 

# THERMOGRAPHIC ANALYSIS TO EVALUATE THE CHANGES OF TEMPERATURE IN THE PASSENGER VEHICLES WITH AIR-CONDITIONING

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***Abstract.*** *The usual method of evaluating the efficiency of the air conditioning system in vehicles is to apply sensors to measure the air temperature at feet and at head level. The main purpose being to investigate how quickly the system will raise or lower the temperature in a warm or cold vehicle and to study the difference between the temperature at feet and head level. And by the consumers` point of view, some aspects like safety and comfort are important rules for choicing to purchase a vehicle. The thermal environment inside a vehicle is not homogeneus, anyway it is complex. This research proposes to base by the thermal distribuition mapping of temperature on the forehead and chest front of the passenger using the Infrared Thermography. This technique associates with values obtained by K type thermocouples installed in the positions proposed, aimed at simplifying the methods and quantify the levels of temperature in these regions in order to further assist in the evaluation of thermal comfort to the vehicle drive system of air-conditioning.Therefore, the results demonstrates that use of thermography could become an auxiliary tool in study and determination the better indices of the thernal comfort in vehicle.*

***Keywords****: Thermographic Analysis, Air-conditioning, Thermal Confort.*

## 1. INTRODUCTION

Nowadays, people have done more constant use of automobilies for business or pleasure, increasing demand for comfort in private or public transport, and questions as safety, health, satisfaction of the occupants, mobilities and aspects of marketing have been required. So, the criteria of consumers in choosing and buying a vehicle, have changed considerably and now involves not only aspects related to cost and performance of the vehicle, but also the aspects of safety and comfort.

The thermal environment in a vehicle cabin is very complex and thus difficult to evaluate. These difficulties are due to the influence of convective, radiative and conductive heat exchange created by external thermal loads and the internal heating and ventilation system. Human's thermal comfort is a result of the combined effect of six parameters: activity level, clothing, air temperature, air velocity, air humidity and mean radiant temperature.

To control the comfort in a car, there are centralized systems of control of temperature and air velocity among others. It is known that the thermal environment inside a car is very complex and not homogeneous, therefore, this work proposes measurements of temperature in strategically position location within vehicle by K-type thermocouples, and with the Thermographic Analysis, draw a parallel to the values obtained to determine the range of temperature that is comfortable in the passenger vehicle when the air conditioner is put into operation.

## 2. LITERATURE REVIEW

### 2.1. Thermal Comfort

During human evolution, the environment where we live has been constantly modified, and these changes modify these environments second the needs of living there. The search for a better quality of life has been characterized by the development and optimization of systems to make them more efficient, with lower cost and less polluting.

With increasing search for alternatives to optimize such systems, it also increased the need to improve methods for analysis of quality of life for users of cars, requiring car industry to use the methods of comfort that reflect as closely possible the real sensation of the occupants according Silva (2002).

The combined effect of: the air temperature, mean radiant temperature and air velocity can be expressed as the Equivalent Temperature that is related to the dry heat loss from the body. A number of standards are under preparation for the evaluation of the thermal environment in vehicles. ANSI/ASHRAE 55-2004 defines the Equivalent Temperature as an integrated physical measurement of the thermal climate in the vehicle and presents methods for its determination.

According to the definition given in the ASHRAE standard 55:2004, thermal comfort is "a state of mind that reflects satisfaction with the thermal environment surrounding the person", sometimes even being in a thermally neutral condition, some people will not have thermally comfortable. According ASHRAE, (2005), when we speak about thermal comfort, you can not make statements about changes in temperature for the body whole, but also in different parts of the body, with large variations in temperature between the feet and head, for example.

Inside a car, occur significant fluctuations in the gradient of temperature and air velocity, with large asymmetries and transient in temperature during cooling and heating. In a car, the trajectory of the air are usually small and confined space, and it may affect air circulation. Moreover, there are a large solar incidence and intensification of radiation inside car due the seats, which cause a rising of temperature. For these reasons, the use of indices of average temperature PMV (ISO 7730:1994) or standards of ASHRAE 55:2004, are not the most appropriate according Madsen et al, 1986; Hosni et al, 2003a; Nilsson, (2004), but practical models that simulate such situations.

Some manufacturers treat the cooling system as a black box and delegate the responsibility of design and avaliation of the system to a partner (supplier), which often makes the project without having much knowledge about other subsystems that interact with this system. Attempts to standardize criteria for evaluation of comfort inside of cars were made by researchers from Visteon in conjunction with the University of Kansas, in the development of quantitative methods for evaluation of thermal comfort in transient conditions according Hosni, et al., 2003a and 2003b, and by Delphi, the development of a method based on equivalent homogeneous temperature (EHT) and a physiological model of the human body.

Thus, each manufacturer has developed and using their own methods for assessing environmental conditions of the vehicle cabins that can provide conditions for thermal comfort. In Brazil could not be different, for the evaluation of the vehicle cabin and system air conditioning, are used values pre-set of the temperatures to be achieved in diffusers and air inside the vehicle in terms of standardized test known as "requirements of the manufacture."

### 2.2. Air-conditioning

In the area of air conditioning are the work of Lee & Yoo (2000) who propose a model for programs to combine the analysis of performance of components (each component studied independently) from an air-conditioning system of the car, which simulates the performance of the integrated system of the car. They also told the effects about size of the condenser and the refrigerant used in the performance of the system. Kedzierski (2001) presents data of the mixtures that were designed to examine the effects of the fraction, the viscosity, and miscibility of the lubricant mass on system performance in the heat transfer of refrigerant R134a.

Crawford & Knobloch, (1992) simple empirical models developed for a compressor and a condenser of an air conditioner of automobile. The models should be obtained from actual operation of the system. The models were developed to power the compressor, the volumetric flow entering the compressor and the entry pressure of the condenser.

Zietlow, VanderZee and Pedersen (1993) presented work on simulation of a steady state of air-conditioning system to evaluate options for automotive performance. The simulation was validated with experimental data and were also cost and power to provide a reasonable basis for comparison.

### 2.3. Infrared Thermography

The foundations about thermography aims to quantify the distribution of surface temperature of the object tested when it is subjected to thermal stresses (usually heat). This measurement is based on the physical phenomenon that any body at a temperature above absolute zero (-273.15 ° C) emits electromagnetic radiation, emitted by this body, equipment or object, according Norbert Schuster, Kolobrodov Valentin, (2000). The measurement is made using a camera that captures the radiation, and decodes into colors visible to the human eye, which are presented and analyzed in computer software "Fig. 1".

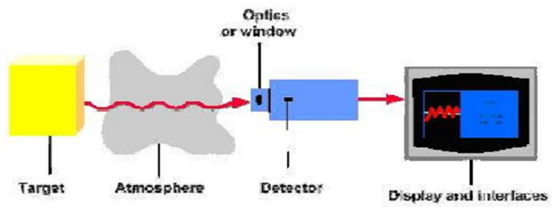


Figure 1. Schematic infrared measurement of temperature.

It is important to highlight the range of detection signal of the spectrometer, or gamma rays, X rays, ultraviolet, visible light, microwave, radio and infrared electromagnetic waves are defined as vibrations of electric and magnetic fields that propagate through space. The infrared radiation, that part of the electromagnetic spectrum is immediately adjacent to the red light of approximately 760 nm on the long wavelength side of the visible spectrum, and extends to a wavelength of approximately 1 mm.

According Touloukian YS, DeWitt DP, (1972), the total radiation (E) issued by a body “Eq. 1”, measured in (W/m2) is directly proportional to the product of the Boltzmann constant with temperature (T), given in Kelvin (K) of this body.

$$\sigma = 5{,}67 \cdot 10^{8} \frac{W}{m^{2} \cdot K^{4}} \quad (1)$$

According to the Stefan Boltzmann equation “Eq.2”, the total radiation emitted by a body, under ideal conditions, is a function only of temperature (T), giving the formula for Plank integrating over wavelength.

$$E = \sigma \cdot T^{4} \quad (2)$$

There are some variables that qualify the boundary conditions to be implemented without many deviations analysis of results. It is necessary to quote the angle of incidence of measurement, the distance measurement, the type of emissivity of the material, the track temperature, ambient temperature, the shape of the surface (finish), the type of material, and interference from the environment where is the measurement.

## 3. EXPERIMENTAL SET-UP AND PROCEDURES

The tests was performed in laboratories to experiment of the Product Engineering of Fiat Automobiles, in the hot room during thermal tests of Cool Down , while the temperature conditions of inside the passenger compartment of the vehicle was controlled with of time until its stabilization (Pereira *et al*, 2008).

Figure 2. Thermographic camera attached to the passenger compartment inside of vehicle.

For this, all tools was provided by Fiat Automobile S/A, such as:  vehicle Fiat Punto HLX 1.8 8V gasoline, all devices for data acquisition via thermocouples that are installed in the hot room, the roller dynamometer where the vehicle will be installed, a thermographic camera brand Flir “Fig. 2”, a laptop with software installed with the Flir Researcher Analisys, and all the support coming from the professionals staff involved in the process.

Installed inside the passenger compartment of the vehicle, the camera Flir S40 thermography will detect changes in body surface temperature in the passenger front focused on the head and chest. In parallel with this tool, there was installed K-type thermocouples in that regions to compare with values sampled in thermal images. And yet, there is an opinion with data provided by the passenger on the conditions of comfort and thermal sensitivity in the vehicle during the experiment.

The experiment  of the temperature decrease inside the passenger compartment of the vehicle was performed through of the air-conditioned action,,under certain conditions standardized by Fiat Group Automobiles. These standardized conditions are parameters such as temperature in various parts of the car cabin, speed of the engine, fuel type, load the attached roller dynamometer, standard temperature, radiation pre-determined, number of installed thermocouples defined “Fig. 3”.

Figure 3. Place of thermocouples installation.

To conduct the tests, thermal images were taken in sequence, collected in an interval of 10 minutes, then a sampling rate of 1 second, and showing through the change of color variations in temperature both in the head and the chest of passenger.

It is based on images taken, and the values obtained by the thermocouples installed in the passenger's head and thorax "Fig. 4", were evaluated the changes of temperature on their rates of decay, and difference between these temperatures.

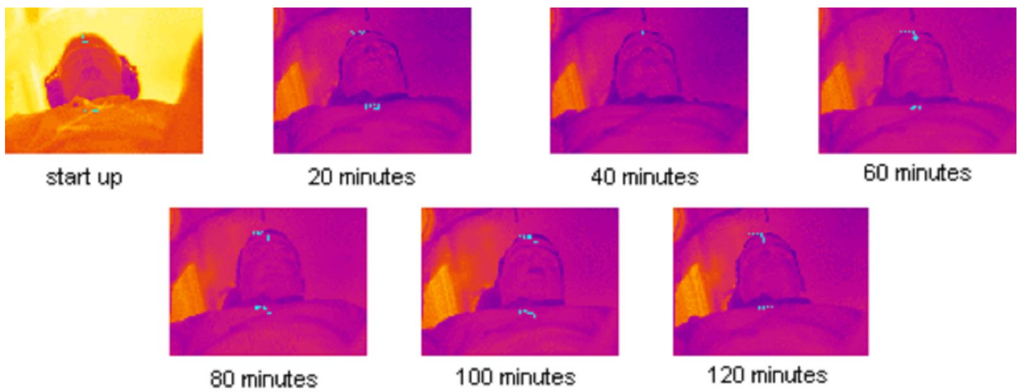


Figure 4. View of collected during thermal test.

These tests, as indicated, were performed in climatic chamber for testing thermal, where the vehicle was installed on a roller dynamometer "Fig. 5". On the vehicle, the lamps simulated solar load and has caused the temperature rise inside the vehicle as being solar radiation, approximately 900 $W/m^2K$.

Figure 5. Vehicle tested installed in the roller dynamometer.

## 4. RESULTS AND DISCUSSION

After the test in the climatic chamber, were make the curves of temperature versus time for local analysis. Thus, according to the chart, there is regularity in the decay of both measures temperatures with thermocouples, as by thermo graphic camera.

It was noted in map of thermocouples temperature, a decrease from the head of the passenger through the chest and then the feet. This is because there is a natural convection inside the vehicle, and that there is a gradient of temperature that follows from top to bottom, hot to the cold, which causes the temperatures larger on the point of highest elevation of the vehicle in this case, near the roof of vehicle.

The differences in temperature between the two references (thermocouple and thermography) for temperatures in the front passenger's head maintained a regular after 18 minutes of stabilization at $\Delta T = 29.9$ º C "Fig. 6", and the chest, the behavior is remained similar throughout the remaining portion "Fig. 7". This indicates that the technology of thermography may be useful to characterize the behavior of temperature inside the passenger compartment of the vehicle, when directed to the front passenger.

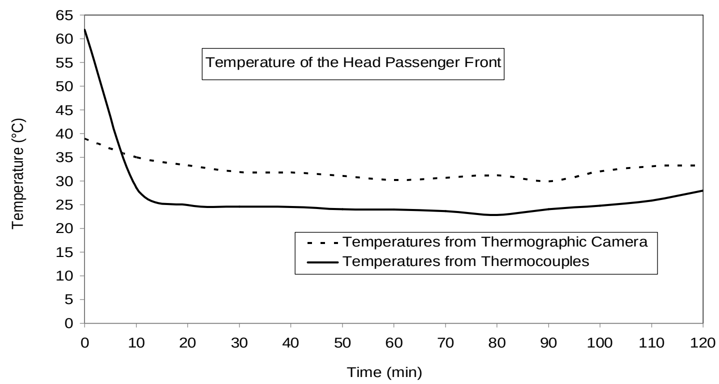


Figure 6. Curves of temperature in the passenger's head at 120 minutes.

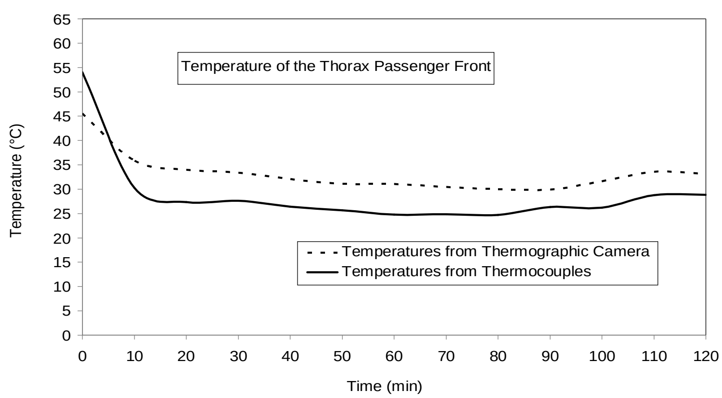


Figure 7. Curves of temperature in the passenger's thorax at 120 minutes.

To evaluate performance of the temperature during the first 20 minutes of testing, which is the intersection of two curves of temperatures, another experiments were performed at a rate of acquisition of 10 seconds.

The fact of having the intersection of the curves, is justified because of the way were the values of temperature. The thermocouples, measured the air temperature in the region near the surface of the body of the passenger. However, with the thermographic camera, has made the measurement of the surface itself, in which case it will remain near the normal human body temperature, around 37 ° C, while the temperature of the environment that at the beginning of the experiment was on average 63 ° C, will tend to a level below 25 ° C "Figs. 8 and 9".

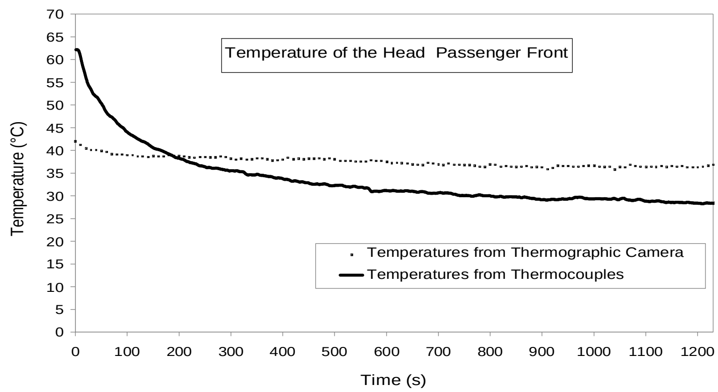


Figure 8. Curves of temperature in the passenger's head at 20 minutes.

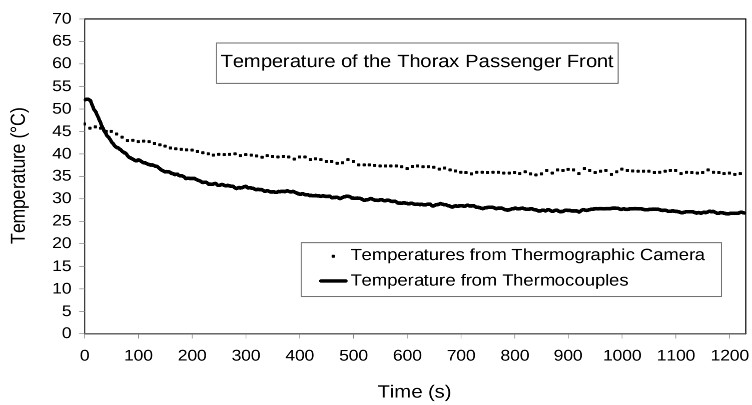


Figure 9: Curves of temperature in the passenger's chest in 20 minutes.

## 4. CONCLUSIONS

According to data analysis, there is a regularity and similarity in decay between the temperatures obtained with both thermocouples and by thermographic camera. This implies the possibility of using the technology for Analysis Thermographic in parallel, or separately to other means of acquisition to detect variations in temperature in passenger compartment of the vehicle, that regulate behavior was presented in the test of the Cool Down.

The results demonstrate that thermograph can supply important information about temperature gradient in a body of the passenger in a car, because the body temperature is a consequence of the process metabolism human and environment. This fact is important to determinate better conditions of comfort thermal.

Although the levels of temperature measured between thermocouples and thermograms be different, but maintaining the same trends, the thermography was effective to determine the thermal comfort in automobiles. Similar studies and researches conducted only with thermocouples, could not show reactions about temperature in the occupants body, but only on the periphery of the body surface, and the thermography can be able to illustrate the interaction of the human body with the environment for thermal comfort.

But even presenting results in a longer expected, it was a homogeneous temperature curve compared to the thermocouples installed, it is necessary a more detailed investigation of this new methodology to make it more efficient and reliable.

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## 4. REFERENCES

Actual Performance Data", Air Conditioning and Refrigeration Center University of Illinois Mechanical & Industrial Engineering Dept.,82p.

American Society of Heating, Refrigerating and Air-conditioning Engineers, New York, NY, ETATS-UNIS (1967)

ANSI/ASHRAE Standard 55-2004, "Thermal Environmental Conditions for Human Occupancy".

Crawford & Knobloch, 1992, "Dynamic Modeling of a Mobile Air Conditioning Compressor and Condenser from

Hosni, et al., 2003a and 2003b, and by Delphi, "Thermal Sensation and Comfort in Transient Non-uniform Thermal Environments", Accepted: 27 January 2004 / Published online: 18 June 2004 Springer-Verlag 2004, 6 p.

Kedzierski, 2001," The effect of lubricant concentration, miscibility, and viscosity on R134a pool boiling", International Journal of Refrigeration, Volume 24, Issue 4, June 2001, Pages 348-366.

Lee & Yoo, 2000, "Performance analysis and simulation of automobile air conditioning systemAnalyse de la performance et simulation d'un système de conditionnement d'air automobile", International Journal of Refrigeration Volume 23, Issue 3, May 2000, Pages 243-254.

Madsen et al, 1986; Hosni et al, 2003a; Nilsson, 2004,"Improvements In Air-Conditioning Vehicle For Improving Environmental Conditions Of Cabin And Reduction In Fuel Consumption", Politecnic School of University of São Paulo, Department of Mechanical Engineering, 11 p.

Pereira, Leonardo Vinícius Mendes Pereira, Maia,Gustavo Fonseca de Freitas, Bicalho,Gustavo Inácio, Silva, Felipe Vereza Lopes, Rocha, Marcio Carneiro, "Virtual Simulation and Experimental Study of the operation of an air conditioning system convey", V National Congress Of Mechanical Engineering, August 18 a 21, 2008, Salvador, Bahia, Brazil.

Schuster, n.; kolobrodov, v., 2000, "Infrarotthermographie", Zweite, überarbeitete und erweiterte Ausgabe, 352p.

Touloukian,y.s., 1972, "Thermal Radiative Properties - Metallic elements and alloys", dewitt,d.p.termophisical propertiers of matter.Vol. 8. IFI/Plenum, New York and Washington, 257p.

Silva, Gameiro., 2002, "Measurements of comfort in vehicles", DEM-FCT, Universidade de Coimbra, P´olo II, 3030 Coimbra, Portugal, Measurement Science And Technology, 13 (2002) R41–R60, 20p.

Zietlow, VanderZee and Pedersen, 1993, "Mobile Air Conditioning System Design Study", Air Conditioning and Refrigeration Center University of Illinois Mechanical & Industrial Engineering Dept., 50p.

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