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Contributions to the car cockpit thermal comfort optimization using numerical simulation

PHD THESIS

-abstract-

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Pitesti, 2011

Preparation of this work is the result of research conducted over several years. Also must be noted that some of these research results were presented and published in various scientific sessions during the study period.

This paper aims to study the possibility of optimizing the thermal comfort of a car interior using numerical simulation. Comparing the results obtained fro, numerical simulations with those obtained from measurements we managed to achieve a methodology that allows us the evaluation of various configurations of air distribution in the vehicle interior.

The numerical analysis of several configurations allows us to find an optimal arrangement of vents and air conditioning flow distribution in the cabin, leading to obtain an optimal thermal comfort for occupants.

This paper represents the positive effect of aid received from various experts, academics, which is my great pleasure to thank on this occasion and assure them of my full appreciation and consideration.

I address all my thoughts and all my best gratitude to **Mr. Ion Tabacu**, **PhD Professor**, scientific coordinator of my thesis, whom I thank for valuable guidance for support without hesitation, the expert advice and guidance for my research, not least for confidence.

I want to thank **Mrs. Mariana Ivanescu PhD Associate Professor** for the close cooperation, patience proven, scientific support and competent advice that she gave to me on the thesis.

Also thank **Mr. Florin Serban PhD Associate Professor** for the help given in experimental research of the parameters characterizing the thermal comfort.

Present thanks and my gratitude to all the professors in the **Automotive Department of the University of Pitesti** for their competent suggestions and kindness given in the internship training period.

I want to thank those of **P + Z Engineering GmbH, Germany**, for providing Theseus FE program and technical support provided.

I am also thinking of my parents and thank them for understanding that showed and for the received moral support in difficult moments.

Thank you!

Pitesti, September 2011

Cătălin-Adrian NEACŞU

The comfort sensation is assured on one side from the factors linked to the heat transfer between human and the environment, that defines the thermal comfort, and on the other side by factors like the air purity and the noise level.

The goals of the thesis:

- Defining the notions of thermal comfort and human body thermal balance;
- Presentation of the parameters that describe the thermal comfort inside car cabin and the relations that appears between them;
- Analysis of the systems used to create an optimum microclimate inside car cabin;
- Measurement of the parameters that describe thermal comfort inside car cabin;
- Presenting the analytical relations that characterize the temperature and humidity evolution;
- Elaboration of a calculus methodology for the numerical simulation of car cabin microclimate using Theseus-Fe and Ansys Fluent software;
- Evaluation of the thermal comfort index of car passengers;
- Different solutions to improve thermal comfort of car passengers;
- Using design of experiments to create a factorial plan of virtual experiments;
- Identification of the optimum solution that gives us the best thermal comfort.

Structure of the thesis

The thesis is structured in four main parts:

Part 1 – formulation of the problem and it consist in the presentation of the parameters that influences the thermal comfort in automobiles

Part 2 – fundamental presentation of the vehicle thermal balance and of the systems used to improve passengers the thermal comfort

Part 3 – evaluation of the results through experimental tests and numerical simulation

Part 4 – optimization of the thermal comfort using numerical simulation

Finally, the thesis is completed by a chapter featuring final conclusions and personal contributions.

The notion of comfort is a very relative notion, which is influenced by numerous parameters.

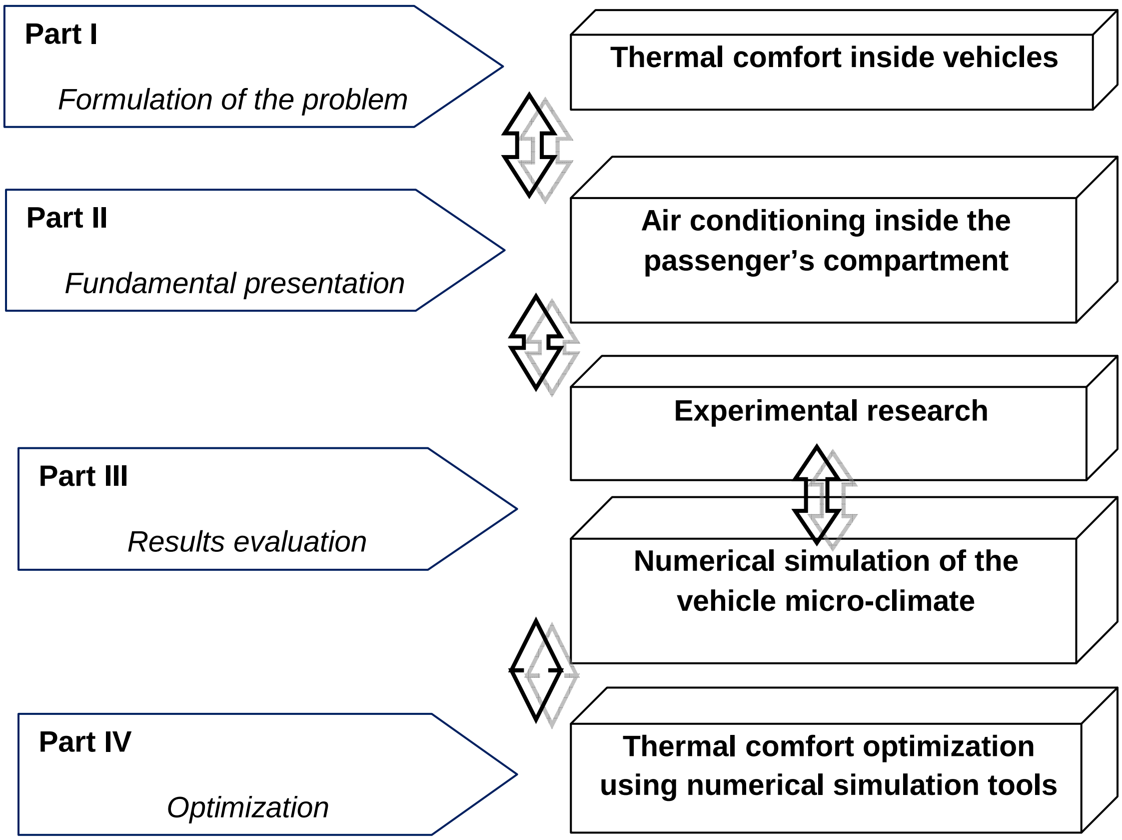


Figure 1.1*Thesis structure*

According to ISO 7730, the thermal is defined in ISO7730 as "that condition of mind which expresses satisfaction with thermal environment".

Human body's thermoregulatory system allows adjustment of physiological heat load and thermal comfort of the body in different conditions, in figure 1.3 being presented the processes that characterize the heat transfer between the human body and the environment.

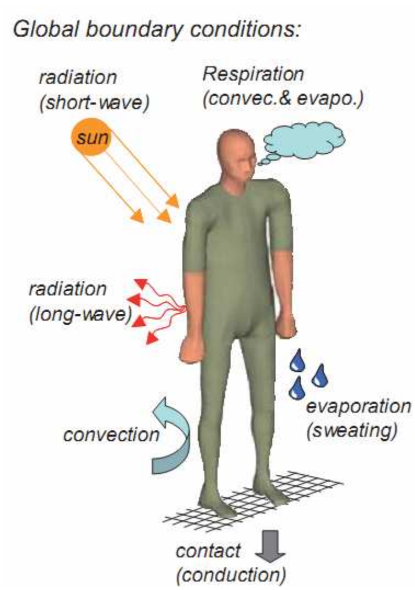


Figure 1.3 *Heat transfer between human body and the environment*

We can state that the thermal comfort is affected by the three existent types of heat transfer: conduction, convection and radiation.

The human thermal comfort can be influenced by six parameters that are divided in environmental and personal factors.

- environmental factors:
  - air temperature
  - air humidity
  - air velocity
  - mean radiant temperature
- personal factors:
  - clothing isolation
  - metabolic rate

To describe the thermal comfort, we must consider a link between these factors, link defined by the thermal comfort index.

Today we can find a variety of thermal comfort indexes, but they can be divided in:

- global factors (PMV, PPD, DTS)
- local factors (defined according to ISO 14505-2)

The thermal manikin was used in the past only in civil engineering, but with the rising demands of vehicle thermal comfort, it is used more often and in the automotive industry. The forms in which it is found are represented by the physical state in climate chamber experiments, or in its mathematical formulation in the numerical simulation.

The manikin helps us to understand the response of the human body to different changes that can take place in the car cockpit micro-climate.

A heating, ventilation and air conditioning system provide thermal comfort parameters in the car interior through air circuits that make possible the exchange of heat necessary to adjust the interior temperature, humidity and air quantity.

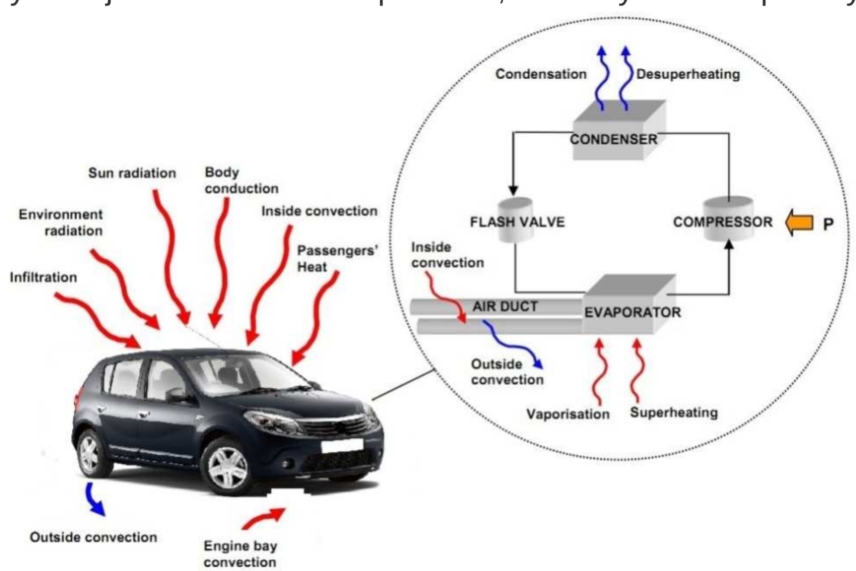


Figure 2.5 *Thermal balance of the car*

Experimental research to determine the parameters of microclimate is in accordance with the rules and aim to determine the actual values of quantities that characterize the convenience of cars.

To assess the efficiency of the heating/air conditioning in the cockpit we must analyze the measured values if temperatures at various points inside the vehicle, the measured air temperature and speed out of the vents, the air velocity in the front passenger and cabin air humidity analysis.

We have conducted several experiments to evaluate the car cockpit parameters, and below we will present the data recorded for the case that puts the biggest problems in achieving the total thermal comfort for all the car occupants.

The measured external temperature in this case was 38℃.

The graphical representation of the temperature evolution inside the car cabin in the 12 measuring points during a period of 30 minutes is presented in figure 3.23.

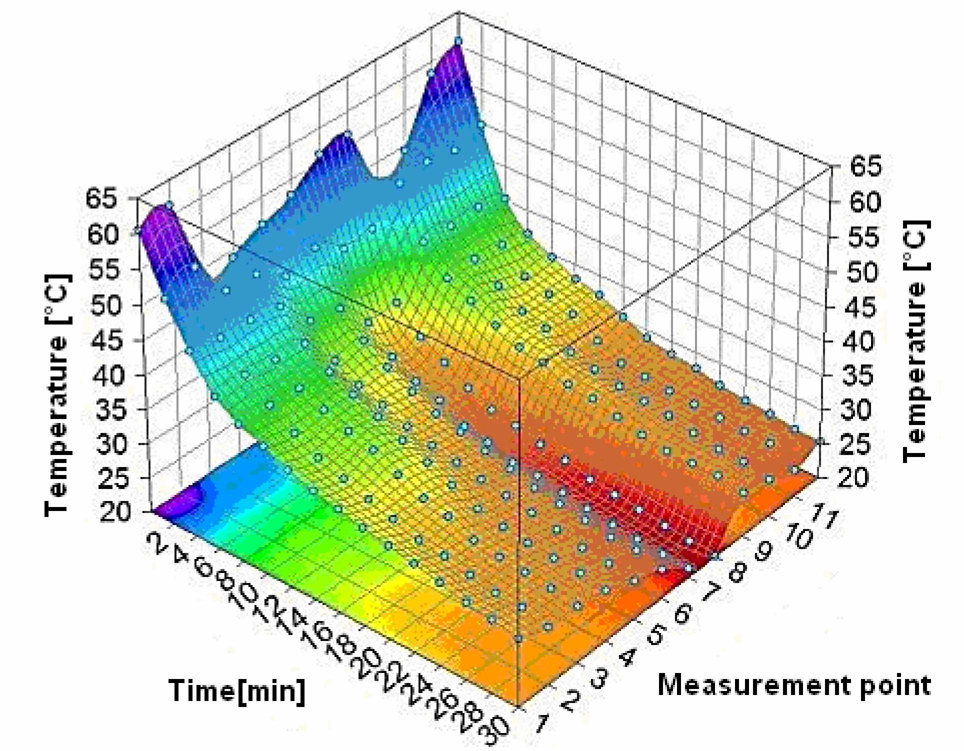


Figure 3.23. *Temperature variation vs. time and measurement point in the car passenger's compartment*

The characteristic equation of the time distribution is given by the Jandel Scientific software, and it is given by:

$$T = a + b \cdot t + c \cdot t^2 + d \cdot t^3 + e \cdot t^4 + f \cdot t^5 + g \cdot i + h \cdot i^2 + j \cdot i^3 + k \cdot i^4 + l \cdot i^5 \quad (3.1)$$

where:

t - time[min]
i - measurement point 1…12
a..l - equation constants: a = 60,592643252 ; b = -4,40264974 ; c = 0,359833052; d = -0,01668272 ; e = 0,000393543 ; f = -3,6717e-06; g = -1,93341769 ; h = 1,14194899; j = -0,39045806; k = 0,046435033;
l = -0,00175171

Analyzing the results we will observe that the average temperature obtained inside the car cabin after 30 minutes is 25,5℃, temperature that does not give a good thermal comfort.

Analyzing all the results obtained for the others measurements we have observed that the biggest evolution of the temperature is viewed in the first 15 minutes of the experiment, after that period the temperature variation is not that big.

Considering an external temperature of 32℃, after 30 minutes of measurement the average cockpit temperature was 22,9℃.

From the winter measurements, we can see that the average temperature inside car cockpit varies from -6,1℃ at the beginning of the experiment to 24,5℃ at the end of the experiment(after 28 minutes).

Regarding the air speed at vents exit, the maximum velocity measured was 9,57m/s when considering the air flow directed only through the four dashboard air vents and the blower at maximum speed.

When we have measured the air velocity at front passenger’s faces, we have observed that the biggest air velocities were measured near the windows and in the center of the car, as shown in figure 3.44. The maximum air velocity is 4m/s.

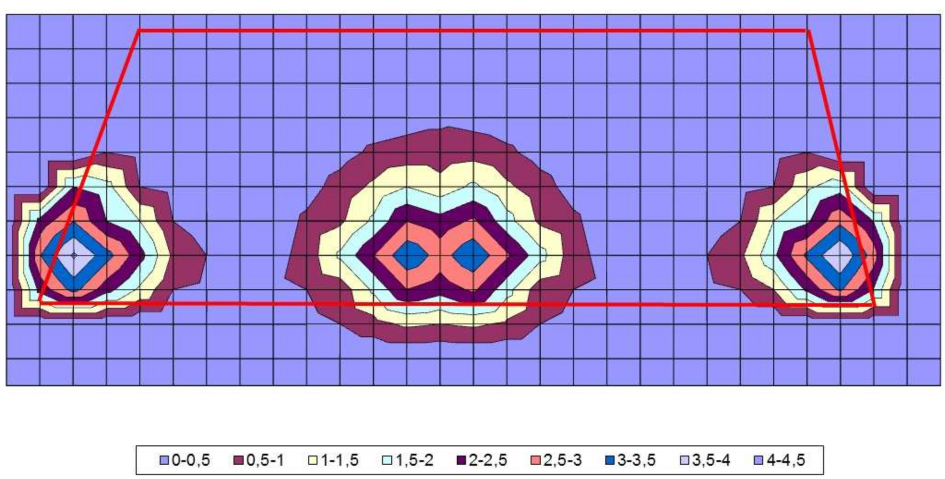


Figure 3.44. *Air velocity at front passenger’s faces*

All these measurement are necessary to help us validate a numerical simulation methodology that will be used to evaluate the impact of the changes proposed in the optimization part of the thesis.

After a bibliographical study, we have decided that the best way to realize a methodology is to use two programs: one that will solve the CFD equation of the air flow inside the cabin, and the other that will solve the thermal transfer between the car interior's components, and also contain a numerical thermal manikin.

The software used was Ansys Fluent and Theseus FE, whilst the linking was done using different Matlab programs and Excel charts.

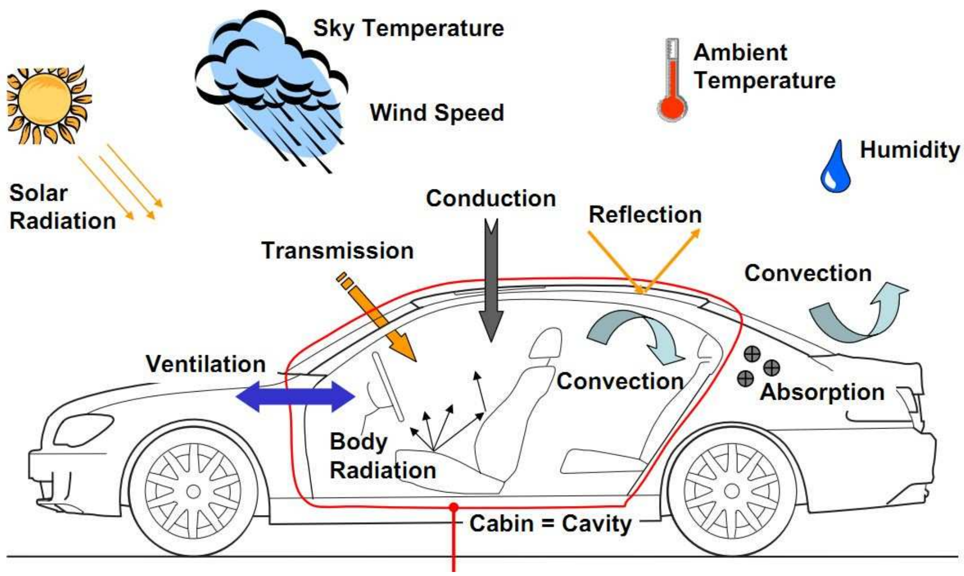


Figure. 4.1*Thermodynamic system boundary for the energy conservation*

Because the evolution in time of the air velocity inside car cockpit is insignificant, we can consider the air flow stationary. That simplification helps us in the reduction of the time needed for the simulation.

Because earlier we have presented the measured temperatures for the case where the external temperature was 38℃, we will pr esent now the results obtained for the same situation.

We will use Ansys Fluent to realize the CFD computation of the air flow inside car cockpit. At the end of the simulation we will use *journal* files to create the post-processing plans, to compute the air flow between the front and rear zone, and also to compute the average velocity near the boundaries. The former value is necessary to better evaluate the convective boundary conditions inside the Theseus-FE soft.

The air temperature inside car cockpit is evaluated using Theseus-FE software. Starting from the car model, we will input the boundaries conditions using Python scripts and the convective boundary conditions, using Matlab procedures and the results that are obtained from Fluent files.

Considering that methodology, at the end of the simulation we will observe that the average temperature obtained inside car cockpit is 25,56℃, with 24,74℃ for the front side of the car and 26,56℃ for the back of the car. The obtained results are similar to those obtained from the experiment.

Using the same methodology, we have obtained similar results in the other two cases, one with external temperature of 32℃ and the other with -10℃. We can conclude that the methodology can be applied to similar cases.

The main advantage of the Theseus-FE software is that it include an thermal manikin, and that will help us to evaluate the thermal comfort index for the vehicle occupants(in our case the driver – left front seat, and the back passenger – right back seat).

Table 4.13*Thermal comfort index*

	Driver				Back passenger			
Time(s)	DTS	PMV	PPD	t_{eq}(℃)	DTS	PMV	PPD	t_{eq}(℃)
0	0,00	3,00	100,00	143,93	0,00	3,00	100,00	161,98
600	1,41	3,00	99,49	34,57	2,31	3,00	100,00	38,06
1200	-0,10	1,17	33,86	29,16	1,66	2,45	92,30	33,19
1800	-1,16	0,19	5,72	26,46	1,06	1,59	55,78	30,69

In table 4.13 we will present the thermal comfort index evolution during the entire simulation for both passengers and in figure 4.29 a representation of the velocity pathlines, temperature of the interior parts and the local thermal comfort of both passengers, according to ISO 14505:2.

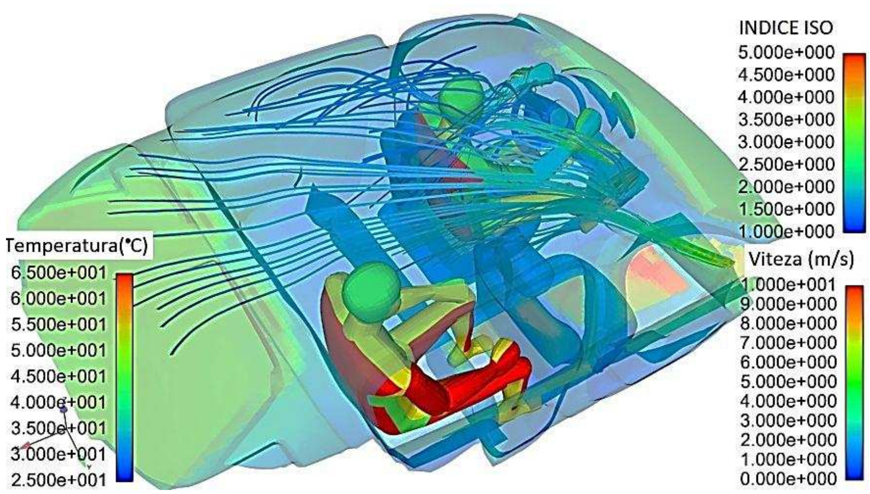


Figure 4.29*Thermal comfort parameters*

By analyzing the obtained results, we will observe that the back seat passenger is not in a neutral state of thermal comfort at the end of the simulation.

Looking at the other cases, we will obtain similar results at the end of the simulation, with the results obtained experimentally.

So we can consider that the procedure developed can be successfully used in evaluating the influences of different configurations of air distribution on thermal comfort inside the car cockpit.

As we observed in the results presented in table 4.13, the rear seat passenger is not in a neutral state of thermal comfort, so we must find the best solution to obtain a good thermal comfort for him.

After analyzing the solutions found on the market, we have decided to evaluate the influence of splitting the total airflow distributed in the front of the vehicle between the front and the rear side of the car.

In figure 5.1 are presented the air vents from which we will introduce air inside the cockpit, at different rates, rates given by a factorial plan.

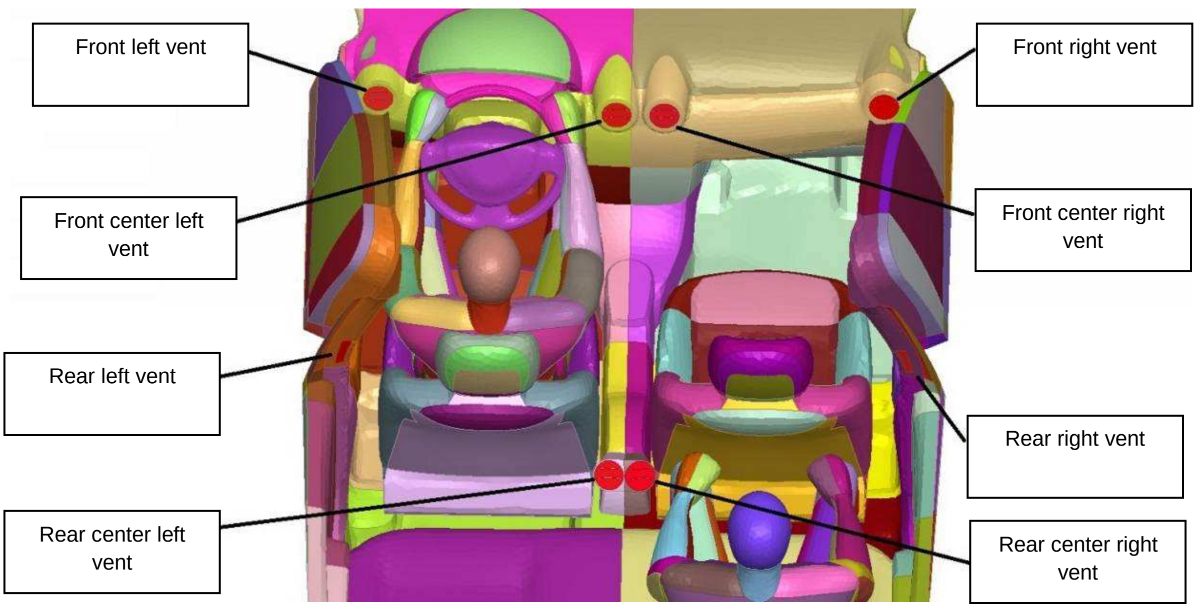


Figure 5.1*Air vents positioning inside cockpit*

The parameters used to create the factorial plan are given in table 5.2 and the factorial plan in table 5.3

Table 5.2 *Test factors and their values*

Test factor		Level		
		0	1	2
A	Distributed air on the rear side(%)	20	30	40
B	Distributed air from the rear side vents(%)	0	50	100

__Table 5.3__ Factorial plan

Case	Parameter	
	A	B
Case 1	0	0
Case 2	0	1
Case 3	0	2
Case 4	1	0
Case 5	1	1
Case 6	1	2
Case 7	2	0
Case 8	2	1
Case 9	2	2

We will evaluate air speed, temperature distribution and thermal comfort indexes (PMV, PPD and DTS) for all the nine cases.

In terms of air speed velocity the maximum value reached at rear passenger head is 3,64 m/s in the 9th case, and for the front passenger, in the reference case the maximum airspeed is 4,02 m/s.

Looking at table 5.3 we can observe that the air introduction on the rear side of the cockpit gives us lower temperatures, compared to the reference case, where red represents the rear part of the cockpit and blue the front part.

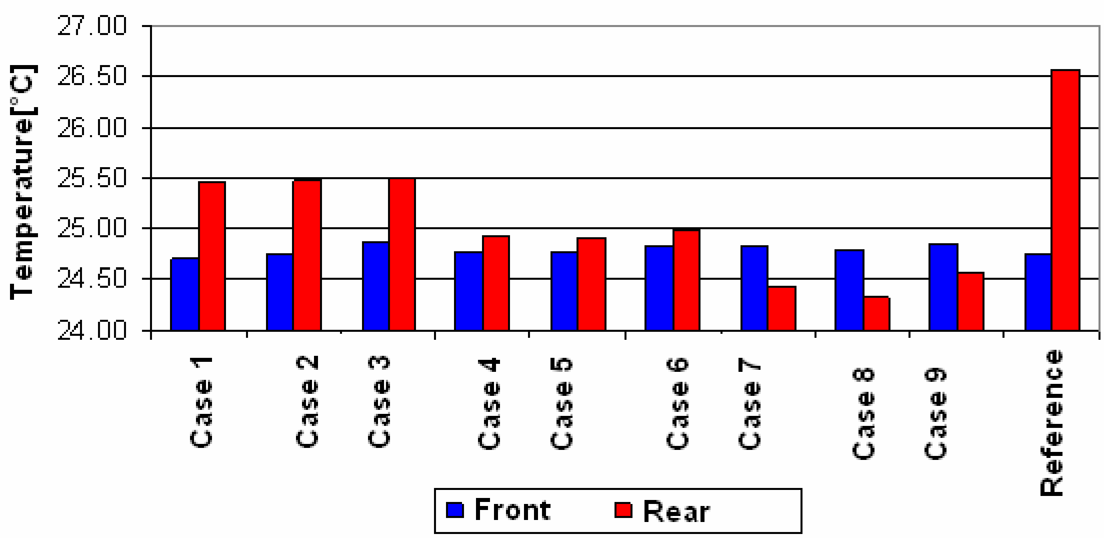


Figure 5.3 *Car cockpit temperature at the end of the simulation*

Because the thermal comfort is characterized by different indexes, we must define a link between those indexes and the general thermal comfort.

As mentioned in previous chapters, ASHRAE believes that comfort level is acceptable if we have a maximum of 20% of people dissatisfied. Thus, the PPD index has a value of 20% and PMV index corresponding to this value must be in the range [-0.85 0.85]. PPD index characterizing the state of comfort is in the range [-1 1].

To be able to represent that on the same scale, from 0 to 3, we will consider that the value of 0% PPD correspond to value 0 on the scale, while 100% PPD corresponds to 3. Also, we will consider the PMV and DTS in absolute value, given the fact that value 0 correspond to an optimum thermal comfort state, while the extremes (-3 and 3) correspond to the worst comfort state.

Those simplified indexes will be noted as PMV_G, DTS_G and PPD_G. The target values for those indexes are PPD_T equal with 0,6 ; PMV_T equal with 0,85 and DTS_T equal with 1.

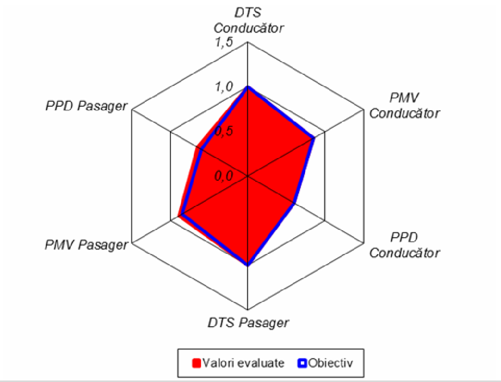
We will define two general comfort indexes: general thermal comfort index and general absolute thermal comfort index. Those indexes are evaluated as an are of a surface, and are represented as graphs.

The graphs are constructed taking into account the value of the thermal comfort indexes for the car occupants, and the general absolute thermal comfort index (GATCI) is defined by the area of the surface defined by the evaluated values. The smaller is the value of the area; the better is the thermal comfort.

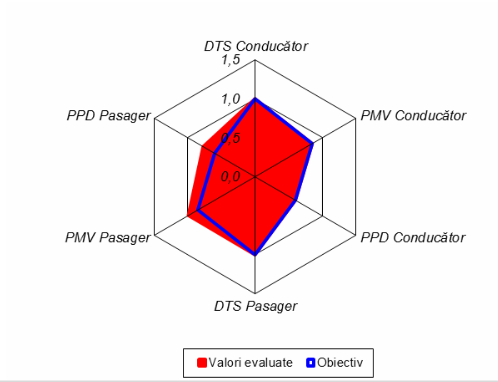
A better definition of the thermal comfort index is given by the general thermal comfort index (GTCI), defined in the same way as the GATCI, but with the specification that if the individual index(PMV, PPD or DTS) is inferior at the target value, it's value is taken by the target. In figure 5.7 are presented the GATCI for the given cases and in table 5.22 the synthesis table for those indexes. The GTCI gives us the answer to the question: "Does all the car occupants have reached thermal comfort?". If the values of GTCI is equal to the target, the answer is YES, if it is bigger than the target, the answer is NOT.

Table 5.22 *Thermal comfort synthesis*

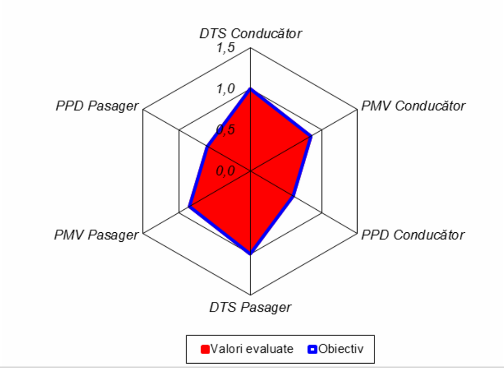
	Level		***GTCI***	***GATCI***
Parameter	***A***	***B***		
Case 1	0	0	2,072	1,748
Case 2	0	1	2,609	1,787
Case 3	0	2	2,359	1,430
Case 4	1	0	2,180	1,219
Case 5	1	1	2,282	1,335
Case 6	1	2	1,942	0,905
Case 7	2	0	1,765	0,706
Case 8	2	1	1,921	0,906
Case 9	2	2	1,697	0,520
Reference			3,646	2,911
Target			1,697	0



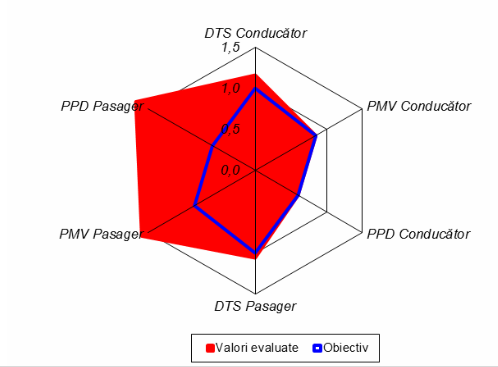
Case 7



Case 6

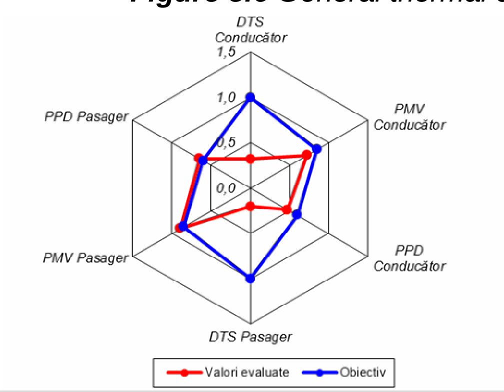


Case 9

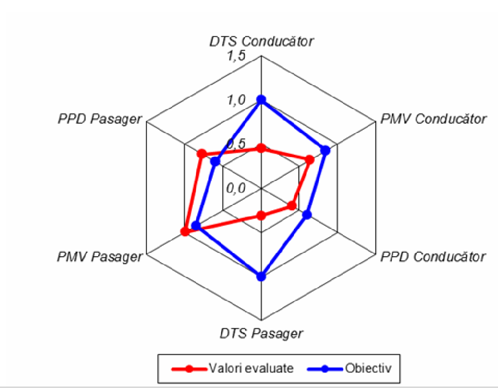


Reference

Figure 5.6 *General thermal comfort index at the end of the simulation*



Case 7



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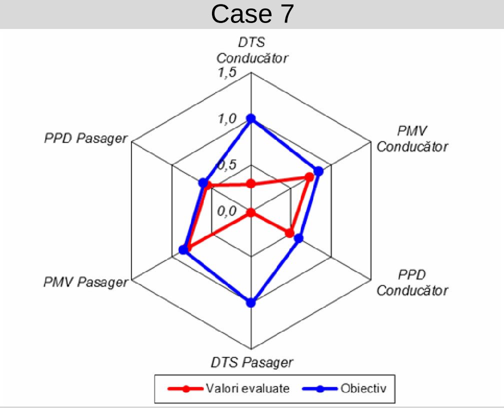
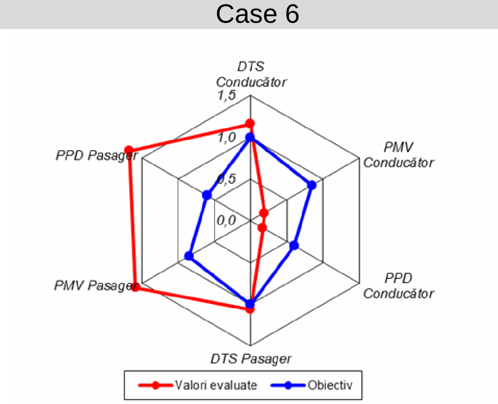


Case 9



Reference

Figure 5.7 *General absolute thermal comfort index at the end of the simulation*

We can observe that the thermal comfort is better in case 9, compared with all the other values.

In figure 5.12 we will represent the results for the selected case.

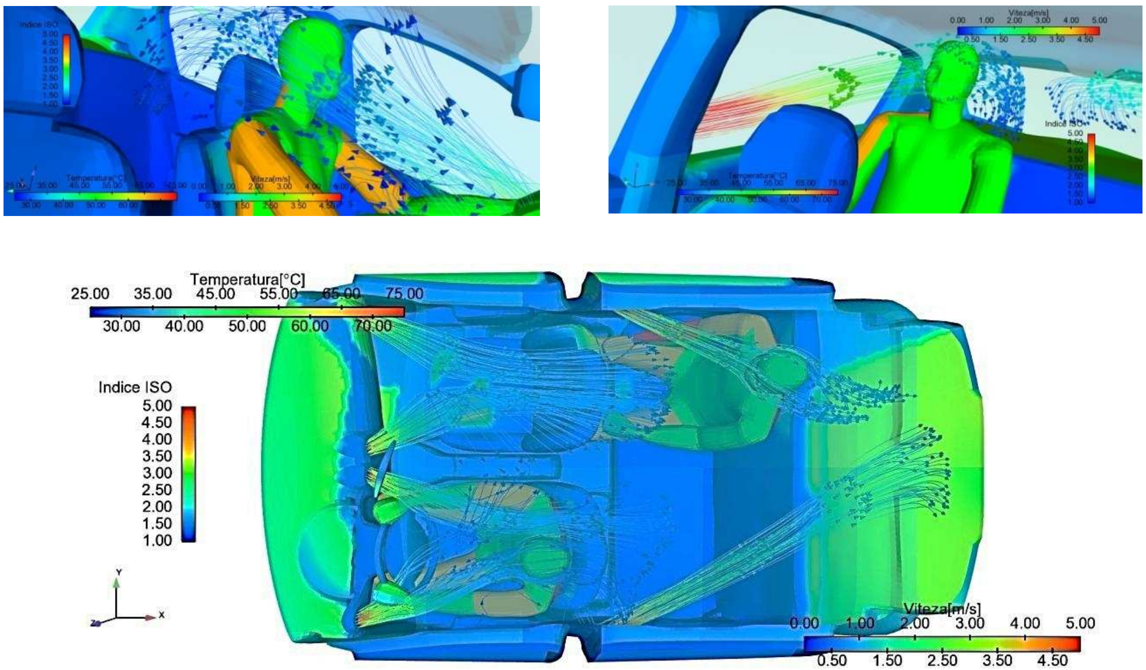
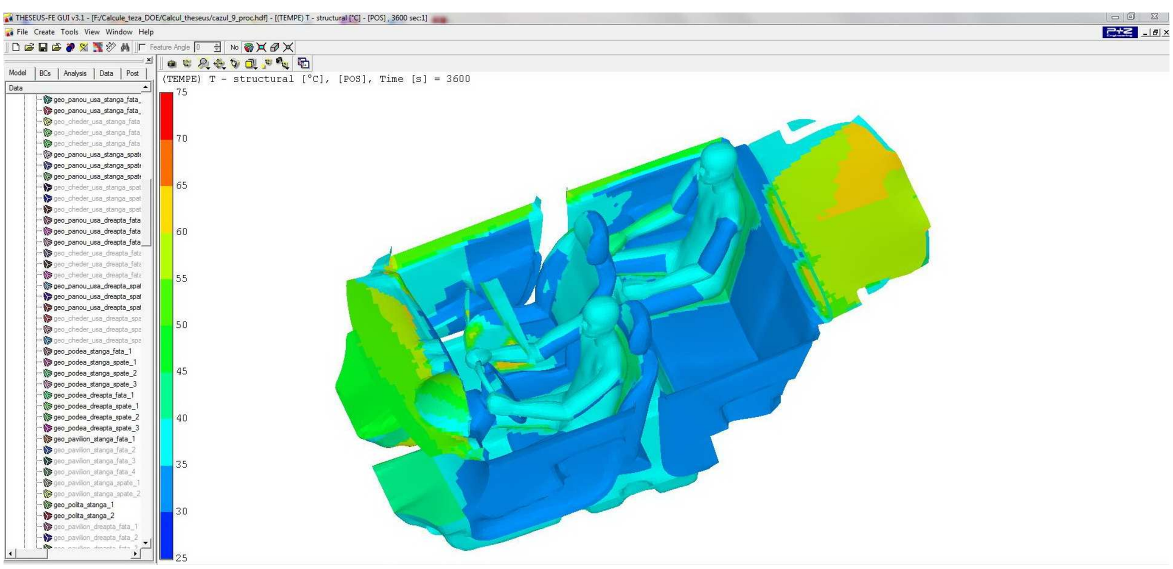


Figure 5.12 *View of the results for case 9*

In figure 5.13 we can observe some pictures taken inside the Theseus FE software, pictures that allows us to observe the temperature distribution inside the car cockpit (a), equivalent temperature for car occupants (b) and the local thermal comfort (c).

a



b

c

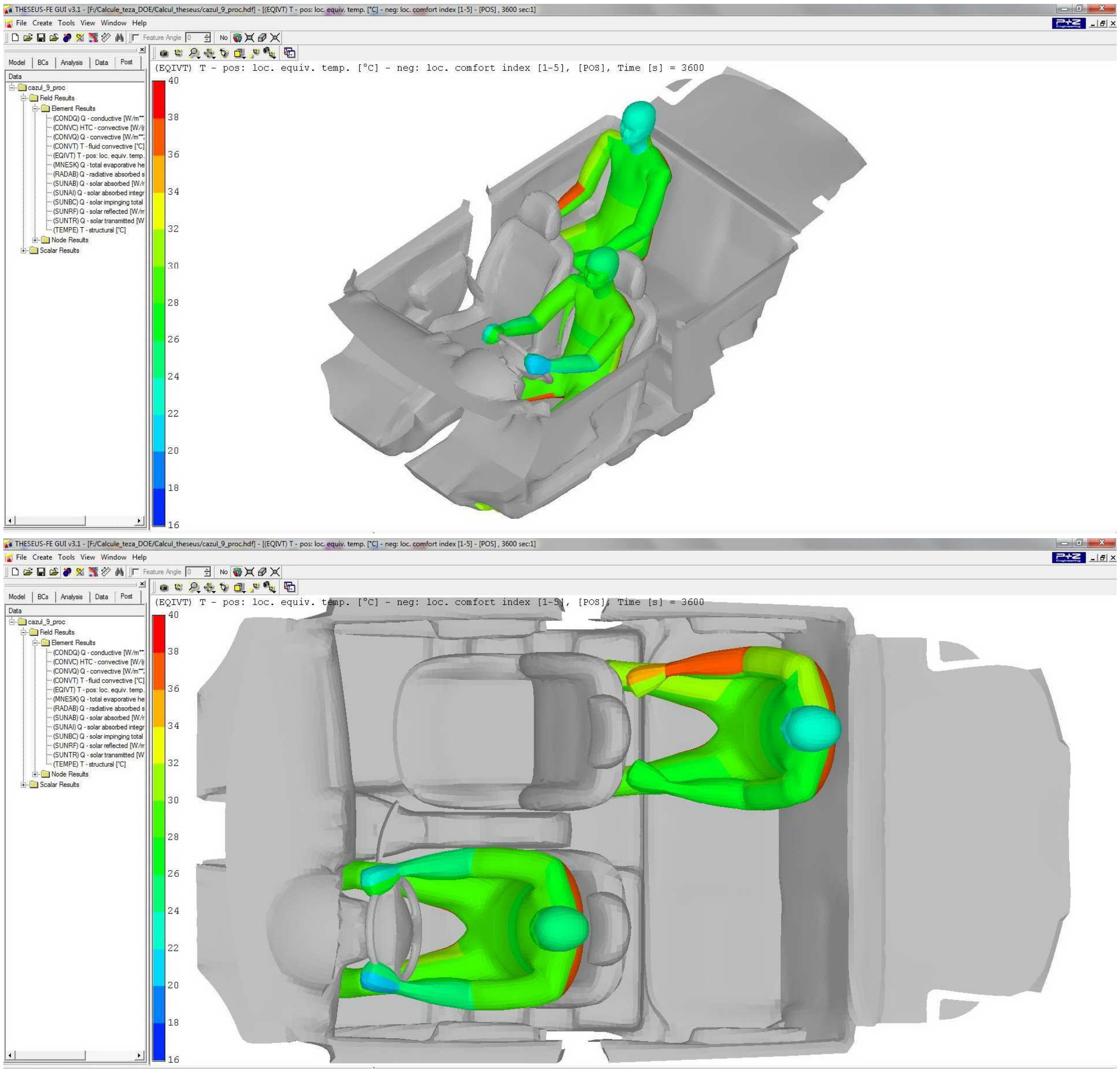
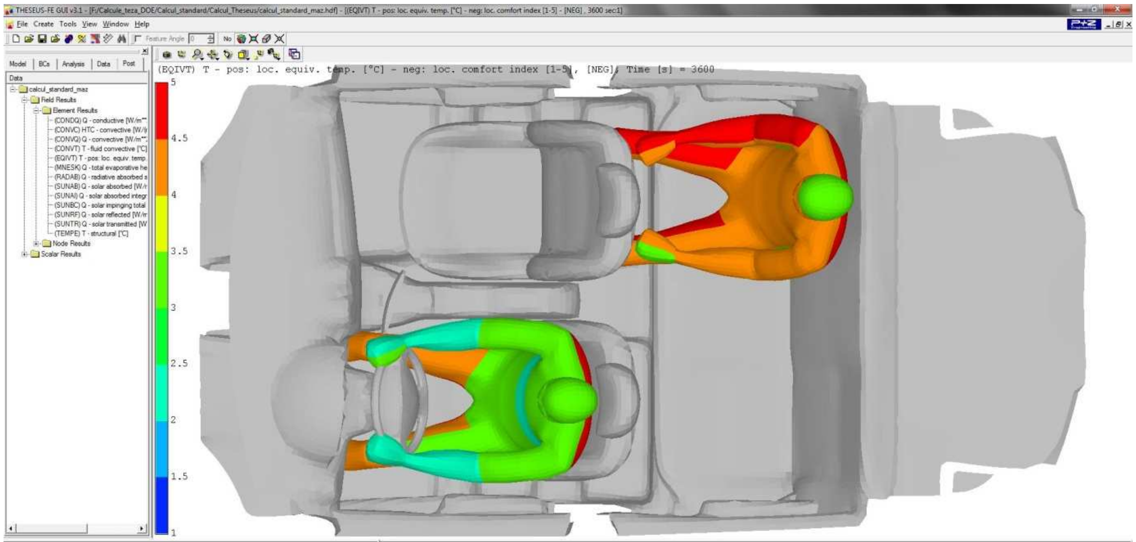
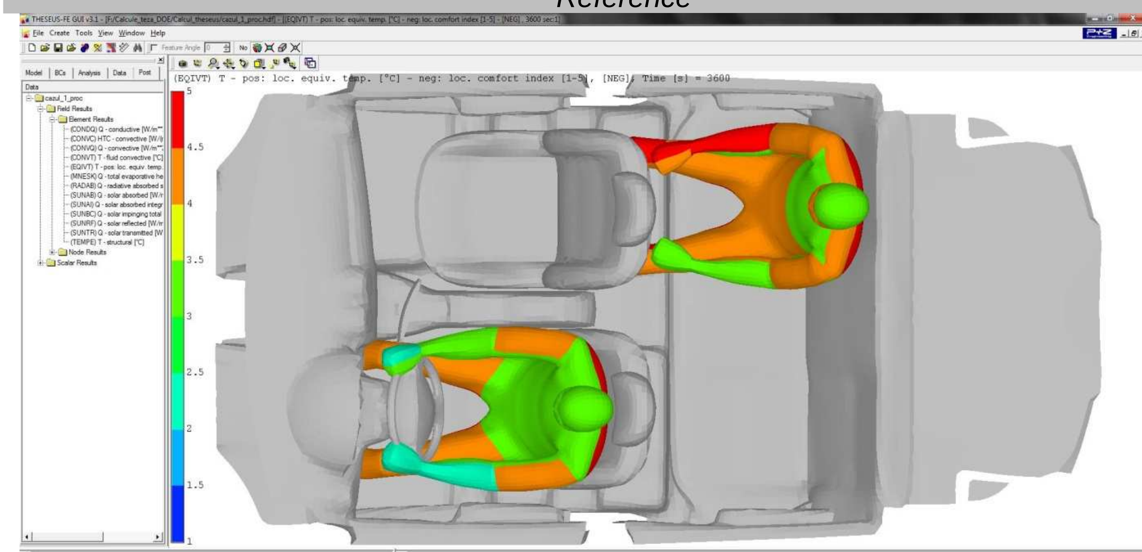


Figure 5.13 *Visualization of the results for case 9: a-temperature distribution; b-passengers equivalent temperature; c-passengers local thermal comfort*

Also we can observe the influence of the air flow repartition on the manikin thermal comfort. This can be seen in the figure III.1

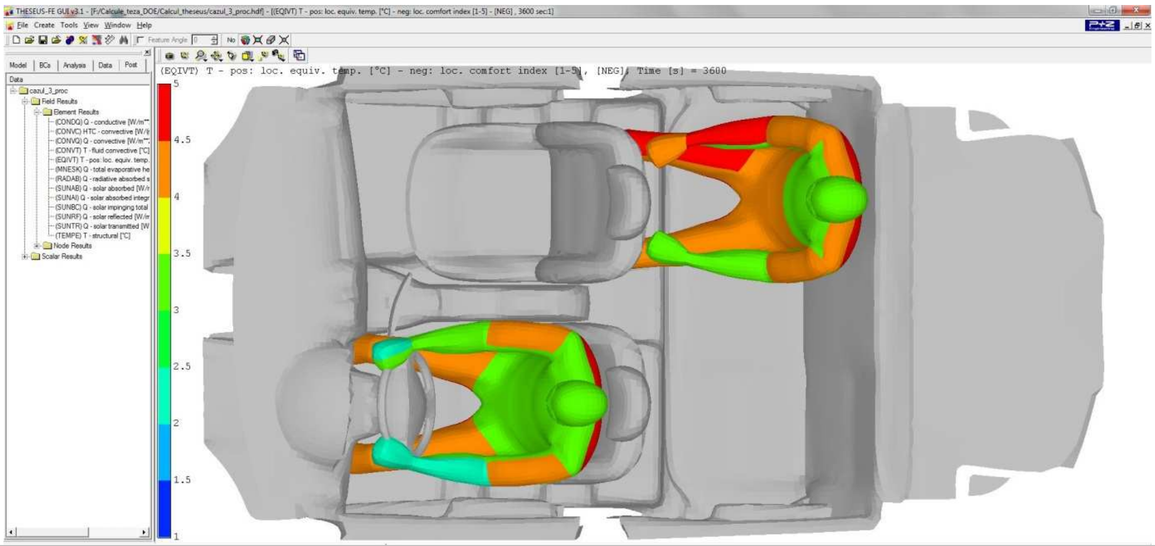


Reference

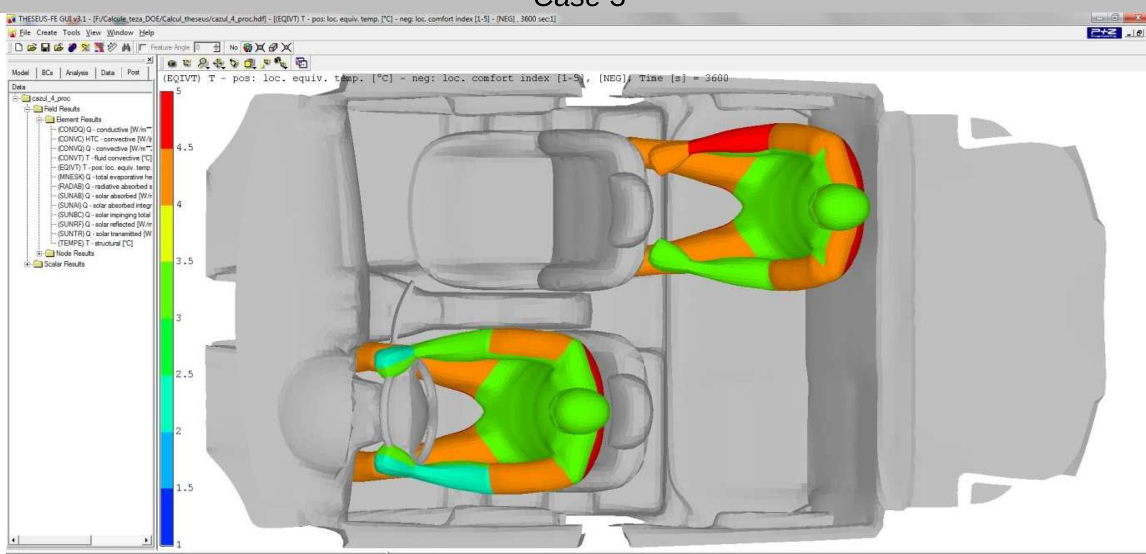


Case 1

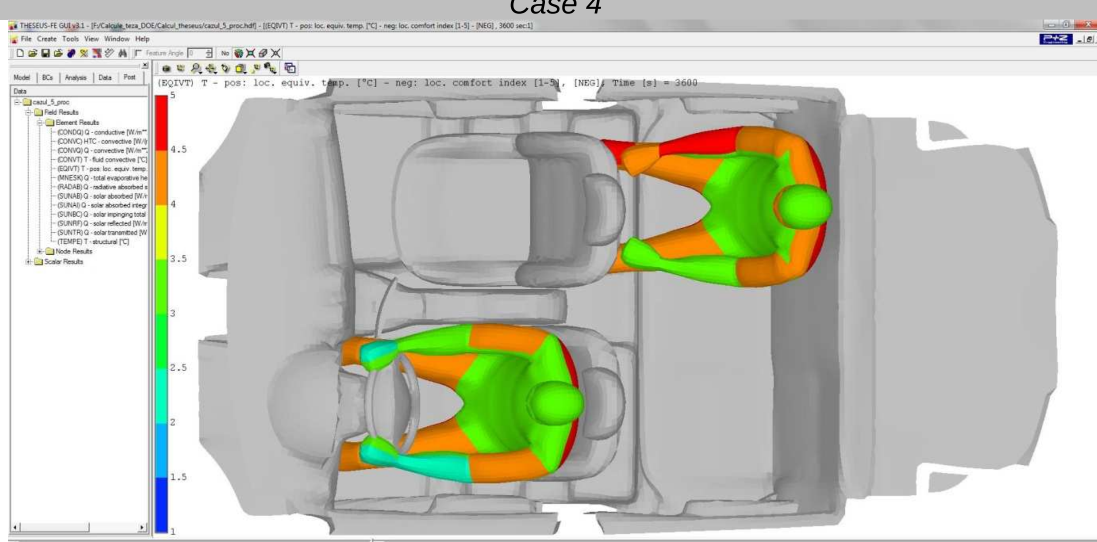
Case 2



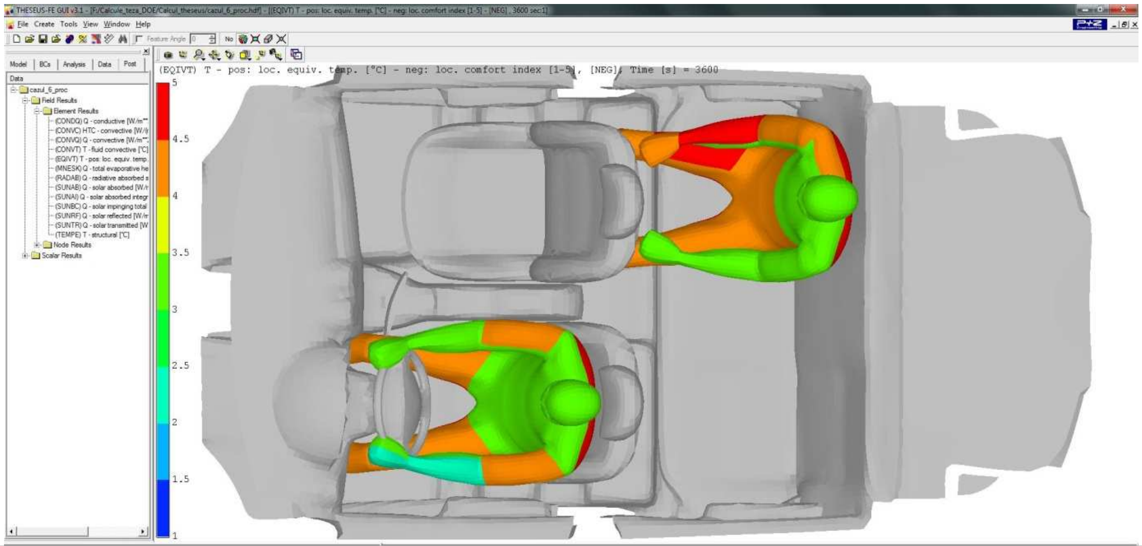
Case 3



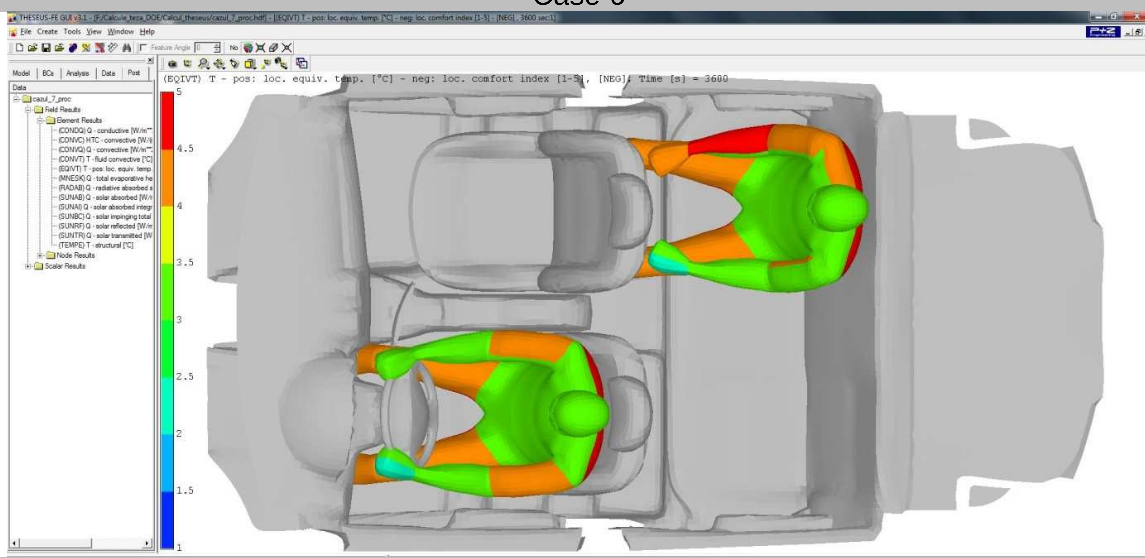
Case 4



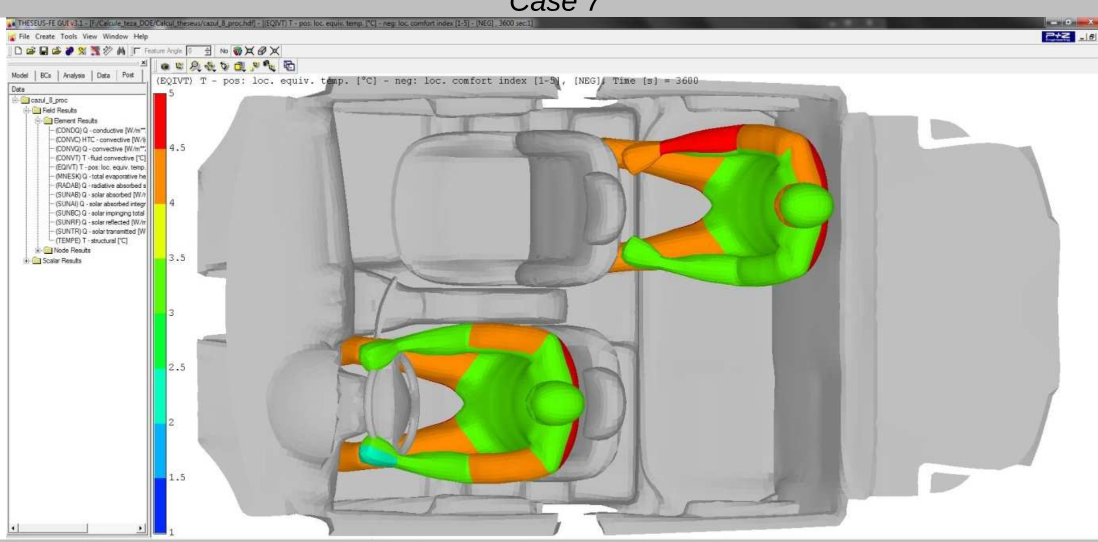
Case 5



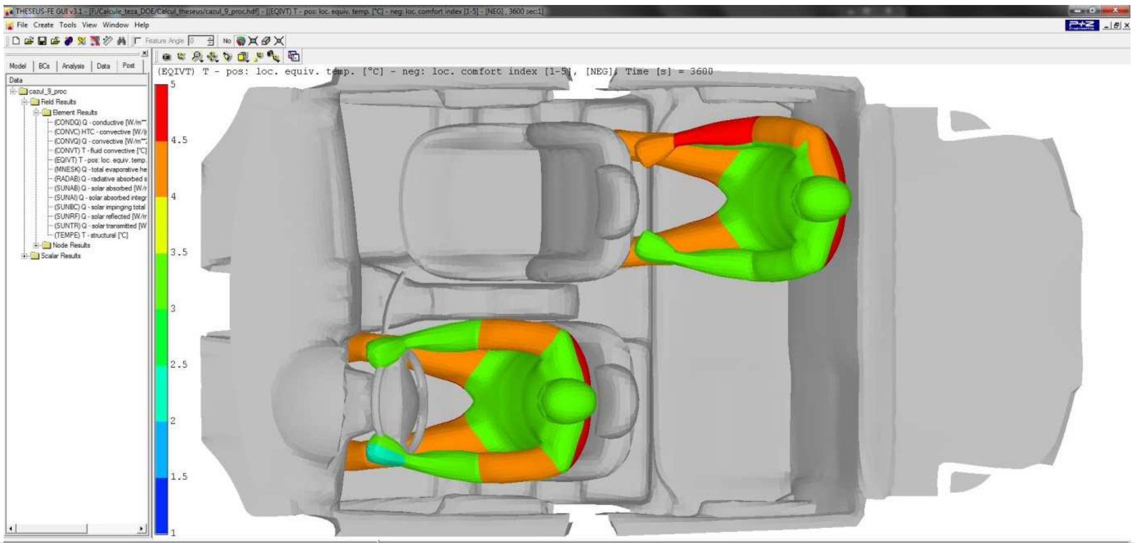
Case 6



Case 7



Case 8



Case 9

We can conclude that using numerical simulation allows us to understand the influences that the vents position in the passenger compartment and the air flow introduced by these, on thermal comfort in a vehicle cockpit.

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