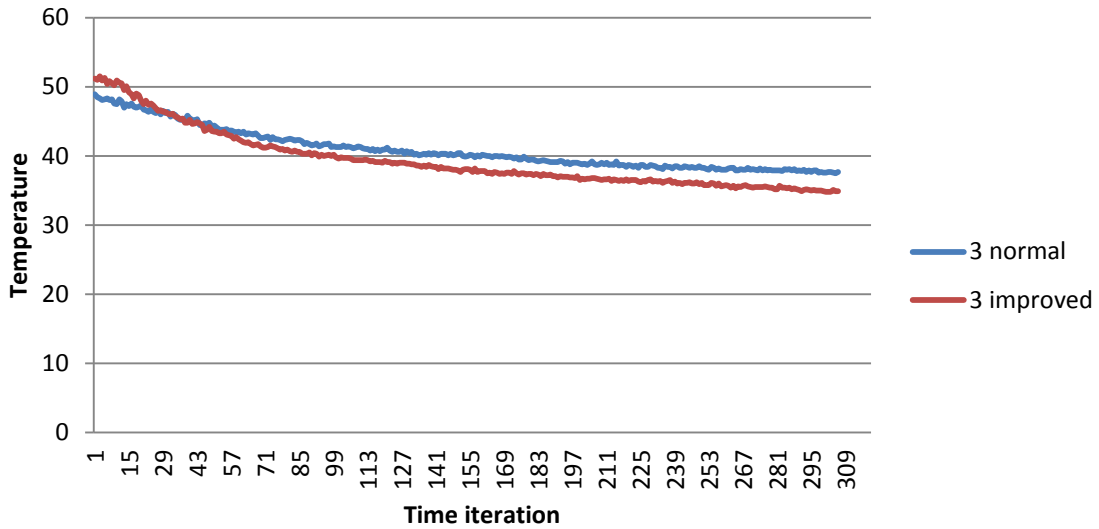


Figure 6.14: Improvement in sensor 3 at A.C. blower speed 2

Figure 6.14 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 3.

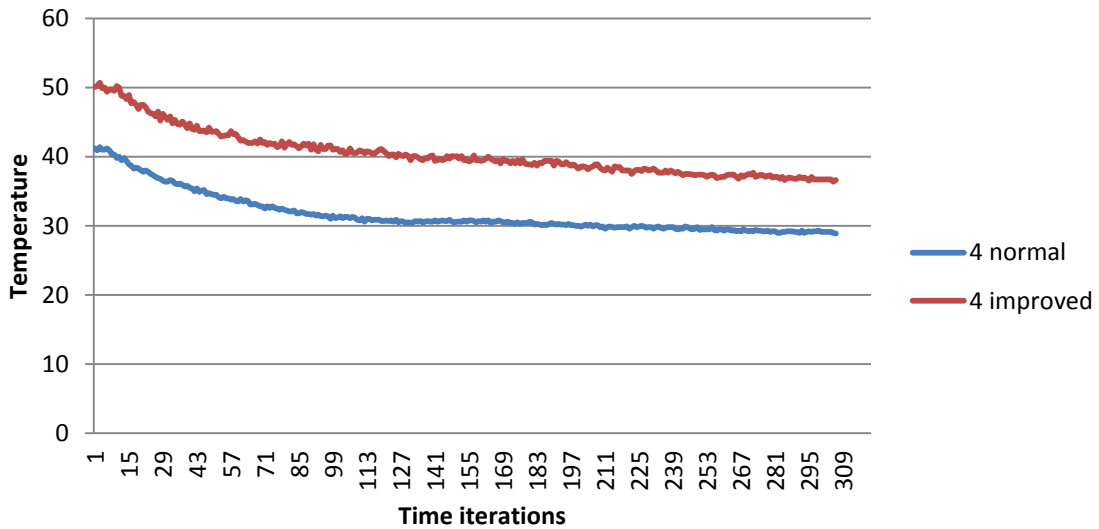


Figure 6.15: Improvement in sensor 4 at A.C. blower speed 2

Figure 6.15 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 4.

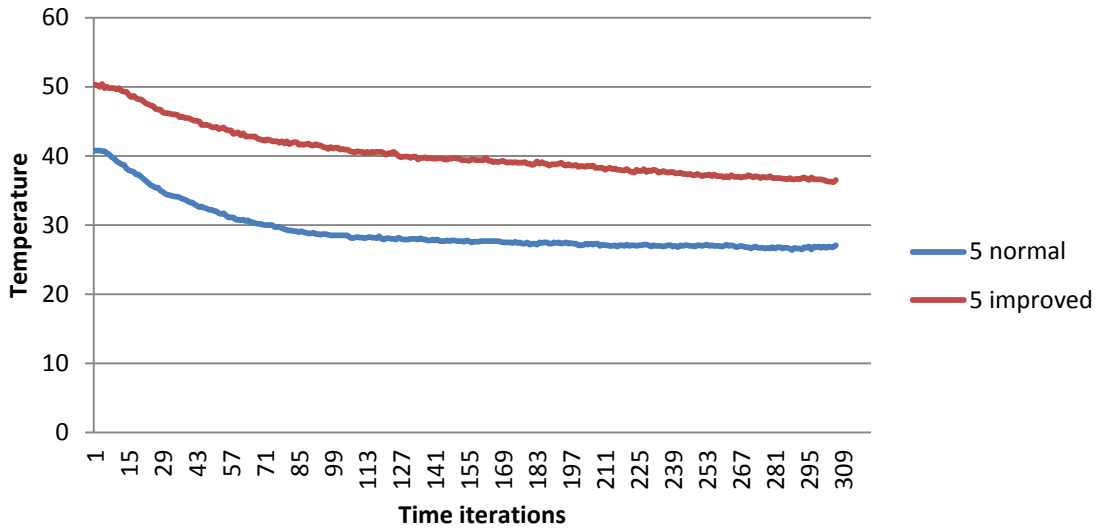


Figure 6.16: Improvement in sensor 5 at A.C. blower speed 2

Figure 6.16 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 5.

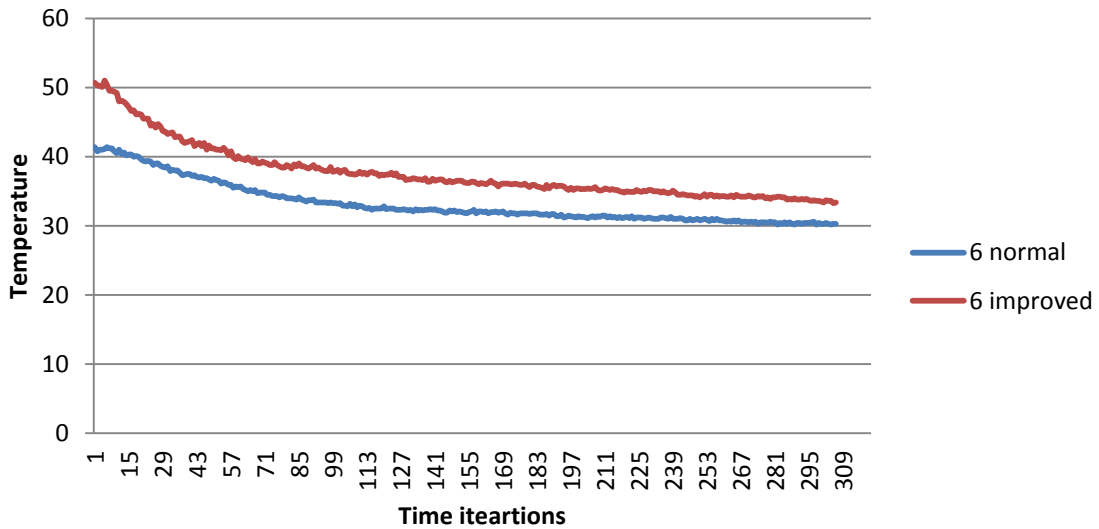


Figure 6.17: Improvement in sensor 6 at A.C. blower speed 2

Figure 6.17 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 6.

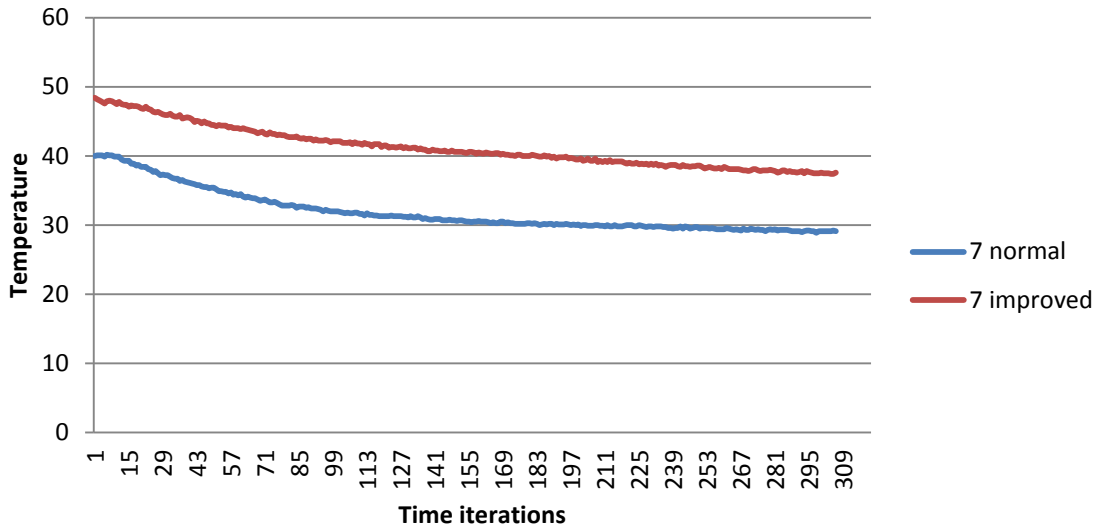


Figure 6.18: Improvement in sensor 7 at A.C. blower speed 2

Figure 6.18 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 7.

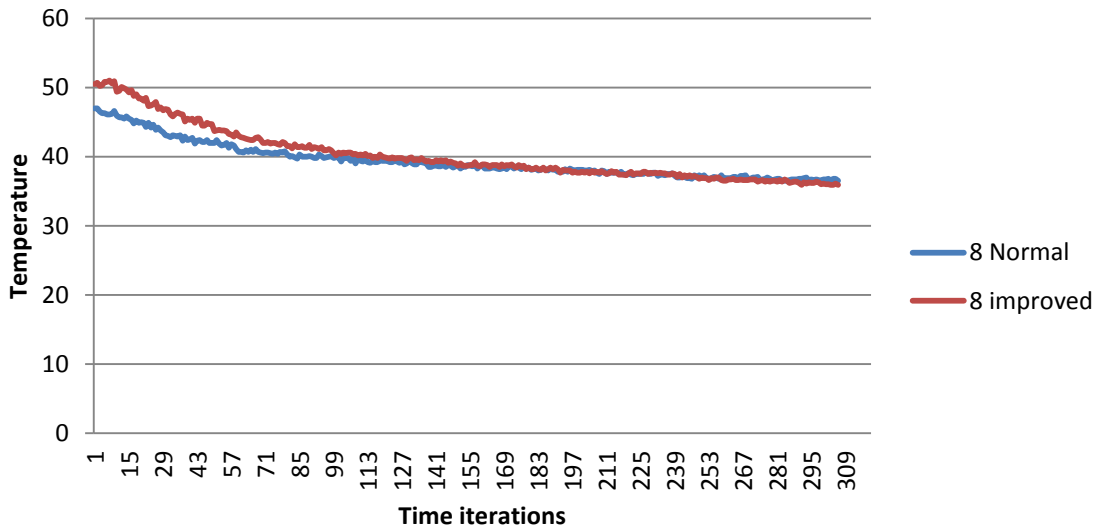


Figure 6.19: Improvement in sensor 8 at A.C. blower speed 2

Figure 6.19 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 8.

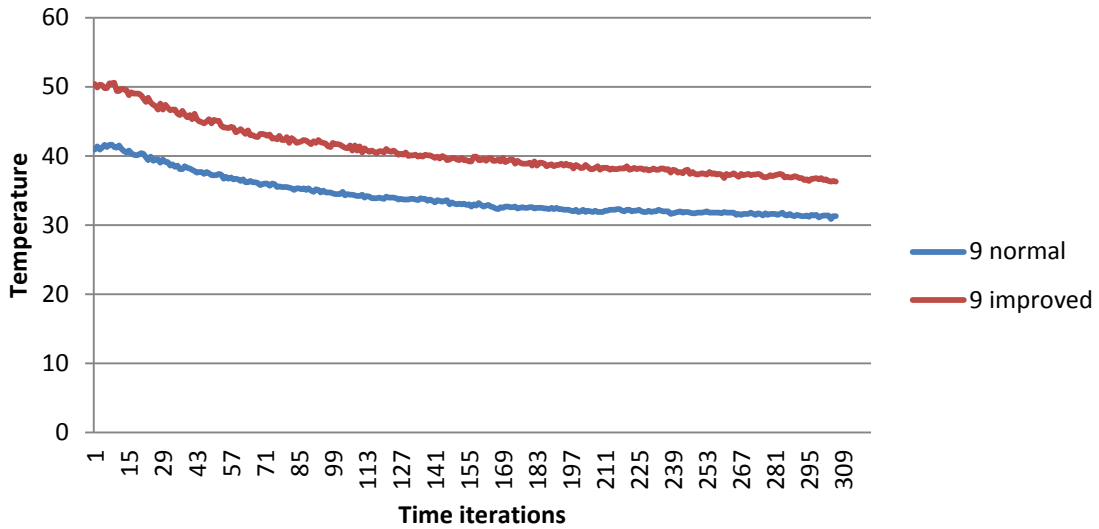


Figure 6.20: Improvement in sensor 9 at A.C. blower speed 2

Figure 6.20 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 9.

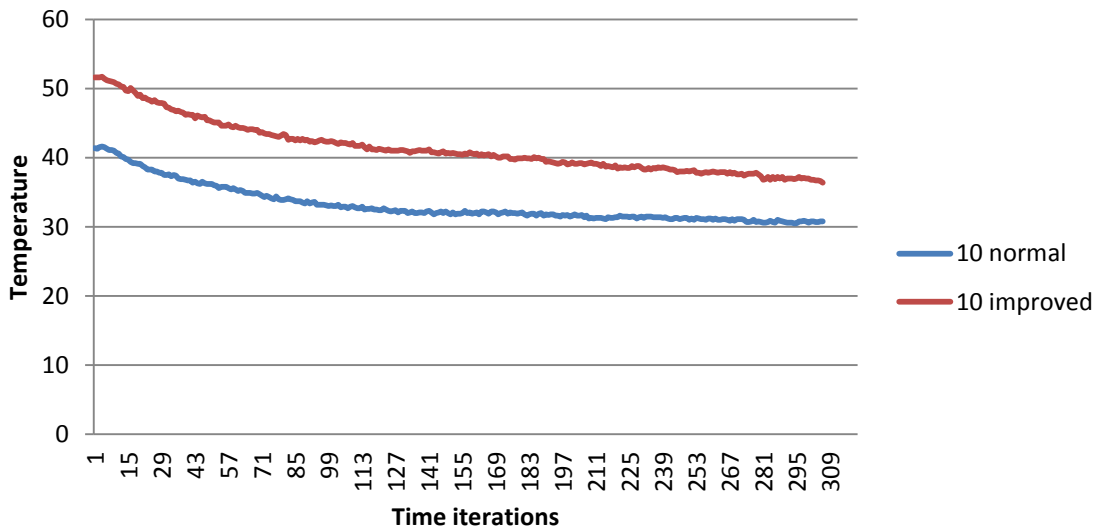


Figure 6.21: Improvement in sensor 10 at A.C. blower speed 2

Figure 6.21 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 10.

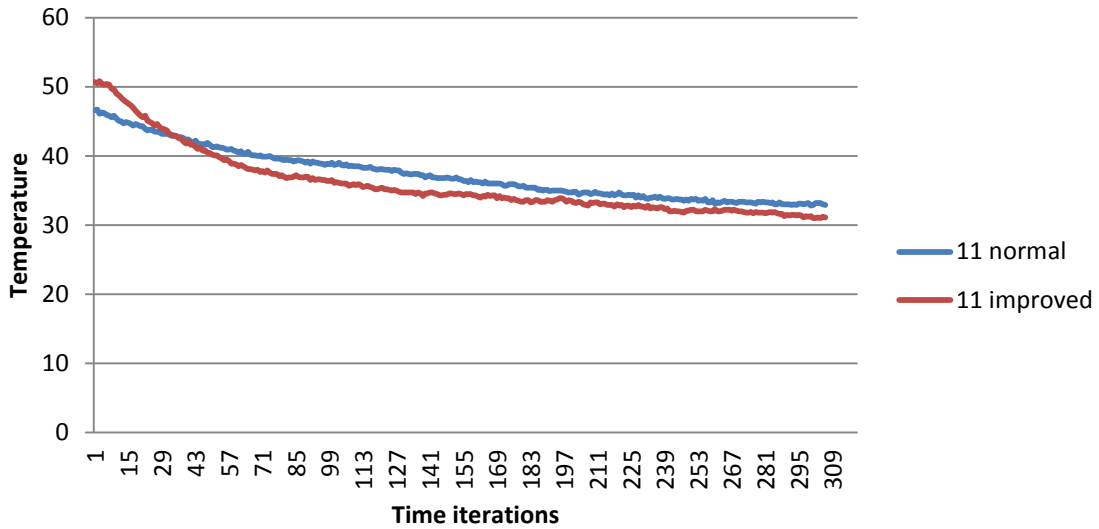


Figure 6.22: Improvement in sensor 11 at A.C. blower speed 2

Figure 6.22 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 11.

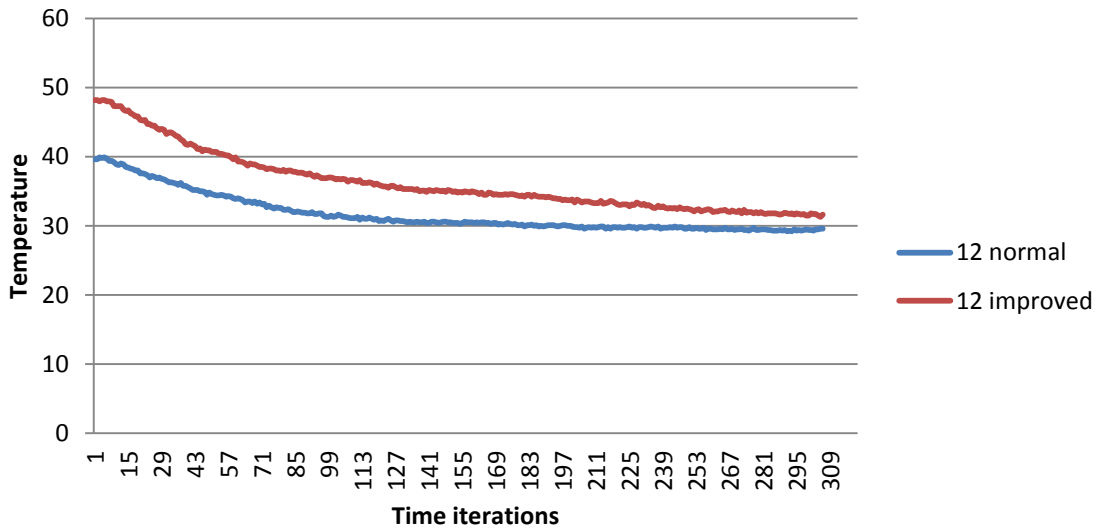


Figure 6.23: Improvement in sensor 12 at A.C. blower speed 2

Figure 6.23 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 12.

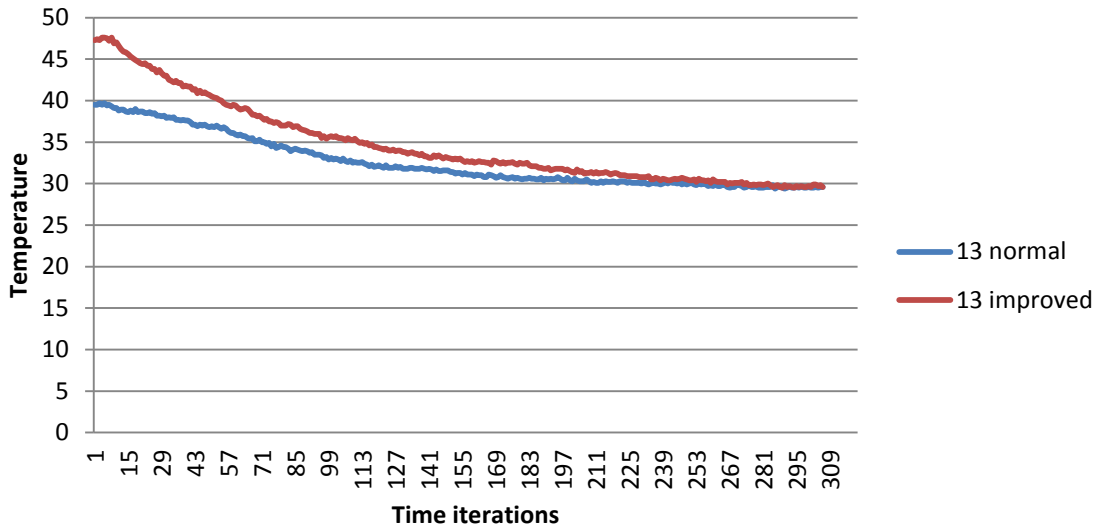


Figure 6.24: Improvement in sensor 13 at A.C. blower speed 2

Figure 6.24 shows the comparison between conventional case and installed set up at of A.C. blower speed 2 and graph shows the improvement in sensor 13.

After comparing graph of all sensors, results are described in Table 6.6.

Table 6.6: Improvement in temperature readings of different sensors at A.C. at blower speed 2

Sensor No	Temperature Measurement (°C)
Sensor 1	2.3
Sensor 2	1
Sensor 3	5
Sensor 4	3.4
Sensor 5	0.2
Sensor 6	9.4
Sensor 7	0.2
Sensor 8	4
Sensor 9	2.7
Sensor 10	1.1
Sensor 11	6.1
Sensor 12	4.8
Sensor 13	5.1

Conclusion for A.C. blower speed 2:

Temperature drop (average) at A.C. blower speed 2 for conventional case during 10 minutes in rear cabin is approximately 11°C whereas in case of installed setup same temperature drop (average) is achieved in **5 minutes** which is one of the main objectives of present work to achieve thermal comfort in less time than the conventional setup, with reduced time.

6.2.2 Temperature readings at A.C. blower speed 3 and improved case

Table 6.7 shows the readings of A.C. blower speed 3 in conventional case.

Table 6.7: Temperature readings at A.C. blower speed 3 (conventional)

Feedback	Temp1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	51.9	49.4	52.2	51.2	50.9	52.2	47.7	52.3	49.8	51.8	50.5	46.7	48.9
15	50.6	49.6	51.6	48.9	49.1	50.9	47.6	50.1	50.8	49.9	47.9	46.5	48.2
30	47.8	47.1	50	45.6	45.5	48.8	45.9	47.9	49	47.4	44.1	45.7	46.8
45	45.1	45.2	48	43.1	42.5	47.1	44.2	45.1	47.3	45.6	42.2	44.6	46.2
60	43.4	43.5	45.9	41.8	40.5	46.2	42.9	43.7	46.3	44.2	41	43.7	46
75	41.8	41.6	44.8	40.2	39.7	44.2	42	42.5	45.4	42.6	39.7	43.1	45.1
90	40.9	40.5	42.9	39.6	38.3	43.6	41.1	41.1	44.6	42	39.2	42.5	45.1
105	40.2	40	43.2	39	37.9	42.8	40.6	40.8	43.8	41.5	38.2	42.2	43.7
120	39.9	39.5	41.8	38.4	37.1	42	40	39.9	43.4	41.6	38	41.7	43.5
135	39.3	39	41.1	38.5	36.9	41.9	39.7	39.2	42.3	41.4	37.1	41.3	43.1
150	38.9	38.5	41	37.9	36.7	42.1	39.2	38.7	42.5	40.6	37.1	41	42.2
165	38.9	38.6	40.8	37.3	36.6	41.4	38.9	38.8	41.9	40.3	36.8	40.8	42.4
180	38.8	38.1	41.1	36.8	36.8	41.4	38.6	39.1	41.6	39.9	36.7	40.4	42.2
195	38.5	38	40.9	36.9	36.6	40.8	38.4	39.5	41.3	39.7	36.6	40.5	42.3
210	38.2	37.8	40.3	37.1	36.1	40.8	38.3	38.1	41	40	36.4	40.2	42.2
225	38.1	37.4	39.7	36.8	35.4	40.2	38.1	37.5	40.7	39.8	36	39.9	41.7
240	37.6	37.2	39.2	36.1	35.2	40.2	37.8	36.8	41.2	39.5	36	39.8	41.3
255	37.3	36.5	39.1	36.4	35.2	40.4	37.9	37.3	40.4	39.2	35.6	39.4	41.5
270	37.4	36.8	38.9	36.1	34.8	40.3	37.4	36.8	40.2	39.2	35.4	39.5	40.8
285	37	36.2	38.5	36	34.7	39.8	37.5	36.7	40.2	39	35.1	39.3	40.2
300	37.1	36.3	38.3	36.5	34.5	39.7	37.3	36.3	40.1	39.3	35.1	39.2	39.9

Table 6.8 shows the readings of A.C. blower speed 3 with installed fans.

Table 6.8: Temperature readings at A.C. blower speed 3 (improved)

Feedback	Temp1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	53.8	51.9	52.9	53.1	52.1	54	47.8	53.6	49.5	54.8	53.2	48.6	48.7
15	50.9	48.8	52.7	46.9	48.2	49.9	46.4	47.5	49.2	51	48.7	46.9	46.8
30	47.3	45.1	49.7	43.4	44.1	47.2	44.7	44.1	47.8	47	44.8	44.9	44.5
45	45	43.1	48.6	42.2	41.4	45.7	43.1	41.4	46.1	44.6	42.1	43.3	42.8
60	43.5	41.1	47	40.6	39.8	44.1	42	39.5	45.1	42.9	40.5	41.7	41.4
75	41.8	40.1	45.1	38.8	38.2	42.7	40.9	38.3	43.8	41.7	39.4	40.7	40.2
90	40.8	38.6	43.6	38	37.2	41.3	39.6	37.7	42.6	40.8	38.2	39.5	39.2
105	40	38	42.6	37.5	36.3	40.7	39	36.8	42.3	40.1	38	38.6	38.2
120	39.5	37.3	41.4	36.9	36.1	39.8	38.5	36.6	41.1	39.1	37	38.3	37.8
135	39.1	36.7	40.9	36.1	35.5	39.3	38	36	40.7	38.6	36.7	37.8	37.2
150	38.2	36.3	41	35.8	35	39.7	37.6	35.8	40	38.4	36.5	37.4	36.6
165	38.1	36.2	40.9	35.9	35	39.3	37.4	35.4	40.3	38.4	36.2	37.2	36.6
180	37.7	35.7	40.2	35.7	34.6	38.7	37	35.1	39.7	38	35.9	36.6	36.3
195	37.4	35.6	39.5	35.5	34.2	38.2	36.6	34.9	39.6	38	35.7	36.7	36.1
210	37.3	35.4	40.3	35.3	34	38.7	36.4	34.5	39.3	37.9	35.6	36.5	35.8
225	37.3	35.1	39.6	34.9	33.7	38	36.2	34.4	39	37.4	35.2	36.2	35.7
240	37	35.1	39.4	35	33.7	37.9	35.9	34.4	38.9	37.2	35.1	35.9	35.5
255	37.1	34.9	39.5	34.9	33.5	38.2	35.8	34.2	39	37.2	34.8	36.1	35.7
270	36.7	34.6	38.9	34.4	33.5	37.6	35.8	34.1	38.5	37	34.9	35.9	35.2
285	36.7	34.4	38.9	34.3	33	37.5	35.6	34	38.2	37	34.9	35.7	34.8
300	36.5	34.5	39.3	34.2	33.1	37.6	35.5	33.8	38.6	36.5	34.5	35.5	34.7

Figure 6.25 shows the face temperature of rear side passenger at the starting (0 min) and end of interval (10 min) at A.C. blower speed 3.

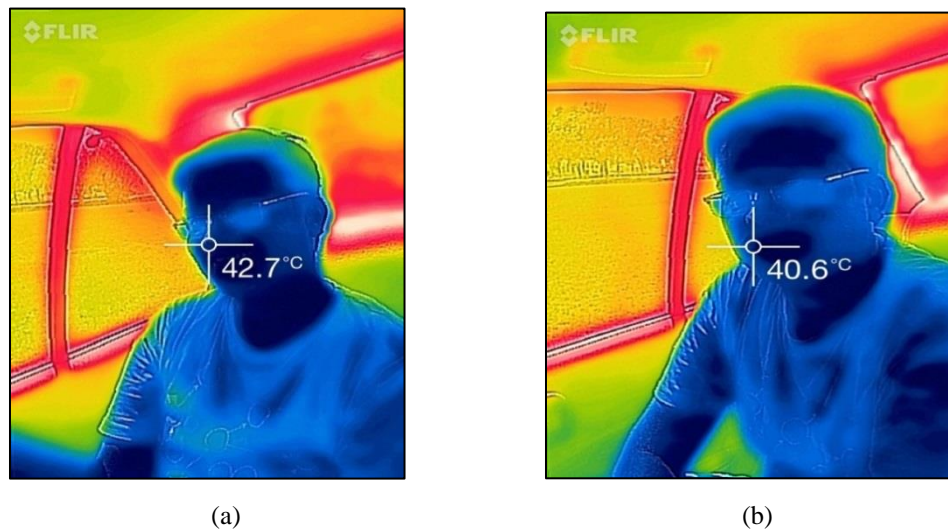


Figure 6.25: Face temp. of rear side passenger at A.C. blower speed 3 after 10 min (a) normal case (b) improved case

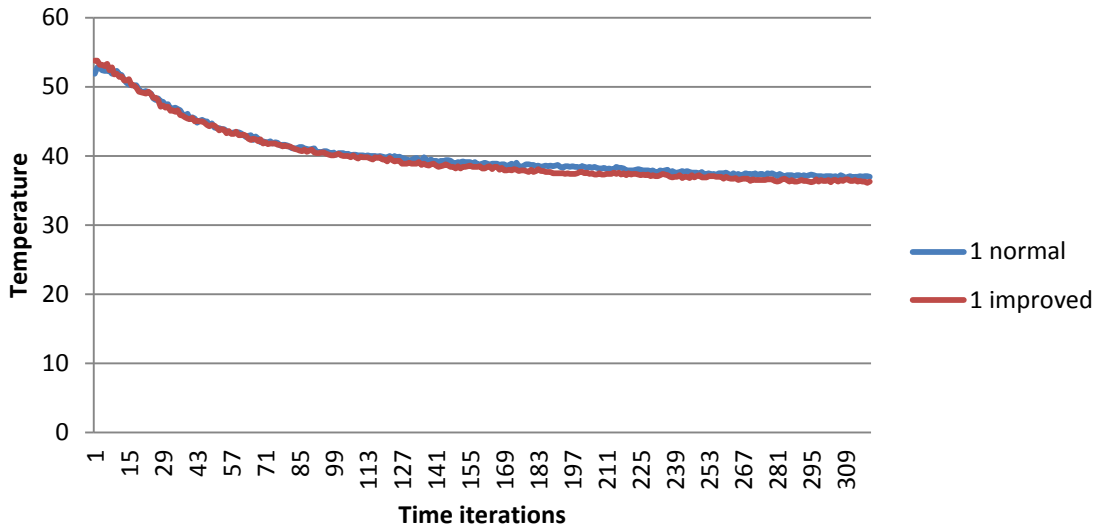


Figure 6.26: Improvement in sensor 1 at A.C. blower speed 3

Figure 6.26 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 1.

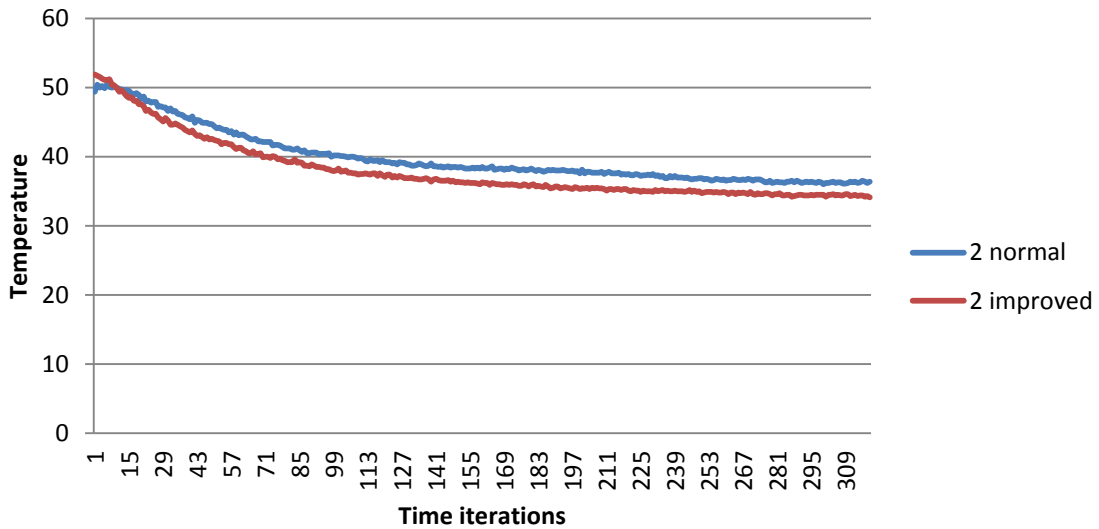


Figure 6.27: Improvement in sensor 2 at A.C. blower speed 3

Figure 6.27 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 2.

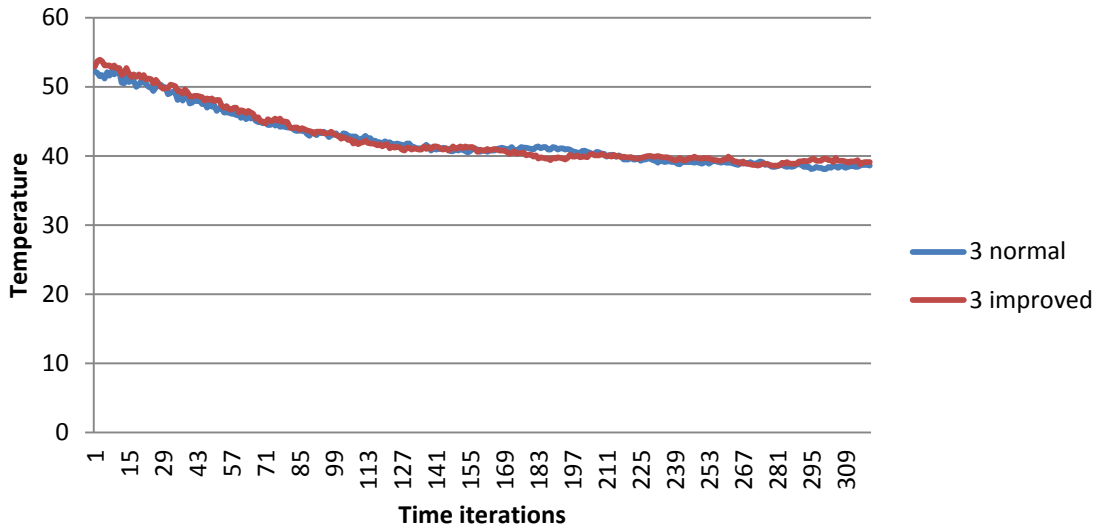


Figure 6.28: Improvement in sensor 3 at A.C. blower speed 3

Figure 6.28 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 3.

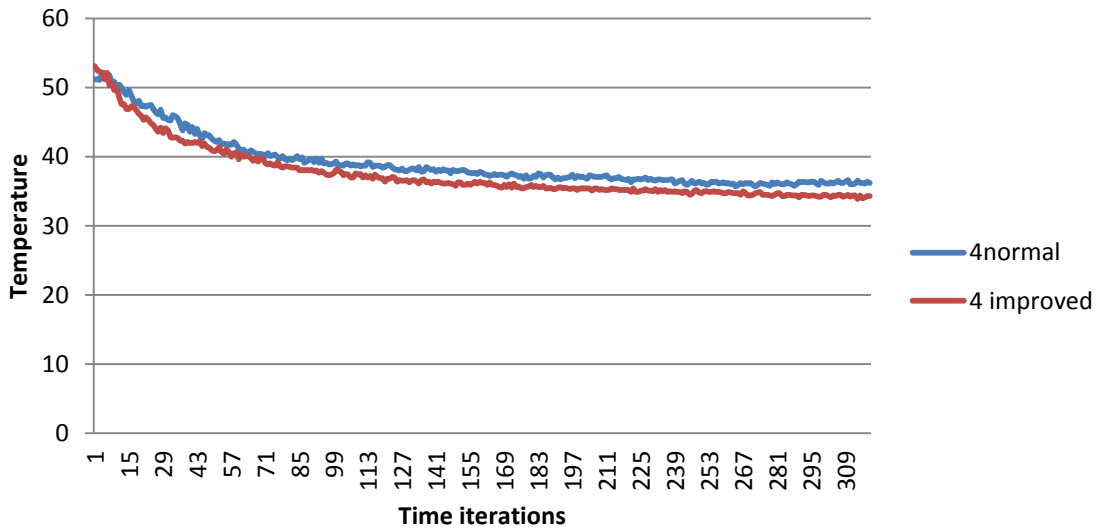


Figure 6.29: Improvement in sensor 4 at A.C. blower speed 3

Figure 6.29 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 3.

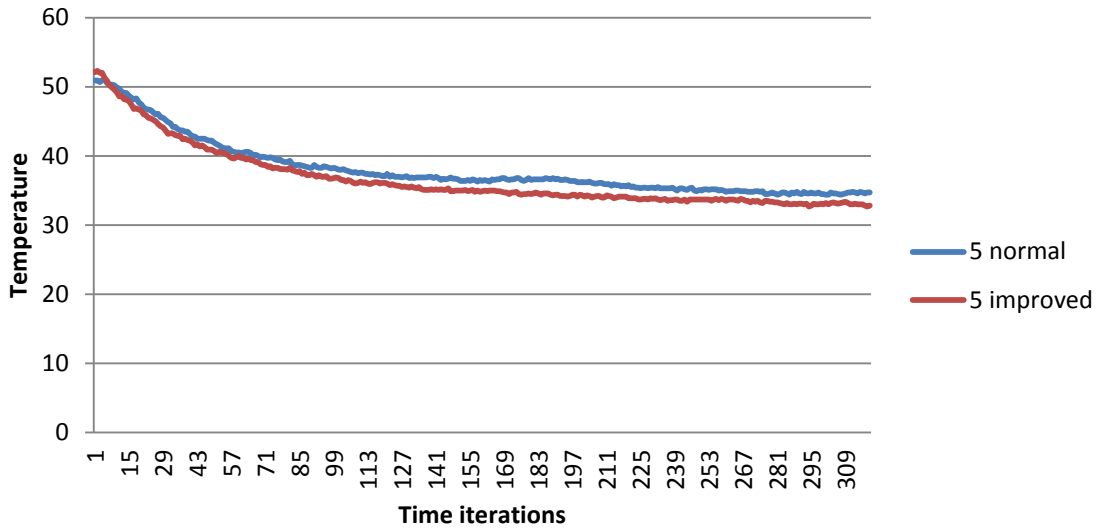


Figure 6.30: Improvement in sensor 5 at A.C. blower speed 3

Figure 6.30 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 5.

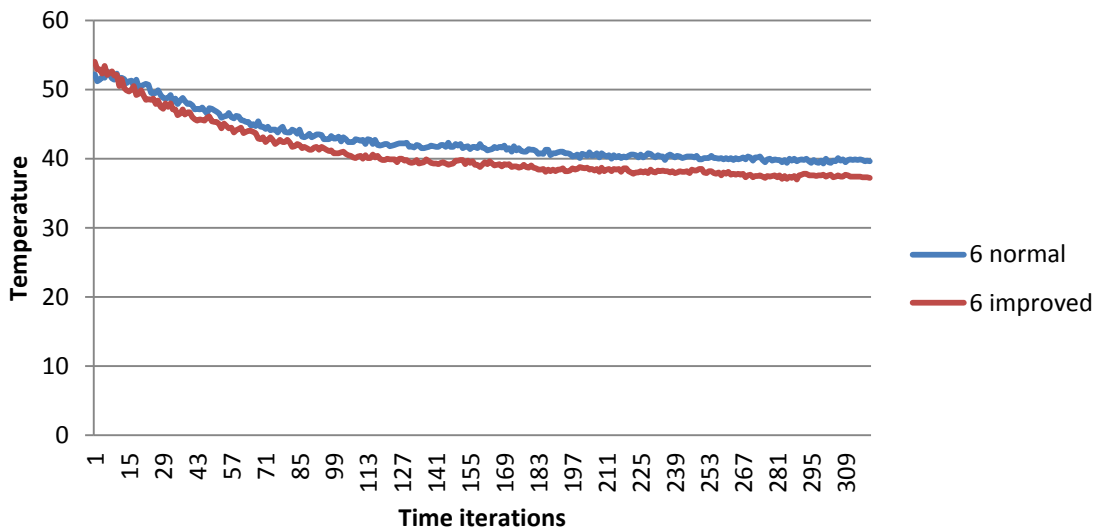


Figure 6.31: Improvement in sensor 6 at A.C. blower speed 3

Figure 6.31 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 6.

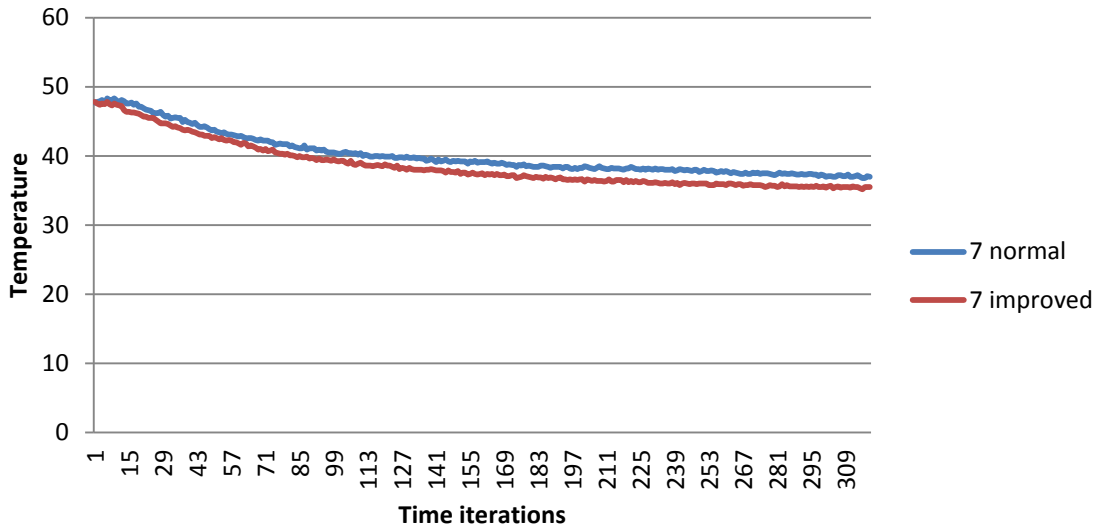


Figure 6.32: Improvement in sensor 7 at A.C. blower speed 3

Figure 6.32 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 7.

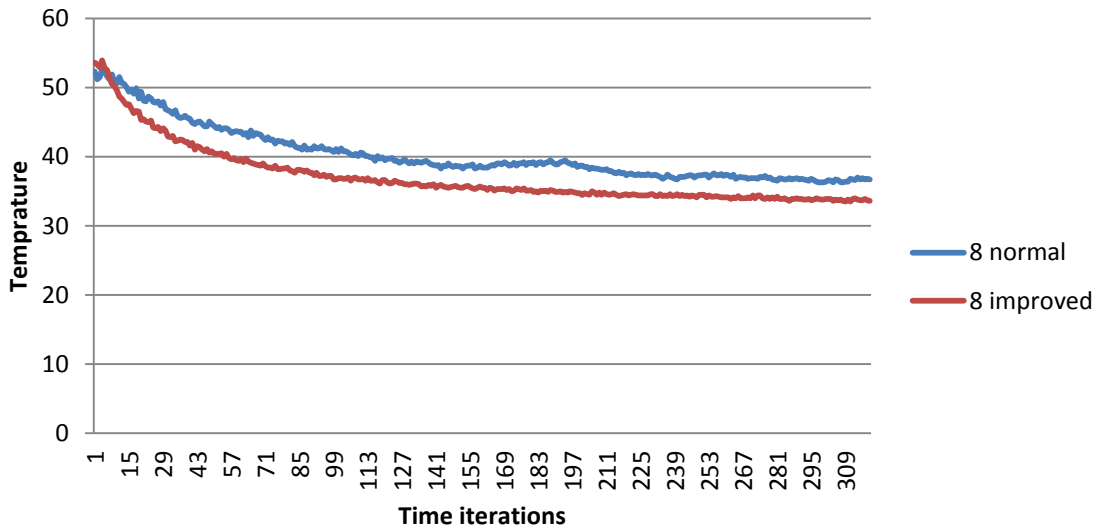


Figure 6.33: Improvement in sensor 8 at A.C. blower speed 3

Figure 6.33 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 8.

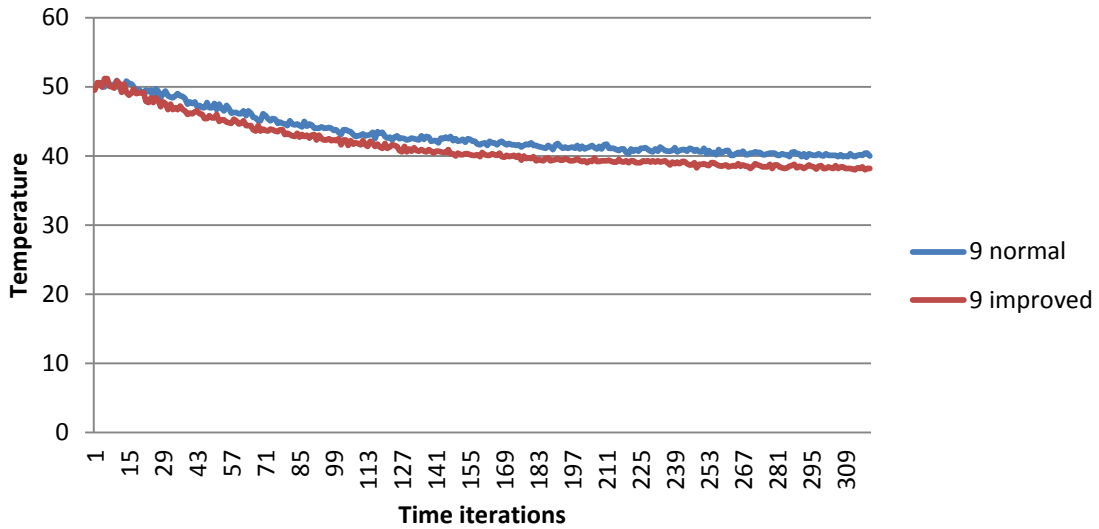


Figure 6.34: Improvement in sensor 9 at A.C. blower speed 3

Figure 6.34 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 9.

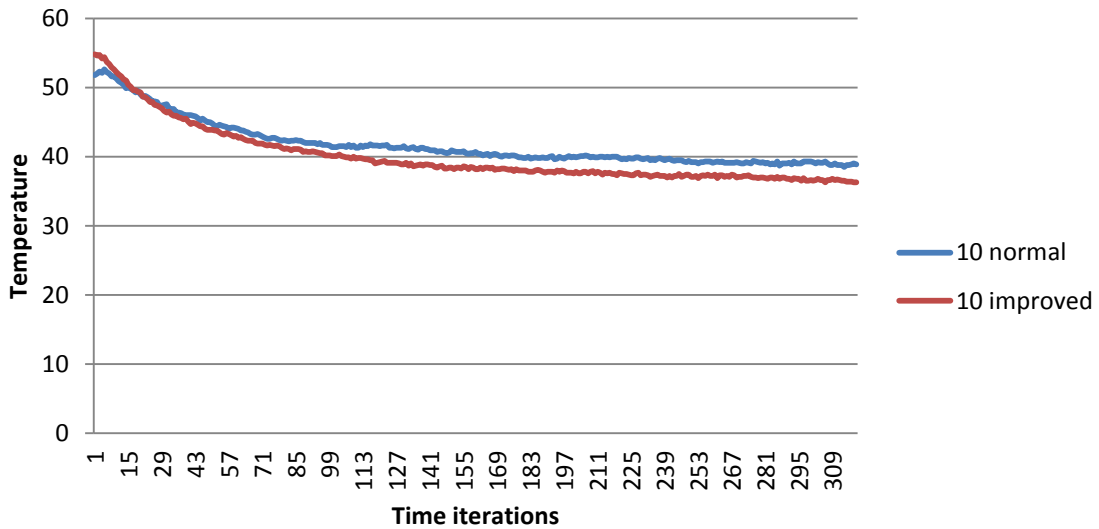


Figure 6.35: Improvement in sensor 10 at A.C. blower speed 3

Figure 6.35 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 10.

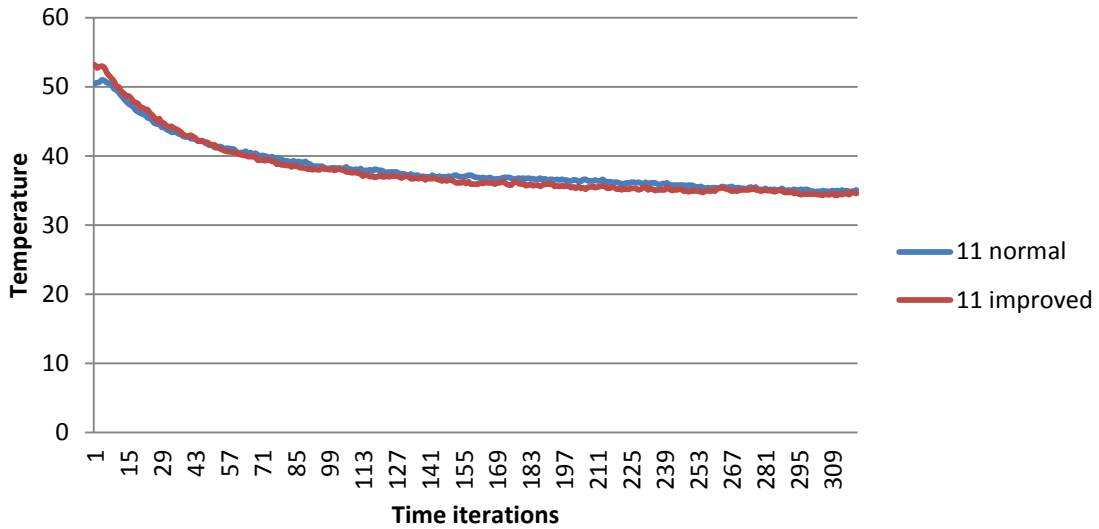


Figure 6.36: Improvement in sensor 11 at A.C. blower speed 3

Figure 6.36 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 11.

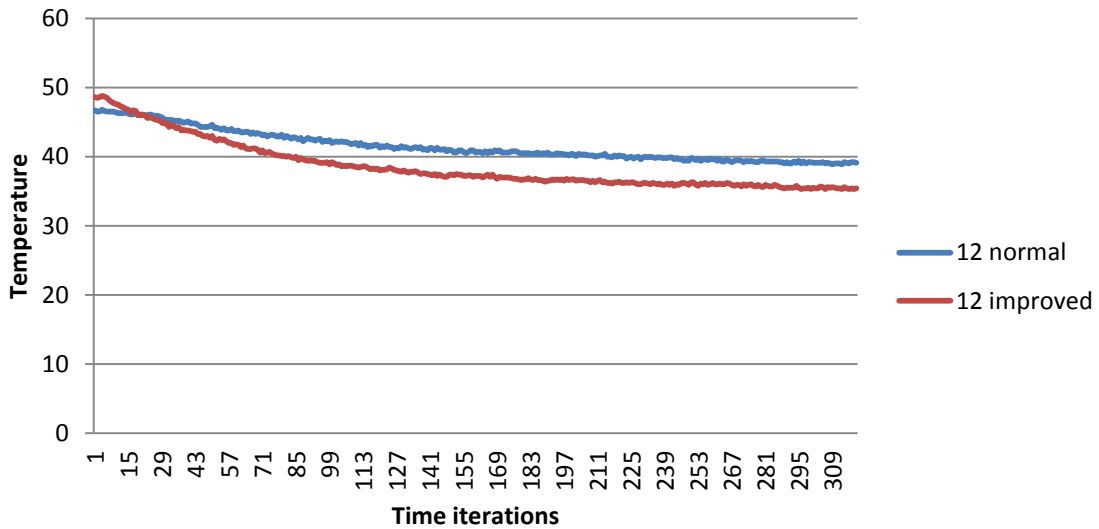


Figure 6.37: Improvement in sensor 12 at A.C. blower speed 3

Figure 6.37 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 12.

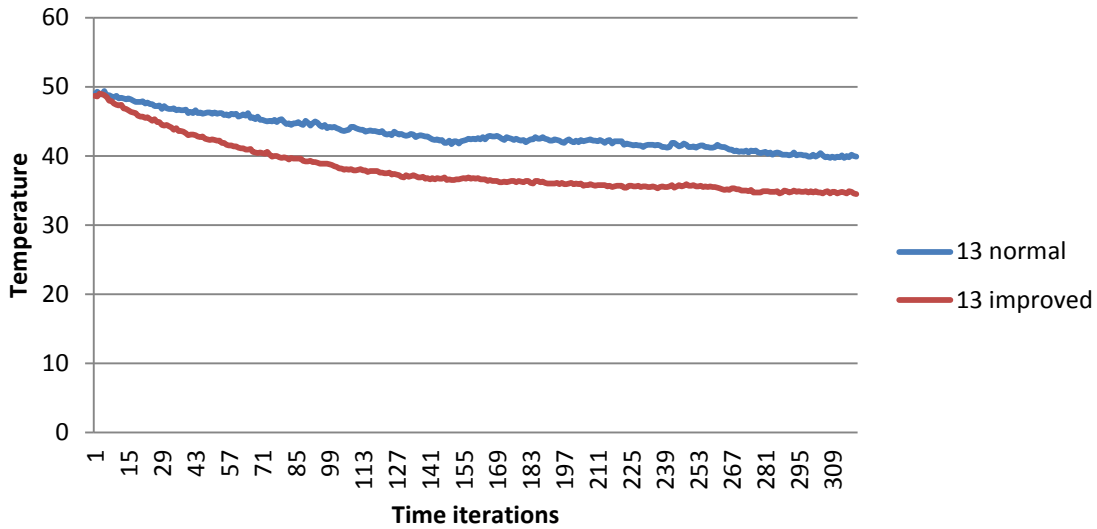


Figure 6.38: Improvement in sensor 13 at A.C. blower speed 3

Figure 6.38 shows the comparison between conventional case and installed set up at A.C. blower speed 3 and graph shows the improvement in sensor 13.

After comparing graphs of all sensors, results are described in Table 6.9.

Table 6.9: Improvement in temperature readings of different sensors at A.C. at blower speed 3

Sensor No	Temperature Measurement (°C)
Sensor 1	2.6
Sensor 2	4.8
Sensor 3	0.2
Sensor 4	3.8
Sensor 5	3.1
Sensor 6	4.2
Sensor 7	1.6
Sensor 8	4.4
Sensor 9	1.5
Sensor 10	5.6
Sensor 11	3.2
Sensor 12	5.6
Sensor 13	5.2

Conclusion for A.C. blower speed 3

Temperature drop (average) at A.C. blower speed 3 in conventional case in duration of 10 minutes in rear cabin is around 14°C whereas in case of installed setup same temperature drop (average) is achieved in 4-5 minutes which one of the main objective of present work to achieve thermal comfort earlier than the conventional case, with reduced noise.

6.2.3 Temperature readings at A.C. blower speed 4 and improved case

Table 6.10 shows readings of A.C. blower speed 4 in conventional case.

Table 6.10: Temperature readings at A.C. blower speed 4 (conventional)

Feedback	Temp1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	56.2	53.9	56.8	56	55	56.6	50.2	56.7	53.2	57.7	56.6	51.6	52
15	52.6	51.9	53.1	51.2	51.5	54.9	49.3	53.4	51.8	53.9	51	49.8	50.3
30	49.1	48.3	49.4	47.4	47.7	50.3	46.9	48.1	49.5	49.3	45.6	48.4	48.5
45	45.5	45.5	46.7	44.3	44.6	48.9	44.9	44.6	48.1	46.4	43	47	47.1
60	44.3	43.8	44.7	43.3	43.2	46.4	43.5	42.7	47.2	44.9	42.1	46	45.5
75	43.2	42.8	43.6	41.8	42.3	45.3	42.6	41.9	45.6	43.7	41	45.2	45
90	42.5	41.7	43.2	41.1	41.6	44.7	42.1	41.9	45.7	43.2	40.2	44.8	44
105	41.3	40.9	42.4	40.7	40.7	44.1	41.3	40.5	44.7	42.4	39.3	44	43.8
120	40.9	40.1	41.8	40	39.8	42.9	40.4	40.4	44	41.8	38.6	43.5	43
135	39.9	39.4	40.5	39.3	39	42.3	40	39	42.6	40.9	38	42.8	42.4
150	39.4	38.6	39.9	38	38.1	42	39.5	38.4	42	40.4	37.5	42.4	42
165	38.8	38.1	39.4	37.7	37.4	41.3	39.1	37.7	42	39.9	37	41.9	41.3
180	38.3	37.8	38.7	37.6	37	41.1	38.6	37.7	41.5	39.9	36.7	41.5	41
195	38.5	37.4	38.4	37.7	36.9	40.8	38.2	37.4	40.8	39.6	36.5	41.1	41
210	37.8	37.1	38.5	37.1	37.2	40.4	38	37	40.8	39.4	36.4	41	40.4
225	38.3	37.1	38.4	37.2	37.1	40.5	37.8	37.1	40.8	39.4	36.5	41	40.5
240	38.1	37.2	38.8	37	37.1	40.1	38	37.5	41	39.2	36.6	41	40.6
255	38.3	37.4	38.9	37.8	37.2	40	38	37.8	40.6	39.6	36.8	41.1	40.5
270	38.3	37.5	39	37.6	37.4	40.6	38.1	38.1	40.8	39.6	37	41	40.5
285	38.3	37.4	39.2	37.6	37.9	40.7	38	38.2	41.4	39.9	37	40.9	40.8
300	38.6	37.6	39.3	37.7	37.8	40.3	38.1	38.3	40.7	39.7	37	41.2	40.8

Table 6.11 represents readings of A.C. blower speed 4 with installed fans.

. Table 6.11: Temperature readings at A.C. blower speed 4 (improved)

Feedback	Temp1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	49.2	47.2	48.5	47.6	47.8	47.4	45.3	48.6	48.6	48	47	45.1	46.7
15	45.2	44	47	42.6	41.6	45.2	43.5	44.4	47	45.3	43.4	42.4	44.7
30	41.6	40.8	44.5	40	37.5	43.4	40.9	41.3	44.7	42.3	40.3	39.8	42.8
45	39.2	38.6	42.8	38.1	35.3	41.3	39.4	39.5	42.5	40.3	38.1	38	41.7
60	37.8	37.1	41.9	36.6	33.8	39.7	37.8	38.2	41.7	39.1	36.8	36.7	40.9
75	36.5	35.8	40.6	35.6	32.6	38.6	36.7	37	40.5	37.7	35.9	35.9	39.5
90	35.6	34.9	39.9	34.4	31.8	37.7	35.6	36	39.3	37	35	35	38.3
105	34.9	34.3	39.3	33.8	31.4	36.9	35	35.6	38.5	36	34.8	34.5	37.6
120	34.2	33.5	38.6	33.3	30.7	36.3	34.4	34.9	38	35.5	34	33.8	37
135	33.9	33.1	37.9	33	30.2	35.9	34	34.7	37.4	35	33.1	33.6	36.8
150	33.5	32.7	37.7	32.7	30.3	35.4	33.5	34.2	37.1	34.9	33.1	33.3	36
165	33.2	32.5	37.1	32.2	30.2	35.5	33.2	33.9	37	34.3	33.1	33	35.8
180	33.2	32.3	36.8	32.3	30	35.1	33	33.6	36.6	34.3	32.6	33.1	35.4
195	33	32.1	36.8	32.3	29.9	35.1	32.9	33.4	36.4	33.8	32.7	32.6	35.2
210	33	32.3	36.5	32.4	30	35	32.9	33.4	36.8	34	32.6	32.6	35
225	32.9	32.4	36.7	32.5	29.8	35	33	33.3	36.4	34	32.4	32.7	35.2
240	33.1	32.6	36.5	32.3	30.3	34.9	32.9	33.3	36.5	34.2	32.6	32.9	35.1
255	33.1	32.4	36.7	32.2	30.4	35	33.1	33.4	36.5	34.1	33	33.2	34.8
270	33.2	32.4	37	32.2	29.9	35	32.9	33.3	36.3	33.8	32.4	32.8	35
285	32.6	32	36.2	32.2	29.7	34.6	32.7	33.1	36.1	33.6	31.9	32.2	34.7
300	32.7	31.8	36.3	32	29.5	34.4	32.4	32.8	35.7	33.6	31.7	32.3	34.7

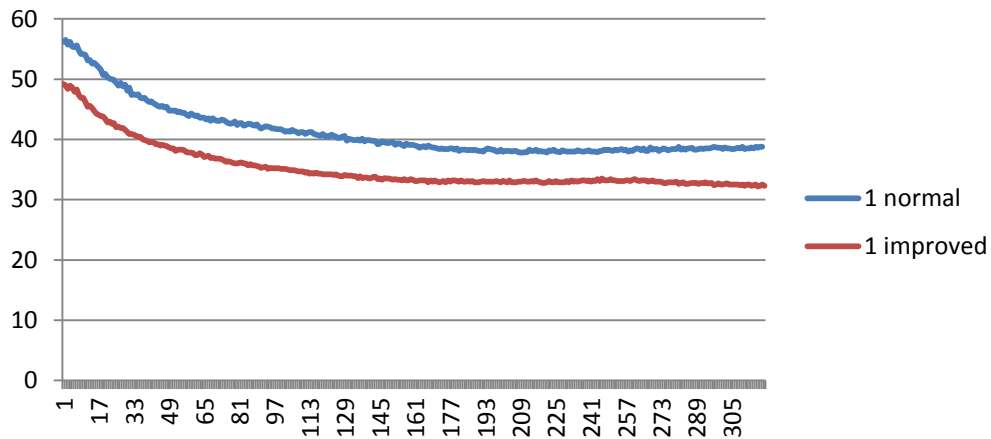


Figure 6.39: No improvement in sensor 1 at A.C. blower speed 4

In case of A.C. blower speed 4, there is no significant difference between conventional and improved case for all 13 sensors as shown in Figure 6.39. Fans attached in central outlet vents causes adverse effects as it does not improve air velocity in rear cabin.

6.2.4 Comparison of A.C. blower speed 2, 3 and 4

A.C. blower speed 2 with installed set-up is compared with A.C. blower speed 4 of conventional case. Table 6.12 represents initial and final temperature of all 13 sensors at A.C. blower speed 2 with installed setup.

Table 6.12: Overall temperature drop at A.C. blower speed 2 with installed set-up

Feedback	TEMP1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	52.6	50.2	51.2	50.1	50.3	50.7	48.4	50.5	50.4	51.6	50.7	48.2	47.3
300	38.7	35.8	35	36.7	36.6	33.6	37.5	36	36.6	37	31.2	31.5	29.6

Table 6.13 represents initial and final temperature of all 13 sensors at A.C. blower speed 4 in conventional case.

Table 6.13: Overall temperature drop at A.C. blower speed 4 in conventional case

Feedback	Temp1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	56.2	53.9	56.8	56	55	56.6	50.2	56.7	53.2	57.7	56.6	51.6	52
300	38.6	37.6	39.3	37.7	37.8	40.3	38.1	38.3	40.7	39.7	37	41.2	40.8

Average temperature drop at A.C. blower speed 4 in conventional case is 1.5-2°C more in comparison to average temperature drop at A.C. blower speed 2 with installed set-up. But in installed set-up thermal sensation of rear passengers is much better as more air flow is directed towards them from head rest fans.

A.C. blower speed 3 with installed set-up is compared with A.C. blower speed 4 of conventional case. Table 6.14 represents initial and final temperature of all 13 sensors at A.C. blower speed 3.

Table 6.14: Overall temperature drop at A.C. blower speed 3 with installed set-up

Feedback	Temp1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	53.8	51.9	52.9	53.1	52.1	54	47.8	53.6	49.5	54.8	53.2	48.6	48.7
300	36.5	34.5	39.3	34.2	33.1	37.6	35.5	33.8	38.6	36.5	34.5	35.5	34.7

Table 6.15 represents initial and final temperature of all 13 sensors at A.C. blower speed 4.

Table 6.15: Overall temperature drop at A.C. blower speed 4 in conventional case

Feedback	TEMP1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
0	56.2	53.9	56.8	56	55	56.6	50.2	56.7	53.2	57.7	56.6	51.6	52
300	38.6	37.6	39.3	37.7	37.8	40.3	38.1	38.3	40.7	39.7	37	41.2	40.8

Average temperature drop at A.C. blower speed 3 with installed set-up is approximately equivalent to average temperature drop at fan speed 4 in conventional case. But A.C. blower speed 3 with installed set-up provides better thermal sensation to rear passengers as more air flow is directed towards them from head rest fans and with better noise comfort as well.

6.3 Noise measurement

Cabin noise without any A.C. blower fan is 58 dbA.

6.3.1 Cabin noise in conventional case

Table 6.16 represents the cabin noise at different A.C. blower speed in conventional case.

Table 6.16: Cabin noise at different A.C. blower speed in conventional case

A.C. blower speed	Cabin noise level (dbA)	Temperature drop (°C) in 10 min.
1	61	---
2	62	11.6
3	64	12.5
4	67	15.7

Noise level inside the car cabin is approximately same throughout the cabin. Hence only one reading is taken at each A.C. blower speed.

6.3.2 Cabin noise in improved case (all 4 fans installed)

Table 6.17 shows cabin noise at different A.C. blower speed in improved case (all 4 fans installed).

Table 6.17: Cabin noise at different A.C. blower speed in improved case (all 4 fans installed)

A.C. blower speed	Cabin noise level (dbA)	Temperature drop (°C) in 10 min.
1	62	---
2	62.7	13.5
3	64.9	15.6
4	68.1	15.8

Noise level inside the car cabin is approximately same throughout the cabin. Hence only one reading is taken at each A.C. blower speed.

6.3.3 Conclusions of noise measurement

As seen from the above tables, temperature drop in improved case at A.C. blower speed 2 is more than conventional case at A.C. blower speed 3. But noise level in improved case at A.C. blower speed 2 is less than noise level in conventional case at A.C. blower speed 3.

Similarly, temperature drop in improved case at A.C. blower speed 3 is more than conventional case at A.C. blower speed 4. Whereas noise level in improved case at A.C. blower speed 3 is less than noise level in conventional case at A.C. blower speed 4. Hence better cooling is achieved at lower noise levels with the proposed set up.

It has been demonstrated that thermal environment inside the cabin at A.C. blower speed 2 and 3 in improved case is almost same or better than thermal environment inside the cabin at A.C. blower speed 4 in conventional case. But noise level at A.C. blower speed 2 and 3 in improved case is much less than noise level at A.C. blower speed 4 in conventional cases. Hence there is no requirement of A.C. blower speed 4 which produces maximum noise level but thermal environment inside the cabin will be same or much better in case of A.C. blower speed 2 and 3 in improved case.

Chapter 7

Conclusions and Future scope

7.1 Conclusions

The following conclusions are made after validating the experimental results with the simulated results. The improvements observed in the present study are described below:

1. Thermal comfort is achieved faster in case of installed set-up in comparison with conventional case at fan speed 2, 3 and 4.
2. Thermal comfort at fan speed 2 with installed set-up is comparable to fan speed 3 in conventional case.
3. Thermal comfort at fan speed 3 with installed set-up is comparable to fan speed 4 in conventional case.
4. Better thermal comfort for all (front and rear) passengers is achieved in approximately 50% less time in the case of installed set-up as compared to conventional case. Effect of installed fans is felt in complete cabin through better air circulation.
5. Thermal sensation for rear passengers is improved drastically in the first 10 minutes of the drive when car is very hot, as the air flow from headrest fans is directed towards the face from a smaller distance with the required velocity of 1.2 m/s.
6. Cabin noise level is substantially reduced as A.C. blower speed 2 and 3 with installed set-up provides same thermal environment at A.C. blower speed 4 in conventional case. Hence sound comfort is achieved in vehicle cabin without compromising in cooling efficiency for every passenger.

7.2 Future scope

Head rest fan is of major concern in the present study, hence efforts are required for optimization of its design and operation parameters. The possibility of radial flow blowers in place of axial flow fans can also be investigated.

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Appendices

Readings taken at A.C. blower speed 2 in conventional case.

TEMP1	TEMP2	TEMP3	TEMP4	TEMP5	TEMP6	TEMP7	TEMP8	TEMP9	TEMP10	TEMP11	TEMP12	TEMP13
52.6	50.2	51.2	50.1	50.3	50.7	48.4	50.5	50.4	51.6	50.7	48.2	47.3
52	50.3	51	50.2	50.2	50.3	48.2	50.7	49.9	51.6	50.5	48.2	47.4
51.8	49.8	51.5	50.7	50	50.2	48	50.2	50.3	51.6	50.8	48	47.3
52.3	50	50.9	49.9	50.4	50.1	47.8	50.3	50.2	51.7	50.4	48.2	47.6
51.8	49.5	51.3	50	49.8	51	47.6	50.8	49.8	51.4	50.3	48.2	47.6
52.2	49.9	50.4	49.4	50	50.4	47.9	50.8	49.8	51.2	50.4	48	47.5
52.4	49.4	50.8	49.7	49.8	49.5	48	51	50.5	51.1	50.3	48	47.2
51.9	49.6	50.5	49.7	49.8	49.5	47.9	50.6	50.5	51	49.7	47.9	47.6
52.3	50	50.2	49.5	49.8	49.4	47.7	50.9	50.6	50.9	49.6	47.3	46.9
51.4	49.5	50.9	50.2	49.6	49.2	47.5	49.4	49.4	50.7	49	47.3	47
51.3	49.3	50.6	50	49.8	48	47.8	49.5	49.4	50.6	48.8	47.3	46.6
50.7	48.5	50.5	48.8	49.4	48.1	47.5	50.1	49.7	50.3	48.4	47.3	46.2
50.7	48.7	49.5	48.8	49.3	47.9	47.4	49.9	49.6	50.2	48.1	46.8	45.9
50.5	48.3	50.1	48.3	49.3	47.6	47.4	49.7	49.5	49.7	47.8	46.6	45.8
50.9	48.4	49.2	48.9	48.8	47.1	47.1	49.3	48.8	49.6	47.6	46.7	45.6
50.4	48.4	48.9	47.7	48.5	46.6	47.3	49.6	49.2	50.1	47.3	46.3	45.3
50.7	47.8	48.3	47.9	48.7	46.7	47.2	48.8	49	49.7	47	46.1	45.1
50.2	48.3	49	47.5	48.3	46.1	47.2	49	49	49.4	46.5	45.8	44.9
50	47.5	48.8	46.9	48.2	46.2	47.1	48.4	49	48.9	46.2	45.8	44.7
50	47.5	48	47.5	48.2	46.1	46.9	48.4	48.8	49.1	45.8	45.3	44.5
50	47.6	47.5	47.5	47.9	45.5	46.8	48.1	48.3	48.6	45.6	45.2	44.4
49.7	47.2	48	47.1	47.6	45.5	47.1	48.5	47.8	48.7	45.8	45.3	44.5
49	47.1	47.4	46.5	47.5	45.5	46.8	47.3	48.4	48.4	45.1	44.7	44.2
49	46.8	47.6	46.3	47.3	44.5	46.7	47.4	47.7	48.3	44.9	44.7	44.2
49.3	46.6	47.3	46.2	47.2	44.7	46.4	47.6	47.4	48.1	44.7	44.5	43.8
48.7	46.6	46.9	45.8	46.8	44.2	46.3	47.9	47.2	48.3	44.4	44.5	43.8
48.8	46.4	46.5	46.5	46.7	44.7	46.4	46.9	46.7	48	44.6	44.1	43.4
48.4	46.1	46.6	45.2	46.7	44.4	46.2	47.1	47.6	47.9	44.2	43.9	43.7
48.1	45.8	46.4	46.2	46.3	43.7	46	46.7	46.7	47.9	43.9	44	43.3
47.9	45.3	46.4	45.7	46.2	43.6	45.9	46.9	47.4	47.8	43.9	43.9	43
47.5	45.5	46.1	45.3	46.2	43.3	45.9	46.8	47	47.3	43.7	43.3	43
47.8	45.5	46	45.8	46.1	43.4	46.1	46.1	46.6	47.2	43.3	43.5	42.5
47.8	45	46.1	44.8	46	43.5	45.8	45.8	46.7	47	43	43.5	42.4
48	45.2	45.7	45.3	46	42.8	45.7	46.2	46.7	46.9	42.9	43.3	42.2
47.9	45	45.6	44.7	45.9	42.9	45.7	46.4	46.1	46.7	42.9	43	42.4

47.2	45.2	45.3	44.6	45.6	42.9	45.9	46.2	45.9	46.8	42.6	42.9	42.1
47.5	44.7	45.4	45.1	45.7	42.2	45.4	46.1	46.5	46.6	42.5	42.5	42.1
47.1	44.6	44.8	44.7	45.5	42	45.5	45.1	46	46.5	42.1	42.3	41.7
47.1	44.7	44.8	44.1	45.5	42.1	45.6	45.5	45.6	46.2	41.8	41.8	41.8
47.1	44.2	45.2	44.8	45.4	42.2	45.5	45.3	45.9	46.3	42.1	41.7	41.7
47.1	44.2	44.6	44	45.2	42.4	45.3	45.5	45.3	46.2	41.6	41.9	41.7
46.9	44	44.7	43.9	45.1	41.5	44.9	44.9	46.1	46.2	41.7	41.7	41.3
46.7	44.2	44.9	44.5	45.1	41.8	45.1	45.5	45.3	45.7	41.3	41.5	41.4
46.3	44	44.7	43.7	45	42	45	45.5	45	46.1	41	41.1	40.9
46.5	43.6	44.5	43.7	44.5	41.5	44.7	44.5	44.9	45.9	41.2	41.2	41.2
46.2	43.9	43.6	43.8	44.5	42	45	44.5	44.7	45.8	40.8	40.8	40.9
46.5	43.7	43.8	43.5	44.5	41	44.7	44.9	45	45.9	40.8	41	41
46.4	43.3	44.2	44.2	44.4	41.6	44.7	44.7	45.3	45.4	40.5	40.9	40.8
45.9	43.4	43.6	43.6	44.2	41.2	44.5	44.7	44.7	45.4	40.4	40.9	40.7
46.2	43.6	43.5	43.6	44.1	41.2	44.5	43.7	45.2	45.2	40.2	40.7	40.5
46.2	43.4	43.5	43.7	44.2	41	44.3	43.8	45.1	45.1	40.1	40.7	40.4
45.7	43.1	43.3	43.3	43.9	41	44.5	43.9	45.1	45.1	40.1	40.7	40.3
45.9	43.1	43.3	42.9	44	40.9	44.4	43.8	44.4	45.1	39.8	40.4	40.1
46.2	43.2	43.5	43	44.1	41.3	44.4	43.8	44.1	44.6	39.6	40.4	40
45.7	42.7	43.1	43.1	43.8	40.9	44.4	43.7	44.1	44.6	39.4	40.3	39.7
45.4	42.9	43	43.1	43.7	40.2	44.1	43.3	44	44.6	39.5	40.2	39.5
45.5	42.4	42.9	43.7	43.7	40.8	44.2	43.2	44.2	44.8	39.3	40.2	39.4
45.5	42.4	42.5	43.3	43.2	39.9	44	42.9	44.1	44.5	38.9	39.9	39.3
44.9	42.2	42.7	43.3	43.3	39.6	44	43.5	43.4	44.4	38.9	39.6	39.5
45.1	42.1	42.4	42.8	43.4	40.1	44	43	43.6	44.6	38.8	39.9	39.4
45.3	42.1	42.2	42.3	43	39.7	43.9	42.8	43.9	44.4	38.5	39.3	39.1
45.2	42.2	42	42.4	43.3	39.6	44	42.7	43.5	44.3	38.7	39.3	38.9
44.8	41.8	41.9	42.2	42.8	39.5	43.9	42.6	43.2	44.3	38.5	39.2	39
44.9	42	42	42	42.8	39.9	43.8	42.5	43.7	44.2	38.3	39	39.1
44.7	42	41.7	42	42.8	39.5	43.7	42.4	43	44	38.1	38.7	39
44.8	41.7	41.5	42	42.8	39.2	43.6	42.4	43	44.1	38.1	39	38.7
44.7	41.6	41.6	42.2	42.8	39.6	43.5	42.7	42.8	44.1	38	38.9	38.3
44.8	41.8	41.7	41.9	42.5	39	43.3	42.8	42.7	44	37.9	38.9	38.3
44.2	41.5	41.4	42.5	42.4	39	43.4	42.5	43.2	44	38	38.7	38.1
44.5	41.7	41.2	42	42.3	39.3	43.5	42	43.2	43.6	37.7	38.5	38.2
44.6	41.6	41.2	42.1	42.2	39.1	43.2	42	43.1	43.7	37.8	38.5	37.9
44.6	41.4	41.3	41.7	42.4	39	43.1	42.1	42.9	43.5	37.6	38.4	37.7
44.8	41.1	41.5	42	42.3	38.8	43.4	41.9	43.1	43.4	37.9	38.2	37.8
44.3	41.3	41.4	41.8	42.1	38.8	43.2	42	42.5	43.4	37.6	38.3	37.5
44.3	41.2	41.3	41.9	42.1	39.2	43.2	42	42.6	43.3	37.4	38.3	37.5
44.4	41.1	41.1	41.4	42.1	38.8	43	41.8	42.4	43.2	37.4	38.2	37.3

44.5	41.1	40.9	41.5	41.9	38.6	43.1	41.7	42.9	43.1	37.4	38	37.4
44	41.1	41	42.2	42.1	38.4	43	42.1	42.3	43	37.1	38	37.3
44.2	41.1	40.8	41.3	41.8	38.4	43	42	42.3	43.2	37.2	37.9	37
43.9	41	40.9	41.8	42.1	38.8	42.8	41.5	42.7	43.4	37	38.1	37
44.3	41.1	40.7	42.1	41.7	38.6	42.7	41.5	41.9	43.3	36.8	37.8	37
43.9	40.9	40.6	41.7	41.9	38.3	42.7	41.2	42.6	42.6	36.9	38	37.2
44	41.1	40.8	41.8	42	38.9	42.7	41.8	42.3	42.7	36.9	38	37.1
44.2	40.7	40.6	41.5	42	38.6	42.8	41.4	41.9	42.7	37	37.8	36.8
44.3	40.8	40.6	41.2	41.6	39	42.6	41.4	42	42.5	37.2	37.8	36.9
44	40.7	40.3	41.5	41.7	38.6	42.5	41.5	42.1	42.7	37	37.7	36.9
44	40.8	40.3	41.9	41.6	38.6	42.6	41.3	42.3	42.5	36.9	37.7	36.6
43.9	40.8	40.3	41.6	41.7	38.4	42.4	41.3	42.2	42.7	36.9	37.7	36.5
44.2	40.7	40.5	41.9	41.8	38.3	42.5	41.7	42	42.5	37	37.5	36.4
43.5	40.7	40.1	41	41.5	38.5	42.5	41.1	41.7	42.6	37	37.4	36.3
44	41	40.4	41.8	41.5	38.8	42.2	41.4	42.1	42.3	36.5	37.6	36.1
43.5	40.6	40.3	41	41.7	38.3	42.4	41.3	41.9	42.4	36.8	37.3	36.1
43.7	40.6	39.9	40.8	41.5	38.4	42.2	41.1	42.3	42.2	36.5	37.1	36
43.7	40.4	40.2	41.7	41.5	38.2	42.2	41.4	42	42.3	36.6	37.3	36
43.7	40.5	40	41.1	41.3	38	42.2	40.9	41.9	42.5	36.6	37.1	36
43.8	40.6	40.1	41.1	41.2	37.9	42.3	40.9	41.8	42.6	36.5	36.9	35.5
43.5	40.3	40.2	41.6	41	37.9	42.2	41.1	41.4	42.4	36.5	36.9	35.7
43.5	40.4	40	41.6	41.3	38.5	42	40.9	41.3	42.3	36.4	36.9	35.4
43.7	40.2	40.2	41	41.1	37.8	42.1	40.5	41.9	42.3	36.4	37	35.6
43.5	40.3	39.8	41.1	41.2	37.9	42.1	40.2	41.7	42.4	36.5	37	35.7
43.4	40.5	39.6	41.1	41.2	38.1	42.1	40.6	41.7	42.3	36.1	36.9	35.6
43.6	40.3	39.8	40.7	40.9	37.7	42.1	40.4	41.6	42.1	36.2	36.7	35.7
43.5	40.2	39.7	40.9	41	38	41.9	40.6	41.4	42	36.1	36.8	35.5
43.2	40.1	39.7	40.4	40.9	38.1	41.9	40.5	41.2	42.2	36	36.7	35.5
43.4	40	39.7	40.5	40.9	37.6	41.9	40.6	41.1	42.1	36	36.8	35.4
42.9	40.3	39.6	41.2	40.7	37.5	42	40.6	41.5	42.1	36	36.7	35.2
43.4	40	39.4	40.6	40.6	37.5	41.7	40.3	40.8	42	35.7	36.4	35.5
43.2	40.1	39.4	40.5	40.5	37.4	42	40.4	41.5	41.9	35.8	36.6	35.3
43.1	40.2	39.4	40.6	40.7	37.5	41.8	40.2	40.8	42.1	35.9	36.6	35.2
43.1	40.2	39.4	40.9	40.6	37.8	41.8	40.3	41.4	41.7	35.8	36.5	35.4
42.9	40	39.4	40.8	40.6	37.5	41.6	40.2	40.5	41.7	35.9	36.4	35.1
42.9	40.1	39.5	40.5	40.4	37.7	41.9	40.4	41.1	41.7	35.8	36.6	34.9
42.9	39.9	39.4	40.8	40.6	37.4	41.7	40.1	40.8	41.9	35.5	36.2	35
42.9	39.8	39.2	40.7	40.4	37.7	41.7	40.2	40.6	41.5	35.6	36.2	34.8
42.9	39.8	39.3	40.5	40.6	37.8	41.4	39.8	40.8	41.2	35.7	36.2	34.9
43	40	39.1	40.4	40.5	37.6	41.7	40	40.6	41.6	35.5	36.3	34.6
42.8	39.9	39.1	40.7	40.6	37.6	41.7	39.8	40.4	41.2	35.4	36.2	34.7

43	40	39.1	41	40.6	37.2	41.7	40.3	40.7	41.2	35.2	35.9	34.4
42.7	39.8	39	41.1	40.6	37.4	41.3	40	40.7	41.1	35.2	36.1	34.4
42.6	39.8	39.3	40.8	40.4	37.3	41.5	39.9	40.5	41.3	35.3	35.9	34.3
42.4	40.1	39.1	40.5	40.2	37.4	41.5	39.8	41	41.2	35.4	35.8	34.2
43	39.7	39.1	40.1	40.4	37.4	41.2	39.7	40.7	41.1	35.2	35.7	34.1
42.3	39.7	38.9	40.3	40.4	37.7	41.3	39.9	40.6	41	35.2	35.7	34.2
42.5	39.8	39	40.3	40.6	37.3	41.3	39.7	40.8	41.2	35.1	35.5	34
42.4	39.6	38.9	39.9	40.3	37.6	41.2	39.8	40.5	41	35	35.8	34
42.7	39.7	39	40.4	40	37.1	41.3	39.8	40.2	41	35.1	35.8	34.1
42.6	39.1	39	40.2	39.8	37.1	41.4	39.8	40.3	41	35	35.6	33.9
42.4	39.3	39	40.1	39.9	37.1	41.1	39.6	40.2	41	34.8	35.4	34
42.3	39.2	38.9	40.3	39.9	36.6	41.3	39.4	40.5	41.1	34.7	35.6	34
42.3	39.2	38.9	40.1	39.9	36.7	41.1	39.8	40	41.1	34.7	35.3	33.8
42	39.3	38.8	39.5	39.7	36.7	41.1	39.9	40.1	41	34.7	35.3	33.8
41.9	39.1	38.8	40.1	39.9	36.9	41.2	39.5	40.1	40.9	34.7	35.3	33.6
42.1	39	38.6	40.1	39.9	36.8	41.2	39.6	40.2	40.7	34.7	35.3	33.7
41.9	39.2	38.6	39.9	39.5	36.7	40.9	39.5	39.9	40.9	34.7	35.3	33.8
41.9	38.9	38.4	39.6	39.7	36.7	41.1	39.8	40.1	40.9	34.5	35.2	33.6
42	39	38.6	39.5	39.7	36.6	40.9	39.5	39.9	41	34.7	35.3	33.6
42.2	38.8	38.4	39.8	39.8	36.9	40.9	39.3	40.2	41.1	34.6	35	33.4
42.3	38.8	38.7	39.7	39.6	36.4	40.7	39.4	40.1	41	34.2	35.1	33.6
41.9	39.1	38.5	40.1	39.7	36.4	40.7	39.2	40.1	41	34.6	35.1	33.3
42.3	38.9	38.4	40.2	39.6	36.8	40.9	39.2	39.9	41	34.6	34.9	33.3
42.3	39	38.4	39.4	39.6	36.5	40.8	39.5	39.7	41.2	34.7	35.2	33.1
42	39.1	38.1	39.5	39.6	36.6	40.8	39.3	39.9	40.8	34.7	35.1	33.1
42.2	38.8	38.4	39.7	39.7	36.7	40.7	39.5	39.6	40.8	34.6	35	33.4
41.7	38.7	38.2	39.5	39.6	36.7	40.7	39.3	40	40.7	34.5	35.2	33.2
41.9	38.7	38.2	39.6	39.5	36.4	40.8	39.5	39.8	40.6	34.3	35.1	33.4
41.7	38.6	38.2	40.1	39.5	36.3	40.6	39.1	39.4	40.8	34.3	35	33.2
42	38.8	38.1	39.7	39.6	36.5	40.6	39.3	39.5	40.9	34.4	35.1	33
41.9	38.7	38	40.1	39.6	36.3	40.8	39.1	39.7	40.6	34.4	34.9	33.2
41.9	38.7	38	40	39.7	36.4	40.6	39	39.7	40.7	34.6	35.2	33.1
41.9	38.7	37.9	40.1	39.6	36.5	40.6	38.7	39.5	40.6	34.6	35.1	33
41.7	38.7	37.7	39.7	39.6	36.5	40.6	39	39.4	40.7	34.5	34.9	32.9
42	38.9	38	40.1	39.4	36.5	40.6	38.7	39.7	40.6	34.5	35	33
42	38.8	38.1	39.5	39.4	36.3	40.5	38.7	39.4	40.5	34.6	34.8	32.9
41.9	38.7	38.1	39.6	39.4	36.2	40.4	38.7	39.4	40.5	34.5	34.9	33
41.9	38.8	38	39.3	39.3	36.2	40.6	38.8	39.2	40.4	34.3	34.8	32.8
41.9	38.7	37.7	39.5	39.5	36.4	40.6	38.8	39.2	40.6	34.5	35	32.6
41.9	38.8	38.2	40.2	39.5	36.4	40.5	39.2	39.9	40.5	34.5	34.9	32.7
41.8	38.6	37.7	39.5	39.4	36.2	40.3	38.7	39.9	40.8	34.5	34.8	32.6

41.8	38.6	37.8	39.5	39.4	36	40.5	38.6	39.4	40.6	34.3	35	32.7
41.7	38.8	37.8	39.4	39.4	36.2	40.4	38.9	39.4	40.5	34.3	34.9	32.5
41.8	38.7	37.8	39.5	39.4	36.1	40.3	38.9	39.6	40.6	34.1	34.8	32.6
41.7	38.8	37.5	39.7	39.7	36	40.5	38.8	39.3	40.3	34	34.6	32.7
41.7	38.7	37.6	40	39.3	36.2	40.4	38.5	39.6	40.5	34.2	34.8	32.6
41.7	38.7	37.4	39.7	39.3	36.5	40.3	38.8	39.7	40.3	34.1	34.5	32.6
41.9	38.7	37.7	39.5	39.1	36.2	40.3	38.8	39.3	40.4	34.4	34.5	32.5
41.5	38.4	37.6	39.3	39.2	36.1	40.4	38.8	39.3	40.5	34.2	34.8	32.5
41.3	38.6	37.4	39.5	39.1	35.7	40.4	38.5	39.5	40.2	34.3	34.7	32.3
41.4	38.6	37.5	39	39.2	36	40.2	38.9	39.2	40.4	34.3	34.5	32.8
41.4	38.8	37.4	39.6	39.3	36.1	40.3	38.6	39.7	40.2	33.9	34.6	32.7
41.5	38.4	37.6	39.4	39.1	36.1	40.2	38.8	39.1	40	34.2	34.5	32.5
41.5	38.6	37.6	39.4	39	36.1	40.2	38.7	39.3	40	33.9	34.5	32.4
41.4	38.6	37.4	39	39.1	36	40.1	38.9	39.5	40.2	34	34.5	32.6
41.3	38.6	37.8	39.4	39	36	40.1	38.6	39.5	40.2	33.9	34.6	32.4
41.2	38.3	37.5	39	39.1	36.1	40	38.4	38.9	40.2	33.9	34.5	32.5
41.3	38.3	37.3	39.5	39	36	40.2	38.8	39.3	39.8	33.6	34.6	32.5
41.5	38.5	37.5	39	39	35.9	40.2	38.5	39	39.8	33.8	34.6	32.6
41.2	38.3	37.5	39.6	39	35.9	40	38.7	38.9	39.7	33.6	34.5	32.4
41.3	38.4	37.3	39	39.1	36.1	40	38.2	38.9	39.9	33.5	34.4	32.3
40.9	38.3	37.4	38.9	38.9	35.8	40	38.4	38.9	39.9	33.4	34.3	32.5
41.1	38.1	37.4	38.9	38.9	35.6	40	38.2	39	39.9	33.4	34.4	32.4
41.2	38.3	37.2	38.8	38.7	35.9	40.2	38.2	38.6	40	33.6	34.2	32.4
41.4	38.2	37.4	39.1	38.8	35.9	40.1	38.4	39.2	39.9	33.6	34.5	32.5
41	38.3	37.3	38.7	39.2	35.7	40	38.2	38.6	39.9	33.3	34.5	32.2
41	38.3	37.1	39.1	38.9	35.6	39.9	38.1	39	39.8	33.4	34.2	32.1
41.2	38.5	37.4	39	39.1	35.5	39.9	38.4	39	40.1	33.6	34.5	32.1
41.2	38.5	37.2	39.4	38.9	35.3	40.1	38	38.9	39.9	33.6	34.3	32.1
41.5	38.4	37.2	39.4	38.9	35.9	39.9	38.2	38.5	40	33.4	34.2	31.9
41	38.1	37.3	39.4	38.6	35.4	40	38.4	38.7	39.8	33.4	34.2	31.9
41.1	38.3	37.1	39.4	38.8	35.8	39.7	38.2	38.8	39.8	33.4	34.2	31.8
41.2	38.2	37.1	38.7	38.8	35.9	39.9	38.4	38.5	39.4	33.6	34.1	31.8
40.9	38.1	36.9	39.4	38.8	35.7	39.6	38.2	38.7	39.5	33.5	34.2	31.9
41.3	38.2	37.1	39.3	38.9	35.8	39.8	37.7	38.7	39.4	33.4	34.1	31.6
41.3	38.1	37	38.9	39	35.8	39.8	38.1	38.9	39.3	33.6	34	31.7
40.8	38.2	37	38.9	38.7	35.7	39.8	38	38.6	39.2	33.7	34	31.8
40.9	38.1	37	39.2	38.6	35.4	39.9	38	38.9	39.1	33.9	33.9	31.8
41	38.3	36.9	38.9	38.8	35.2	39.6	38	38.6	39.2	33.9	33.9	31.8
40.9	37.9	36.9	38.7	38.6	35.5	39.7	37.7	38.7	39.4	33.7	33.7	31.8
40.8	37.9	36.8	38.9	38.6	35.2	39.6	37.8	38.2	39.3	33.4	33.8	31.6
40.8	38	37.1	38.6	38.7	35.4	39.5	37.7	38.7	39	33.6	33.7	31.7

40.9	37.8	36.5	38.3	38.4	35.4	39.5	37.7	38.5	39.1	33.5	33.7	31.5
41	37.9	36.7	38.5	38.5	35.3	39.6	37.8	38.3	39.3	33.3	33.8	31.4
40.8	38	36.6	38.6	38.5	35.3	39.3	37.7	38.3	39.1	33.2	33.4	31.3
40.8	37.8	36.7	38.5	38.4	35.3	39.4	37.8	38.7	39.1	33.4	33.8	31.7
40.3	37.8	36.7	38.2	38.6	35.4	39.6	37.6	38.4	39.2	33.3	33.6	31.4
41	37.7	36.8	38.4	38.5	35.3	39.3	37.9	38.1	39.2	33	33.4	31.5
40.5	37.9	36.8	38.6	38.6	35.4	39.3	37.7	38.1	39	32.9	33.5	31.2
40.6	37.8	36.7	38.9	38.3	35.6	39.6	37.8	38.3	39.1	32.8	33.5	31.3
40.8	37.6	36.6	38.9	38.3	35.2	39.1	37.7	38.5	39.2	33.3	33.5	31.3
40.7	37.8	36.5	38.4	38.3	35.1	39.3	37.9	38	39.3	33.2	33.4	31.4
40.6	37.3	36.6	38.1	38.3	35.2	39.1	37.7	38.3	39.1	33.3	33.3	31.2
40.2	37.2	36.6	38	38	35.4	39.3	37.5	38.3	39.1	33.3	33.3	31.4
40.1	37.4	36.7	38.4	38.2	35.3	39.1	37.6	38.3	39	33	33.3	31.2
40.5	37.3	36.4	38.1	38.3	35.2	39.4	37.9	38	38.8	33.1	33.6	31.3
40.4	37.2	36.6	37.8	38.1	35.3	39.1	37.7	38.2	39.1	33.1	33.2	31.3
40.2	37.3	36.5	38.6	38.2	35.2	39.2	37.8	38.1	38.7	32.9	33.3	31.4
40.2	37.4	36.4	38.4	38	35.2	39.2	37.4	38.1	38.8	32.9	33.4	31.3
40.4	37.3	36.5	38.5	38	35	39.2	37.4	38.2	38.7	32.9	33.6	31.1
40.3	37.3	36.4	38	37.9	34.9	39.2	37.4	38.2	38.6	32.7	33.5	31.2
40.1	37.2	36.6	38	37.9	34.8	39	37.3	38.2	38.9	33	33.3	31.3
40	37.2	36.4	38	38.1	35	38.9	37.6	38.5	38.4	32.8	33.1	31.2
40	37	36.5	38	37.8	34.9	39	37.8	38	38.6	32.9	33	31
40.4	37	36.5	37.5	37.7	34.9	38.9	37.4	38.1	38.5	32.6	33.1	31
40	37.1	36.5	37.9	37.6	34.9	38.9	37.6	38.3	38.6	32.8	33.1	31
39.9	37	36.3	38.1	38	35.2	39	37.6	38.1	38.5	32.8	33.1	30.9
40	37.2	36.2	38.1	37.8	35	38.8	37.5	38.2	38.5	32.6	32.8	30.9
40	37.2	36.4	37.9	37.8	34.9	38.9	37.8	38.2	38.8	32.8	33.1	30.9
40.1	37.3	36.3	38.3	38.1	35.1	38.8	37.8	38	38.6	32.7	33	30.9
39.9	37.2	36.5	38.2	37.7	35	38.9	37.5	38.1	38.8	32.9	33.4	30.9
40.1	37.2	36.6	38	37.9	35.2	38.7	37.7	37.9	38.8	32.7	33.2	30.8
40	37	36.3	38.1	37.8	35.2	38.9	37.6	38	38.5	32.7	33	30.8
40.1	37.2	36.4	38.3	38	35	38.7	37.7	38.2	38.3	32.5	33.2	30.8
40.2	37	36.3	38	37.9	35	38.9	37.6	38	38.3	32.8	32.9	30.8
39.9	37.1	36.4	37.7	37.6	35	38.6	37.7	38	38.5	32.4	33	30.9
39.9	36.9	36.1	37.7	37.7	34.8	38.7	37.6	38.2	38.3	32.6	32.8	30.5
39.8	37.1	36.3	37.7	37.8	35	38.6	37.6	38.2	38.5	32.5	32.6	30.5
39.9	37	36.4	38	37.7	34.8	38.4	37.4	38	38.4	32.4	32.6	30.7
40.1	37.1	36.5	37.7	37.6	34.7	38.6	37.4	38.1	38.6	32.6	32.9	30.6
40.1	37	36.1	38	37.7	34.8	38.7	37.6	37.6	38.5	32.6	32.7	30.4
39.8	36.9	36.3	37.8	37.7	35.1	38.7	37.5	38	38.6	32.3	32.8	30.6
39.9	37	36	37.6	37.5	34.8	38.7	37.1	37.9	38.5	32.4	32.6	30.5

39.8	36.8	36.1	37.8	37.5	34.5	38.5	37.5	37.6	38.4	32	32.5	30.4
40.1	36.9	35.9	37.6	37.6	34.5	38.4	37	37.7	38.3	32	32.6	30.4
39.6	36.6	36.1	37.3	37.4	34.6	38.7	37.3	37.5	38.3	32.1	32.5	30.5
39.6	36.6	36.1	37.5	37.4	34.5	38.5	37.1	37.9	38.2	32	32.6	30.6
39.7	36.7	36.2	37.5	37.3	34.4	38.5	37.3	38	37.9	32	32.4	30.5
39.6	36.6	36	37.5	37.4	34.4	38.4	37.1	37.4	38	31.9	32.7	30.6
39.6	36.5	36	37.4	37.2	34.4	38.5	37.2	37.7	38	31.8	32.5	30.7
39.4	36.5	36.2	37.3	37.2	34.2	38.5	37.1	37.4	38	32.1	32.4	30.6
39.3	36.3	35.9	37.4	37.4	34.3	38.6	36.8	37.3	38.1	32.1	32.5	30.5
39.3	36.7	36.1	37.4	37.2	34.1	38.6	37	37.4	38	32.2	32.4	30.4
39.4	36.6	35.8	37.4	37.1	34.3	38.4	36.9	37.5	38.1	32.2	32.3	30.4
39.7	36.4	35.8	37.3	37.2	34.6	38.2	36.9	37.4	38.2	32	32.1	30.5
39.3	36.5	35.8	37.1	37.2	34.2	38.3	36.6	37.3	37.8	32	32.3	30.2
39.6	36.5	36.1	37.3	37.3	34.5	38.4	36.9	37.7	37.8	32	32.4	30.6
39.5	36.4	36	37.4	37.1	34.5	38.3	36.8	37.4	37.7	32	32.1	30.4
39.3	36.4	35.7	37.3	37.3	34.2	38.2	37	37.5	37.8	32.2	32.2	30.4
39.3	36.3	36	36.9	37.1	34.4	38.2	37	37.3	37.9	32.1	32.3	30.3
39.3	36.5	35.6	37	37.1	34.2	38.3	36.6	37.4	37.8	32	32.4	30.4
39.3	36.4	35.7	37.1	37.1	34.3	38.1	36.5	37.3	37.9	32	32.3	30.1
39.1	36.3	35.8	37.1	36.9	34.3	38.4	36.5	36.8	38	32.3	32	30.5
39.4	36.3	35.7	37.3	37.1	34.2	38.3	36.7	37.4	37.9	32	32.1	30.3
39.2	36.2	35.4	37.4	36.9	34.2	38.1	36.7	37.2	37.8	32	32.1	30.2
39.4	36.3	35.7	37.4	37.2	34.4	38.1	36.8	37.3	37.9	32.1	32.2	30.2
39.3	36.5	35.3	37.4	37	34.1	38.1	36.6	37.5	37.9	32.2	32.2	30.2
39.4	36.3	35.6	37.1	37	34.5	38.1	36.6	37.2	37.9	32.2	32.3	30.2
39.7	36.5	35.5	36.8	37	34.3	38.1	36.7	37	37.7	32.2	32.1	29.9
39.3	36.4	35.7	37.3	36.9	34.2	38	36.6	37.4	37.9	32.1	32	30.1
39.2	36.6	35.8	37.1	37	34.2	37.9	36.6	37.2	37.7	32.2	32.2	30
39.2	36.3	35.6	37.3	37	34.2	37.9	36.6	37.3	37.8	32.1	32.1	30.1
39.2	36.4	35.5	37.5	37.2	34.4	37.8	36.7	37.4	37.6	32	32	30.1
39.3	36.4	35.4	37.4	37.1	34.3	37.9	36.7	37.2	37.6	32	32.2	30.1
39.2	36.3	35.5	37.7	36.9	34.1	38.1	36.7	37.3	37.7	31.9	31.8	30.2
39.1	36.5	35.5	37.1	37.1	34.1	38.1	36.4	37.3	37.4	31.8	32.3	29.9
39.1	36.3	35.5	37.2	37	34.3	37.9	36.5	37.4	37.6	31.8	31.9	30.1
39.2	36.3	35.5	37.4	36.8	34.2	37.8	36.6	37.3	37.7	31.9	32	29.8
39	36.3	35.6	37.3	37	34.3	37.9	36.4	37	37.7	31.7	32	29.8
39	36.3	35.5	37.1	36.9	34	37.9	36.5	36.9	37.7	31.9	31.8	29.9
39.2	36.2	35.4	37.2	36.9	34.1	37.9	36.4	37	37.8	31.8	32	29.8
39.2	36.3	35.4	37.3	37.1	33.9	38	36.5	37.2	37.6	31.8	31.8	29.9
39.4	36.3	35.2	37	36.8	34.1	37.9	36.5	37.1	37.3	31.8	32	29.9
39.3	36.4	35.2	37.1	36.8	34.1	37.8	36.4	37.2	36.8	31.7	31.8	29.8

39.4	36.4	35.7	37.1	36.8	34.2	37.6	36.6	37.3	36.9	31.8	31.7	29.9
39.1	36.3	35.4	36.8	36.8	34.2	37.7	36.4	37.4	37.2	31.9	31.8	30
39.2	36.1	35.4	37.1	36.7	34.1	37.9	36.7	37.3	36.8	31.8	31.8	29.8
39.1	36.2	35.3	36.6	36.7	34.1	37.9	36.5	36.9	37.2	31.9	31.8	29.6
38.9	36.1	35.4	36.9	36.6	33.8	37.7	36.2	37	36.9	31.7	31.8	29.7
38.9	36	35.2	37	36.8	33.9	37.8	36.3	36.9	37.2	31.6	31.7	29.8
38.8	35.9	35.3	36.9	36.6	33.8	37.7	36.4	36.9	37	31.6	31.6	29.6
38.9	36.1	35.2	36.8	36.6	34	37.7	36.4	37.1	37.2	31.3	31.7	29.5
38.9	36	35.1	36.8	36.7	33.8	37.6	36.2	37	36.8	31.5	31.9	29.8
39.2	36.2	34.9	37.1	36.6	33.8	37.7	35.9	36.8	37	31.4	31.8	29.6
38.8	36	35.1	36.9	36.8	33.9	37.8	36.3	36.8	37	31.5	31.7	29.7
38.9	36	35.2	37	36.9	33.8	37.5	36.1	36.5	37	31.5	31.8	29.6
38.8	36	35.1	36.8	36.7	33.9	37.8	36.3	36.6	36.9	31.4	31.6	29.5
38.8	35.8	35	36.5	36.5	33.7	37.7	36.2	36.4	37	31.5	31.8	29.7
38.7	36	35.1	37.1	36.9	33.6	37.6	36.2	36.7	37.2	31.4	31.7	29.6
38.7	36.1	35	36.7	36.6	33.7	37.5	36.4	36.7	37	31.1	31.6	29.7
38.9	35.9	35	36.7	36.6	33.6	37.5	36.3	36.8	37.1	31.3	31.7	29.6
38.7	35.8	35	36.7	36.6	33.6	37.5	36	36.6	37	31.2	31.5	29.6
38.5	35.9	34.9	36.7	36.6	33.5	37.6	36.1	36.8	37	31.3	31.5	29.7
38.7	35.7	34.8	36.7	36.5	33.4	37.5	36	36.5	36.8	31	31.8	29.6
38.7	35.7	34.8	36.7	36.4	33.7	37.5	36	36.6	36.8	31	31.7	29.9
38.7	35.8	34.8	36.7	36.3	33.6	37.5	35.9	36.4	36.7	31.1	31.7	29.9
38.4	35.6	35.1	36.7	36.3	33.6	37.4	35.9	36.3	36.7	31	31.5	29.7
38.6	35.6	34.9	36.4	36.2	33.3	37.4	36.1	36.4	36.6	31.2	31.3	29.8
38.6	35.6	34.9	36.6	36.5	33.4	37.6	35.9	36.3	36.4	31.1	31.6	29.6