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Dominant causes of cooling in automobile vehicles for thermal comfort

[1]Pinara Hiral J.,[2]Kunalsinh Kathia,[3]Navnit Patel
[1]PG student,[2]Assistant professor,[3]HOD Mechanical Dept.
[1]M.E.(CAD/CAM),
[1]HJD Institute of Technical Education and Research,Kera,India

***Abstract*—Today traveling is a part of day to day life. This increase use of personal vehicles. People are now more conspicuous about vehicle safety features as well as comfort level it provides. This paper overview factors which affect comfort, especially thermal comfort. Methods of assessing thermal comfort, like subjective and objective methods. Effect of thermal comfort on car performance.**

***Index Terms*—Car driving seat, ergonomics, thermal comfort.**

I. INTRODUCTION

Today traveling becomes a part of day to day life. People travel with various reasons including job profile or daily activities. Research shows that an average person spent 100 minutes' time in driving a car on daily basis this lead to almost 35,000 hours of lifetime. Also there is increase in average distance travel by 45% compare to 70's. People use both public transport as well as private vehicle. Data shows that out of total trips, trips by car accounted for 64% as driver or passenger of all trips made and 78% of distance travels.

These demands for increase comfort in driving. Which lead to more safety on road and less accidents. Various factors affect comfort in driving including seat ergonomics, vibration, noise, road condition and thermal. This paper review factors particularly thermal comfort factors, it measurement methods and effectof thermal comfort on car performance.

II. FACTORS AFFECTING COMFORT IN VEHICLES

Krunoslav Ormuz, **Osman Muftic**[1]state regarding vehicle comfort that it play significant role in deciding vehicle as people nowadays spend a significant proportion of their time in traveling.Improving riding comfort is triggered off by numerous reasons, the performance of the driver will be better in pleasant ambience, safety will also be improved while the tiredness of the passengers will be significantly reduced.

From the automotive industry point of view, the image of the brand depends largely on the passenger comfort, among many other factors. It may be that vehicle comfort plays the key role on the market, in case when different brands have similar performance cars.

Comfort implies a conscious well-being. Discomfort implies a consciousness of unwell being, corresponding to feelings such as annoyance or irritation.

Riding comfort can be analyzed in three different respects:

- dynamic factors (vibrations, shocks, and accelerations);
- ambient factors (thermal comfort, air quality, noise, pressure gradients...) and
- factors dealing with the ergonomics of the passenger's position.

Higher level of comfort experienced by passengers in vehicles is the objective of numerous researches. The expectations and demand for higher ride comfort of the customers (driver and passengers) have been dramatically increased over past few years. Therefore, new vehicle models launched on the market have to have not only better performance and design-wise appealing, but also ride comfort has to be increasingly better than its predecessor.

Humans classify experienced comfort subjectively as there are considerably different response and assessment to the same situation. The factors on which people base their opinions on comfort level are physical variables characterizing the surroundings such as temperature, air velocity, acceleration, and light intensity.

The main ambient factors of vehicle comfort are: vibration, noise, thermal comfort (temperature), air quality, light and ergonomics.

Thermal comfort is by definition 'that condition of mind that expresses satisfaction with the thermal environment'**.** The human beings evaluate environmental conditions through their senses and this type of comfort is a subjective concept.

The thermoregulatory system in the human body keeps the body temperature within safe Limits. The center that controls various physiological processes is located in the hypothalamus, and it maintains the temperature around a value defined as a function of the metabolic rate (typically 36.8 ºC to 37.9 ºC for a highly active person).

The air temperature, the radiant temperature, the air velocity, and the relative humidity are the physical parameters characterizing the environment and influencing the heat exchange from a person's body. The metabolic rate and the clothes thermal insulation are also important for the subjective sensation of thermal comfort. The passenger area in a vehicle is a very specific type of thermal environment.

The external climatic conditions have a strong influence on the vehicle interior. The issues playing very important role are: size and position of glass surfaces, the number of passengers per volume or per area, the limited amount of insulation material, weight restrictions, and asymmetries in air velocity, air temperature, and radiant temperature.

Poor climate conditions may affect the driver performance, decreasing the ability to concentrate and the driver reaction time. Therefore, air-conditioning systems are to be presumed as a part of safety rather than comfort extra equipment.

Car seat manufacturers have also participated in researches with the objective of seat performance regarding thermal comfort due to cover laminate and use of ventilation devices in the seat to improve the thermal sensation.

Hanumant N. Kale, C. L. Dhamejani[2]in discussion regarding design of driver seat focus on factors like anthropometry of human, ergonomics related parameters, seat materials, safety related parameters, comfort related parameters as well as weight and aesthetics. Driver seat is important and very complicated system of any vehicle design and it directly affect driver performance. Poor design lead to more chances of accidents.

Thermal comfort directly related to seat cushion material which absorb heat from driver body any acts as heat reservoir, this phenomenon is good for health in winter season but responsible for un-comfort in summer season.

Nazi Faisal A. Chowdhury [3]examined driver responses in terms of speed variability at different ambient temperature ranges, 51-60 °F (Low), 61-70 °F (Medium) and 71-80 °F (High) to determine if there is any effect on driving performance under such conditions. The highest and lowest temperature was selected 51 and 80°F respectively because of the findings of Pilcher et al, where they mentioned significant performance decrease below 50 °F and above 90 °F. This research found significant temperature effect on speed variability for high temperature (71-80 °F) over low (51-60 °F) and medium (61-70 °F) temperatures.

At the time of driving, drivers have to observe, concentrate on and understand several factors on the roadway and make instant decisions based on that. The accuracy of such decisions depend on not only the experience but also drivers' physiological condition and comfort.

According to several studies, it has been found that human performance bears a close relationship to the indoor environment quality that depends on several factors, including thermal environment, indoor air quality, lighting. Warm uncomfortable environments have a negative effect on both performance and motivation.

Mihaela Simion, Lavinia Socaciu, Paula Unguresan [4]while studying factors which influence the thermal comfort inside of vehicle, they classified them in two classes:

- measurable factors which include: the air temperature, air velocity, radiant temperature and relative humidity and
- personal factors which include: activity level and clothing insulation.

An optimal level of the thermal comfort inside a vehicle can only be achieved by taking into account these measurable and personal factors. Based on these factors we can calculate Predicted Mean Vote (PMV) which represents the average thermal sensation felt by a group of people placed in the vehicle and determining the Predicted Percentage of Dissatisfied (PPD) index, which is the quantitative measure of thermal comfort of a group of people at a particular environment. The thermal comfort sensation is assured by the factors that depend on the heat exchange between the human body and the ambient environment.

The PMV index provides a score that corresponds to the ASHRAE thermal sensation scale and represents the average thermal sensation felt by a large group of people. The PMV establishes thermal strain based on a steady state heat transfer between the human body and thermal comfort ratings from panel subject. The PMV has been proposed and established for homogenous conditions only and when applied in non-homogenous conditions as the case in vehicular cabins, it did not provide accurate prediction. In PMV index measurable parameters were taking into consideration, such as a band of interior temperature and humidity range that is prescribed to satisfy at least 80% of the vehicle occupants. PMV index can be determined when the personal factors (human activity level and clothing insulation) are estimated and the environmental factors (air temperature, air velocity, radiant temperature and relative humidity) are measured. Fanger also noted that the values of PMV are not sufficient to define the feeling of discomfort, as slightly warm or too cold, don't express how dissatisfied people are. Therefore, the idea of Predicted Percentage of Dissatisfied (PPD) was associated to the PMV calculation. The PPD calculates a prediction of the number of thermally dissatisfied people.

Berkeley model provide a sophisticated thermal comfort models by using a virtual thermal manikin to represent the human thermoregulatory system in addition to representing the local and overall sensations, all this can be done in non-uniform and transient conditions.

Most of the automotive manufacturers had focused on increasing human thermal comfort. To achieve a high thermal comfort, most manufacturers provide a system for their cars to ensure ventilation, heating and cooling air in the passenger compartment. Thermal comfort inside vehicles was highly regarded as one of the most important factors when vehicular thermal environments were designed. A comfortable thermal sensation could bring the occupants not only a great felling and a good physical state but also more concentration and motivation at work or in life which brings a tremendous contribution to the work efficiency and to life quality.

There are several researches regarding the thermal comfort inside of vehicles in the scientific literature, but the number of studies which focus on analyzing the factors is just a few.

The constantly changing conditions of both internal and external environments of vehicles make it particularly difficult to study.

Thermal comfort of the occupants in a vehicle cabin is a growing concern due to occupant's health and safety. In addition to that, with more stringent requirements for efficient utilization of energy resources, the transport industry must rely on improving energy efficiency of vehicles. With this respect, engineers have to consider energy consumption during heating or cooling of an automobile cabin due to legal restrictions and efficient use of energy resources.

The air temperature inside the vehicles is inhomogeneous due to the installed air conditioning system. According to the requirements for thermal comfort in summer conditions, interior air temperature should be in the range of 23 to 28°C. Vertical air temperature difference between head and ankle level prescribe 3ºC. These variations can lead to thermal discomfort which can affect the driver concentration on driving and also the passenger wellbeing.

The air temperature depends on the cabin space of vehicles, class of vehicle and upholstery fabric. Relative humidity between 30% ~ 70% doesn't influence thermal comfort. When RH is over 70%, it will prevent the sweat evaporation and then cause hot and sticky weather sensation and let occupants fell discomfort. When RH is lower than 30%, it will cause dry sensation and has a bad effect on mucous membranes.

The air flow from the air conditioning increases the air velocity inside the vehicle, and the values of air flow velocity vary between 0.1 ~ 0.4 m/s. Humans require energy to perform work and produce heat to maintain the internal body temperature around 36.5°C. The higher activities level is more intense, the more heat is produced. If is produced too much heat, then the body will sweat which will cause discomfort. If is produced too little heat then the blood will be withdrawn from the hands and feet, the skin temperature will fall and the person will feel cold and uncomfortable. Activity level has a strong influence on human thermal sensation, comfort and indoor temperature preferences.

The thermal comfort is related to fabrics ability to maintain skin temperature and allow transfer of perspiration produced from the body. Clothing insulation could reduce the heat loss from body and influence the heat balance, which means that it could either keep body warm or lead to overheating.

Measuring each parameter requires a lot of instrumentation and it is difficult to measure all the parameters in the exact same location and then later calculate the combined influence. Usually, the personal factors, which include the human activity level and clothing insulation, are estimated. These factors are independent, but together they contribute to establish the thermal comfort.

III. METHOD OF THERMAL COMFORT ASSESSMENT

CheeFai Tan, Ranjit Singh Sarban Singh, Siti Aisyah Anas[5]in their paper about truck seat comfort, discuss about various measurement factors for seat comfort variables. Truck manufacturers recognize comfort as one of the major selling point, as it is thought to play an important role for the buyer as well. Seat is one of the most important components of truck and they are the place where professional driver spends most of their time, 2408 hours driving time per year. There are the subjective and objective measurement methods that are used to evaluate the truck seat.

Seat comfort is a very subjective issue because it is the customer who makes the final determination and customer evaluations are based on their opinions having experienced the seat.

Comfort is defined as a pleasant feeling of being relaxed and free from pain by Cambridge Advanced Learner's Dictionary. Comfort is a generic and subjective feeling that is difficult to measure, interpret, and related to human physiological homeostasis and psychological well-being. Posture changes and continuous motion are strategies of the driver to avoid mechanical load and ischemia of tissue, which has been identified as one main reason for discomfort.

The comfort experienced by humans in seat can be classified as a subjective assessment, because it is possible to find a variation with different people in a same situation. The factors on which the opinions of people on comfort or discomfort level are based on physical variables that characterize the seat, for example, pressure, vibration, posture and temperature.

The most effective of which is to survey potential users of the seat as they compare the "feel" of a seat for a short period of time against other seats in the same class.

The vehicle manufacturers developed elaborative subjective evaluation protocols that involved highly structure questionnaires. The questionnaires direct occupants to assign feelings of discomfort to a specific region of seat. The questionnaires, which typically contain numeric scales (e.g. 1 = very uncomfortable to 10 = very comfortable), produce subjective ratings that are translated into performance requirements/specifications. Studies involving seat mapping, seat is divided in different areas and subject is asked to rate on a scale. For subjective measurement, local discomfort rating and body mapping method is the most frequently used methods.

The problem, however, with subjective evaluations is that they are costly and time- consuming. In response, a great deal of research has been performed in recent years to find objective measures for predicting seat comfort perception. Some of the proposed objective measures include vibration, interface pressure, and muscle activity, pressure distribution, posture, computer-aided design (CAD), computer-aided engineering (CAE), temperature, humidity.These objective measures are correlated with subjective data to determine the relative effects of each measure related to comfort.

Paul Danca, Andreea Vartires, Angel Dogeanu [6]during their study of metods for assessment of thermal comfort marked that, Indoor Environmental Quality in buildings has gained importance in the last decade and now is developing a new direction of research, the environmental quality in vehicles. The ambience quality is an important criterion in marketing this type of products. It influences not only the thermal comfort inside the car, but it also reduces the risk of accidents by reducing the driver's stress and ensuring a good visibility, which leads to a safer trip.

The thermal comfort of occupants in vehicles has become more important due to their increasing mobility, leading to more time spent by people inside the cars. Current methods of assessing thermal comfort are not optimized following two crucial and interrelated aspects: achieving thermal comfort with the lowest possible level of energy consumption. Actually, energy consumption and thermal comfort are major concerns for research engineers in heating, ventilation and air conditioning systems, who are studying solutions, which are more or less feasible to implement.

The influence of external factors and the subjective responses regarding the expressed thermal state make the prediction of optimal values of comfort parameters in vehicles difficult, as a number of additional parameters compared to buildings influences this particular environment. One such parameter is the space in the cabin, which is tight, passengers being constrained to spend relatively long periods seated in a confined space.

The current standards which propose methods for evaluating thermal comfort in the interior car environment are EN ISO 14505 [3-5] divided into three parts and the American ASHRAE – 55.

The EN ISO 14505 standard "Evaluation of thermal environments in vehicles" is structured into three parts:

1. Principles and methods for assessment of thermal stress;
2. Determination of equivalent temperature;
3. Evaluation of thermal comfort using human subjects.

In the first part of the standard reference is made to EN ISO 7730, proposing the use of PMV and PPD. Unfortunately, these two indices are generated particularly for homogeneous environments inside buildings.

The second part of the standard proposed the T_{eq} Index – the equivalent temperature index. The equivalent temperature method using directional sensors or a thermal manikin to evaluate the thermal sensations in vehicles has, in our opinion, as main drawback the fact that thermal sensation, primarily due to local sensitive heat variations, is evaluated by using the clothing-independent thermal comfort diagrams.

In the third part of the standard EN ISO 14505 a direct method for assessing thermal comfort in automobiles is presented, the main index being the Thermal Sensation Vote (TSV) of human subjects that are surveyed. This subjective method quantifies and records the response of people about their thermal sensation in an environment, on the same scale of values as for the PMV. The TSV only takes into account the psychological and physiological factors. A study using this method involves standardized questionnaires for a controlled and representative sample of population. By centralizing the obtained results, one could then have an idea about the particular investigated situation.

Moreover, if we are talking about the thermal comfort in the vehicles' cockpit, other design parameters may influence the occupants' sensation in an unpredictable manner. One such parameter is the thermal sensation offered by the car seats, in terms of seat cover conduction coefficient, the environment inside the cabin is affected by a number of parameters that include: various structures of the surfaces and their temperatures, the local variation of air temperature, the speed distribution of air in an interior over complex geometry, relative humidity, solar radiation intensity and its reflection, the angle of incidence, type of clothing, etc. Moreover, some of these parameters are connected by relations that are still unknown. All these factors complicate both modelling and experimental approach attempts.

Indoor temperature inside the car can reach 72°C in summer for an outdoor temperature of 34°C. In most cases, air distribution grilles that allow the control of the heating or cooling loads in the cockpit are installed only in the front part of the vehicle, the state of thermal comfort for passengers in the back being obtained with more difficulty. Equilibrium is attained in the front part of the cockpit in around 5 minutes and in the rear part of the cockpit in around 10 minutes. Taking into account that the period of use of the vehicles is sometimes very short and insufficient to obtain a uniform thermal environment and knowing that 85% of automobile travelling involves a travel distance of less than 18 km, with a duration between 15 and 30 minute, it could be difficult to achieve a real state of thermal comfort.

The skin temperature was evaluated by using a discrete thermocouples network, and the local thermal sensation was evaluated by using a seven-point thermal comfort scale.

The use of multi-zonal air distribution systems is another method of reducing the fuel consumption of the vehicle.

At the moment there are no international standards which allow to easily assess thermal comfort specific to the vehicular environment space. Researchers who have studied thermal comfort in vehicles have adopted many concepts and methodological procedures from the only previously existing thermal comfort literature which was mainly intended for buildings.

Tulin Gunduz Ceniz [7]give their view on the effects of thermal comfort in real traffic conditions. An experimental system on road is designed to evaluate drivers' thermal comfort, while they drive on the real traffic conditions.

Meaning of comfort/discomfort or thermo neutral is still under great discussion among scientists. Basically, comfort is absence of discomfort. Thermal comfort has an important aspect to be considered for the ergonomic evaluation of vehicle according to ISO 7730. Human thermal comfort in automobiles is a complex task.

The comfort analyses are based on several evaluating methods. These methods can be as theoretical or simulation on computer, in laboratory using human subjects, in a laboratory using a thermal manikin, or on the road with participants. Driving performance in real traffic has more realistic than the simulator tests. Cengiz and Babalık suggested that the effects of real traffic conditions must be accounted for in comfort predictions. Nishimatsu et al. have investigated the relationship between seat cover material and thermal comfort using subjective and objective measurements in human subjects. Brooks and Parsons have presented the thermal comfort as skin temperature, seat surface temperature and subjective measurements with human subjects.

How the drivers feel themselves is important issue since this feeling is a result of the all effects of the comfort in the car. The results of the objective measurements are really important while the drivers feel themselves ideal or thermo neutral.

Ten locations were chosen to measure on human body. Eight sensors for skin temperature and two sensors for skin wetness were placed to the locations, for objective measurement. Participants were required to complete a questionnaire at the start of each session and every 5 minutes' intervals and the answers were recorded at the same time. The questionnaire consists of two parts including thermal sensation on 8 different areas and body moisture on 2 areas. The measurements were performed with ten subjects during one hour driving period.

Data were analyzed with SPSS. Firstly, the objective data were re-arranged that the data fitted by subjective results were only "thermo neutral" responses for temperatures and only "dry" responses for skin wetness. In other words, only "ideal" responses were selected, the other results were neglected. Objective results were taken into consideration, which only corresponded to "ideal" responses. By this approach, it can be detected the objective values stated subjectively ideal by drivers during experiments.

The study revealed that waist and back area were the most sensitive among the other measuring areas. Weighted average of skin temperature, which has been preferred as thermo neutral, changed between 32.95°C and 35.4°C. It was determined that skin wetness of 26% on front and 38% on back was most preferred. Industries can use findings to evaluate their ergonomic seat comfort in vehicle.

IV. FIELD EFFECT

D. Bharathan, L. Chaney, R.B. Farrington,J. Lustbader, M. Keyser, and J. Rugh [8]in their analysis of fuel used for A.C. with the primary mission of the National Renewable Energy Laboratory's Vehicle Ancillary Load Reduction Task is to develop and evaluate technologies that reduce the fuel use for automobile air conditioning. Using thermal comfort-based logic, we project that the United States uses 7 billion gallons of fuel per year for air conditioning light-duty vehicles.

Renewable Energy Laboratory (NREL) analysis shows air conditioning (A/C) increases fuel Consumption between 1.8 and 2 liters/100 km for a conventional gasoline and diesel powered medium sized vehicles. The analysis showed that the United States uses approximately 7.0 billion gallons of gasoline every year for air conditioning vehicles, equivalent to 5.5% of domestic light-duty vehicle petroleum consumption. It would take 9.5% of U.S. imported crude oil to produce this much gasoline.

One logical step is to remove energy as effectively as possible from the occupants. Conditioning the entire cabin can be inefficient when there is only one occupant. The potential to reduce fuel use for A/C and increase occupant comfort is great.

Ventilated seats were tested and measurement shown a seat contact temperature reduction of ~ 4.7 °C and an increase in heat loss from the back and bottom of ~ 60 W/m2. A/C system capacity could be reduced by 7%. Using NREL's A/C fuel use model, an estimated 522 million gal/year or 7.5% reduction in U.S. A/C fuel use could be achieved.

A prototype meshed backseat was tested and provided encouraging results. With a reduced, 96% heat capacity A/C system, an average seat back and bottom temperature reduction of 4°C and 0.6 °C respectively were observed. Assuming that a meshed bottom would provide similar results to the meshed back, much of the thermal benefit gained through ventilation could be achieved using low-mass meshed seats while avoiding energy costs. A lack of thermal control, physical ergonomics, and safety is a significant challenge for mesh seats.

Jason A. Lustbader [9]highlight advantage of ventilated seat. Automotive ancillary loads have a significant impact on the fuel economy of both conventional and advanced vehicles, negatively impacting both fuel economy and tailpipe emissions. In a conventional vehicle, A/C use can decrease vehicle fuel economy by 21%-24%, indicate oxides of nitrogen (NOx) and carbon monoxide (CO) increases of 13%-66% and 60%-120% respectively.

Improving the delivery methods for conditioned air is an effective way to increase thermal comfort at little energy cost, resulting in reduced air conditioning needs and fuel use.

Ventilating a seat has low energy costs and eliminates insulating effect while increasing evaporative cooling. The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has applied a combination of experimental testing and modeling to quantify improved thermal comfort and potential fuel savings by using a ventilated seat.

An existing automotive seat was modified for ventilation. Two fans were installed in the seat back and seat bottom. A coarse spacer was used between the fan exits to prevent flow blockage and allow initial diffusion. A fine diffusion layer then further diffuses airflow, which passes through a porous seat cover. At maximum flow, the four fans together consumed 9 watts of power. The back of the seat is constructed from a tension drawn low mass porous fabric. The bottom of the seat is similar to a standard automotive seat. The decrease in back temperature resulted in a substantial improvement in back thermal comfort.

Decreased time to achieve a higher level of back thermal comfort when using a ventilated seat with a 96% heat capacity A/C system. Once the back thermal comfort peak is reached, the comfort level begins to fall, eventually resulting in overcooling of the back. A/C system, resulted in an average steady-state reduction in seat back temperature of 4°C and seat bottom temperature of 0.6°C, giving a seat average temperature reduction of 2.3°C.

The thermal comfort improvement can be used to reduce the A/C heat capacity by 4%, resulting in a predicted A/C fuel use reduction of 2.8% on an EPA highway cycle and 4.5% on an EPA city cycle. This is a 0.3%-0.5% reduction in total vehicle fuel use when the A/C system is on; while modest for an individual car, the potential fuel savings is significant on a national level.

V. CONCLUSIONS

1) The main factors on which human beings base their opinion and feelings on comfort level are physiological variables characterizing their environment such as the temperature feeling, feeling of air speed in the cabin, the feeling of vertical acceleration, the feeling of light type and intensity in the interior and of course ergonomics.[1]
2) The air velocity influences the thermal comfort inside the car because the human body is very sensitive.[2]
3) It is recommended that objective measurement and subjective measurement should be combined for the seating research for better result [5],traffic conditions must be considered for thermal comfort prediction.[7]
4) At the moment there are no international standards which allow to easily assess thermal comfort specific to the vehicular environment space. Researchers who have studied thermal comfort in vehicles have adopted many concepts and methodological procedures from the only previously existing thermal comfort literature which was mainly intended for buildings.[6]
5) Climate control loads can significantly impact the fuel economy and tailpipe emissions of conventional and hybrid electric automobiles.The analysis showed that the United States uses approximately 7.0 billion gallons ofgasoline every year for air conditioning vehicles. It would take 9.5% of U.S. importedcrude oil to produce this much gasoline.[8]
6) The ventilated seat decreased steady-state seatcontact temperature by 3.5°C ± 0.9°C and increasedback thermal comfort. A low mass mesh back seat wasalso shown to reduce back temperature byapproximately 4°C Using ADVISOR© software, thereduction in A/C cooling capacity can be translated intoa reduction of compact car A/C fuel use by 2.8% on anEPA

highway cycle and 4.5% on an EPA city cycle. Thisis a 0.3%-0.5% reduction in vehicle fuel use when theA/C system is on. While this reduction is modest for anindividual car, the potential fuel savings is significant ona national level.[9]

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