UNIVERSITY OF PITESTI
FACULTY OF MECHANICS AND TECHNOLOGY
SCIENTIFIC BULLETIN
AUTOMOTIVE series, year XVI, no.20 (B)

NUMERICAL SIMULATION OF CAR COCKPIT HEATING DURING WINTER[1]

Cătălin NEACŞU[1], Mariana IVĂNESCU[2], Ion TABACU[3]

[1] SC Automobile Dacia SA, [2] University of Piteşti,
e-mail: catalin.neacsu@renault.com, mariana.ivanescu@upit.ro, ion.tabacu@upit.ro

Abstract:

Thermal comfort inside the car involves reaching a neutral state, both in summer and winter. In the literature we can find a lot of papers that describes the processes that take place inside the cockpit, but only a few of them covers the subject of heating inside the car during cold time.

In the present paper we will want to simulate the conditions that we will meet in a cold winter inside the car cockpit. The software that we will use for this numerical simulation will be Theseus FE, because it is a state of the art program that is easy to use and also have integrated various models of manikins, manikins that will help us to evaluate the thermal comfort inside the cockpit.

The numerical simulation will be done in two stages, one in which the vehicle will be considered stationary for a long period of time without any manikins sitting inside, this being considered the "cooling" period and the aim will be to evaluate the temperatures on the internal components of the vehicle. In the second stage, we will insert the thermal manikin inside the cockpit on the driver position and simultaneously we will start the heating of the cockpit. The main aim of the second stage will be to evaluate the thermal comfort indexes of the manikin, and the secondary aim will be to evaluate the temperatures reached on the internal components of the cockpit.

Keywords: numerical simulation; thermal comfort; winter weather; manikin, Theseus-FE

NOMENCLATURE

DTS	-	Dynamic Thermal Sensation
TS	-	Thermal Sensation
PMV	-	Predicted Mean Vote
PPD	-	Predicted Percentage of Dissatisfied
ISO 7730	-	A standard that presents methods for predicting the general thermal sensation and degree of discomfort of people exposed to moderate thermal environments.

INTRODUCTION

One of the areas that have been taken into account by car manufacturers in recent years is that of thermal comfort inside the car cockpit. By using new materials, the manufacturers need to meet multiple requirements regarding to recyclability and also to their properties of heat accumulation.
An important place in the product development is occupied by numerical simulation, and one of the software used to evaluate the thermal comfort inside a car cockpit is Thesus-Fe.
According to ISO 7730, the thermal comfort is "that condition of mind which expresses satisfaction with thermal environment"[4]. This definition is generally accepted by most people because thermal comfort is a measure that varies for each individual.
Evaluation of thermal comfort depends on a number of physical parameters such as air velocity, temperature, humidity.

[1] This article was produced under the project "Supporting young Ph.D students with frequency by providing doctoral fellowships", co-financed from the EUROPEAN SOCIAL FUND through the Sectoral Operational Program Development of Human Resources

The integration in the stages of development of the numerical simulation allows us, based on a simplified model of the car to establish conditions regarding heating processes and also air flow distributions.
Therefore, the complete 3D simulation of car cockpit allows us to observe the thermal comfort changes in different situations, with various external and internal conditions.

NUMERICAL SIMULATION

For the numerical simulation we have used the interior geometry of a mid size car. The geometry was pre-processed with ANSA software and then imported in Theseus-Fe where we have established material properties, internal and external boundary conditions and also the period simulated. Then, the results obtained after calculation were post-processed using Theseus-Fe.
The simulation will be divided in two stages. In the first stage we will consider that the car is exposed in a cold environment for a period of time. The second stage begins immediately after the first and is characterized putting the manikin inside the car, and starting the heating unit.
The duration of the first stage will be 60 minutes, while the second stage will last only 30 minutes.

Model creation

As we mentioned earlier, for the numerical simulation we will use the geometry of a mid-sized car. Because our aim is to evaluate only the comportment of the cockpit and passenger, we will keep just the parts that compose the interior.
The pre-processing of the geometry was done using ANSA software, obtaining a number of about 48000 elements with an average size of 30mm and distributed in 41 groups. For the second stage of the simulation, we will integrate the Fiala-Fe manikin in the geometry of the car. The Fiala-Fe manikin alone has a number of 8365 elements divided in 48 groups, each group representing a body-part. In figures 1 and 2 are presented the finite element model of the car and the finite element model of the Fiala-Fe manikin.

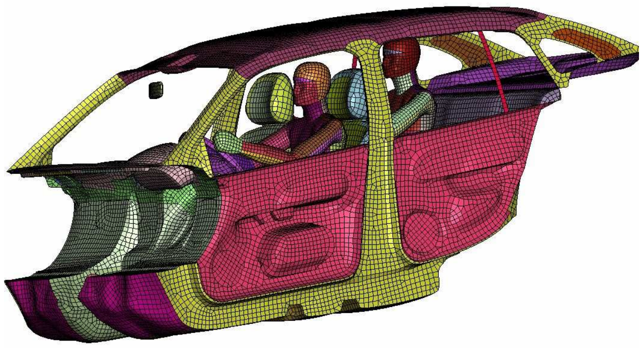

Figure 1. Section through the thermal finite element model of the vehicle with manikin inside

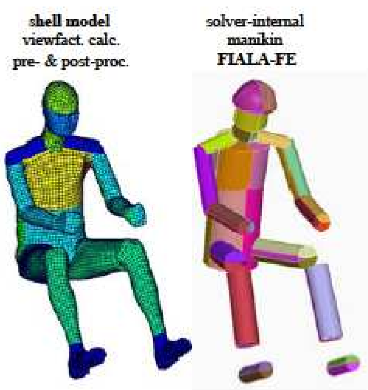

Figure 2. Fiala-Fe manikin

Boundary conditions

The boundary conditions applied to the model are divided into external boundary conditions and internal boundary conditions[3].
The external boundary conditions refer to parameters such: exterior temperature and humidity, sun position characterized by altitude and azimuth angle[8], direct and diffuse sun intensity and sky temperature.
Theseus FE contains a few scenarios regarding external boundaries, each one characterized by specific values. In our simulation will use the scenario called “Alpen Winter”[10], with the characteristics presented in the table 1. These external boundaries will be used in both stages of the numerical simulation. As an initial boundary condition, we will consider that the temperature at moment 0 on all the car interior components equals to 0°C.

Parameter	**Value**	**Parameter**	**Value**
Direct sun intensity	0[W/m^2]	*Environment temperature*	-20[°C]
Diffuse sun intensity	75[W/m^2]	*Environment humidity*	80[%]
Sun azimuth angle	180[°]	*Sky temperature*	-30[°C]
Sun altitude angle	22[°]	*Initial cockpit temperature*	0[°C]

Table 1. External boundaries used for the simulation

The internal boundary conditions are represented by the air temperature and flow rate provided by the heating system of the car. For the first stage of the simulation, the heating system will not work, so we will not have any internal boundary conditions. In the second stage, where we will consider also a manikin inside the car, we will start the heating system. The flow rate and temperature of the air are presented in table 2.

Time[min]	*60*	*65*	*70*	*75*	*80*	*85*	*90*
Flow rate[m^3/s]	0.078	0.078	0.078	0.078	0.078	0.078	0.078
Temperature[°C]	-20	15.1	27.5	34.2	38.5	39.6	40.2

Table 2. Internal boundary conditions

The materials used for the internal components of the car are standard materials, provided by Theseus-Fe. In [9], we have seen that a slight change in material properties may have a great impact on the overall temperature distribution. In case of [9] we have changed only the glass properties.

Manikin characteristic

As we stated earlier, for the thermal comfort evaluation we will use the manikin provided with the Theseus-Fe software, called Fiala-FE. The manikin provides all the thermo-physiological effects of the human body model. For the mathematical point of view, the human organism can be separated into two interacting systems of thermoregulation: the controlling active system and the controlled passive system. In figure 3, there are presented the layers that form the interior of the manikin, first a general view of each body part, then a presented section through a body part. Here we can see that the manikin contains a layer that represents the clothing of manikin. [2], [7]

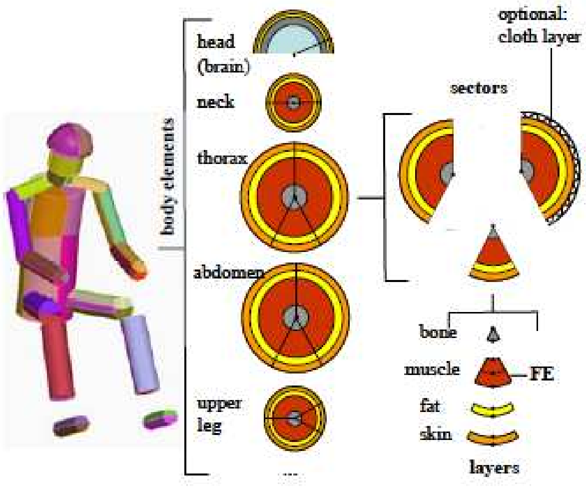

Figure 3. Discretization of the thermo-physiological manikin Fiala FE

In Theseus database [10] exists materials that simulates the clothing of manikin with various clothes. Because we will simulate winter cold weather, we must equip the manikin with clothes that characterize that season. Given that, we must define the insulation provided by clothes. For the given manikin we will want to compute the PMV, TS, DTS and ISO 7730 thermal comfort indexes [5],[6]. In table 3 are given the characteristics that must be introduced in Theseus for both manikins: driver and rear place passenger.

Parameter	**Value**
Clothing insulation for PMV	1.32
Activity level	1.2

Table 3. Manikins characteristics

RESULTS

Next we will present the results obtained following the numerical simulation. In table 4 are presented the temperature values obtained for the air inside the cockpit, during the first stage of the simulation, and in figure 5 the temperature values for the second stage of the simulation. In figure 4 the graphic including the values that characterize the temperature of air introduced.

Time[min]	0	10	20	30	40	50	60
Temperature[°C]	0	-3.5	-5.9	-7.9	-9.6	-10.9	-12.0

Table 4. Temperature values for the first 60 minutes

Time[min]	60	65	70	75	80	85	90
Temperature[°C]	-12.0	3.2	12.8	18.8	23.0	25.2	26.6

Table 5. Temperature values for the cockpit heating

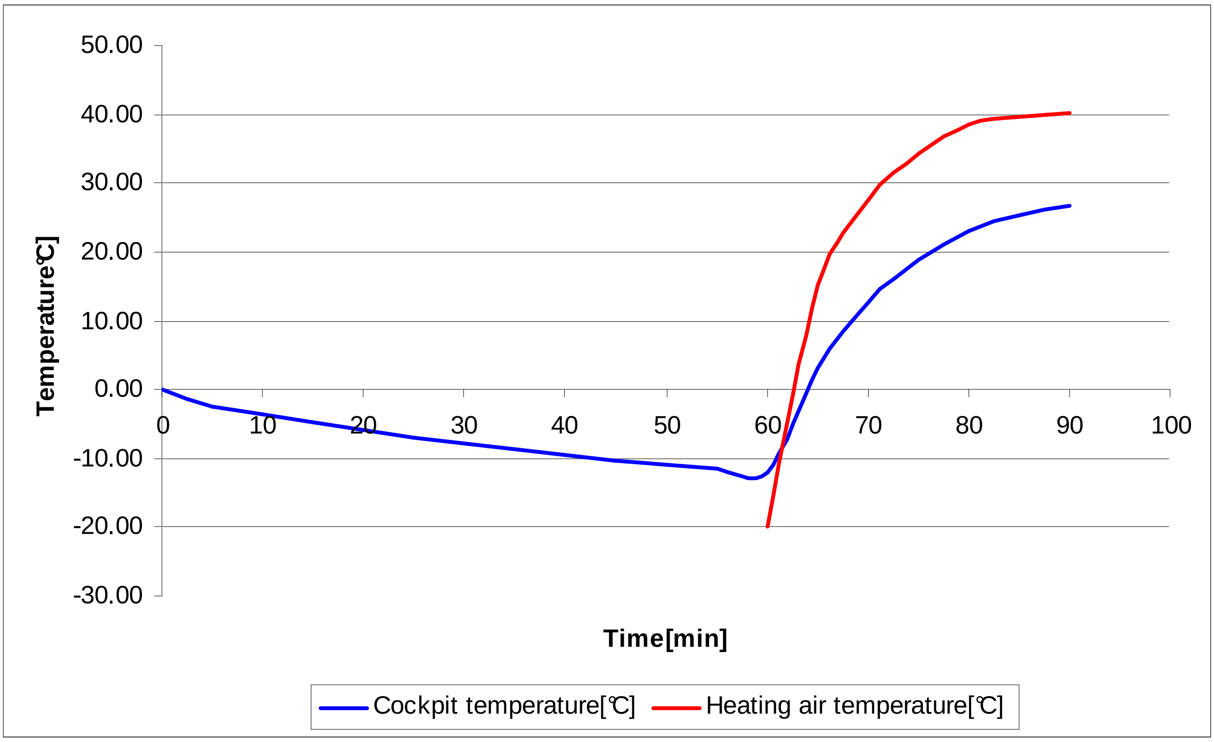

Figure 4. Cockpit temperature and introduces air temperature variations

The Theseus Fe software has integrated functions that help finding directly the comfort indices: DTS, TS, PMV and PPD which are presented in table 6 and figure 7 for the driver and in table 7 and figure 8 for the rear passenger.

Time[min]	60	65	70	75	80	85	90
DTS	0.00	-2.61	-2.37	-1.88	-1.47	-1.18	-0.98
TS	0.00	-1.19	-1.58	-1.69	-1.68	-1.62	-1.53
PMV	-3.00	-3.00	-1.87	-1.06	-0.45	-0.07	0.18
PPD[%]	100.00	99.60	70.81	28.78	9.24	5.11	5.70

Table 6. Thermal comfort indices for the driver

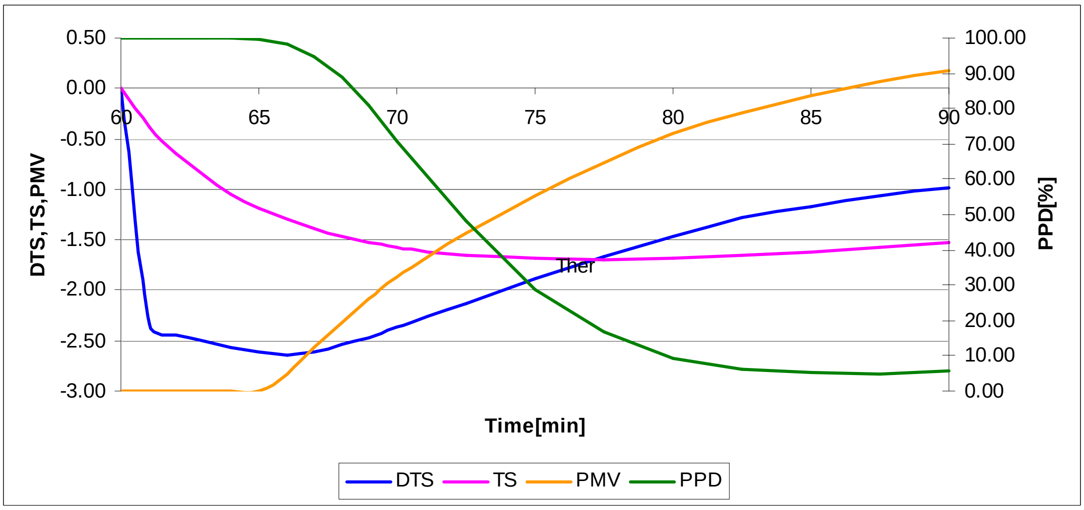

Figure 5. The variation of the comfort indices depending on time for driver

Time[min]	60	65	70	75	80	85	90
DTS	0.00	-2.60	-2.33	-1.80	-1.32	-1.07	-0.87
TS	0.00	-1.18	-1.55	-1.66	-1.63	-1.56	-1.47
PMV	-3.00	-3.00	-1.76	-0.95	-0.34	-0.02	0.27
PPD[%]	100.00	99.37	65.24	24.16	7.49	5.01	5.58

Table 7. Thermal comfort indices for the rear passenger

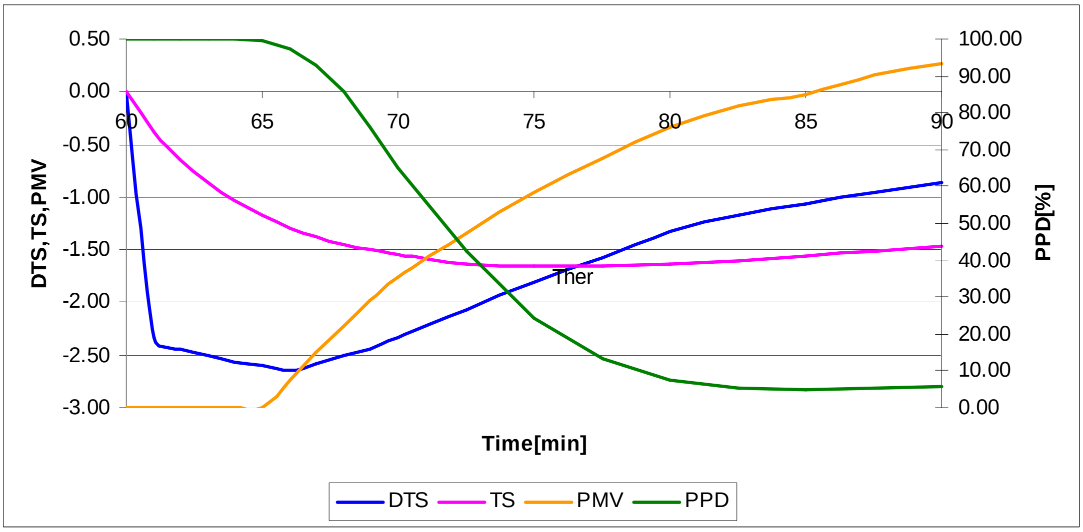

Figure 6. The variation of the comfort indices depending on time for the rear passenger

Looking at the comfort indexes, in tables 6 and 7 we can observe that after 20 minutes, the passenger and the diver will approach the thermal neutrality. The value for PMV is superior to -0.5 and the PPD is inferior to 10%. Also, analyzing the same tables and the figures 5 and 6 we can observe that in the same time, the rear passenger will have a better thermal comfort than the driver. Looking at the same tables and figures, we can observe that in the interval 25-30minutes, the passenger and the driver will reach thermal neutrality.

In figure 7 we can see the temperature distribution inside the compartment at different times of the simulation. In these pictures the manikins are not present, because we want to show also the contact zones between the manikins and the front and respectively the rear seat.

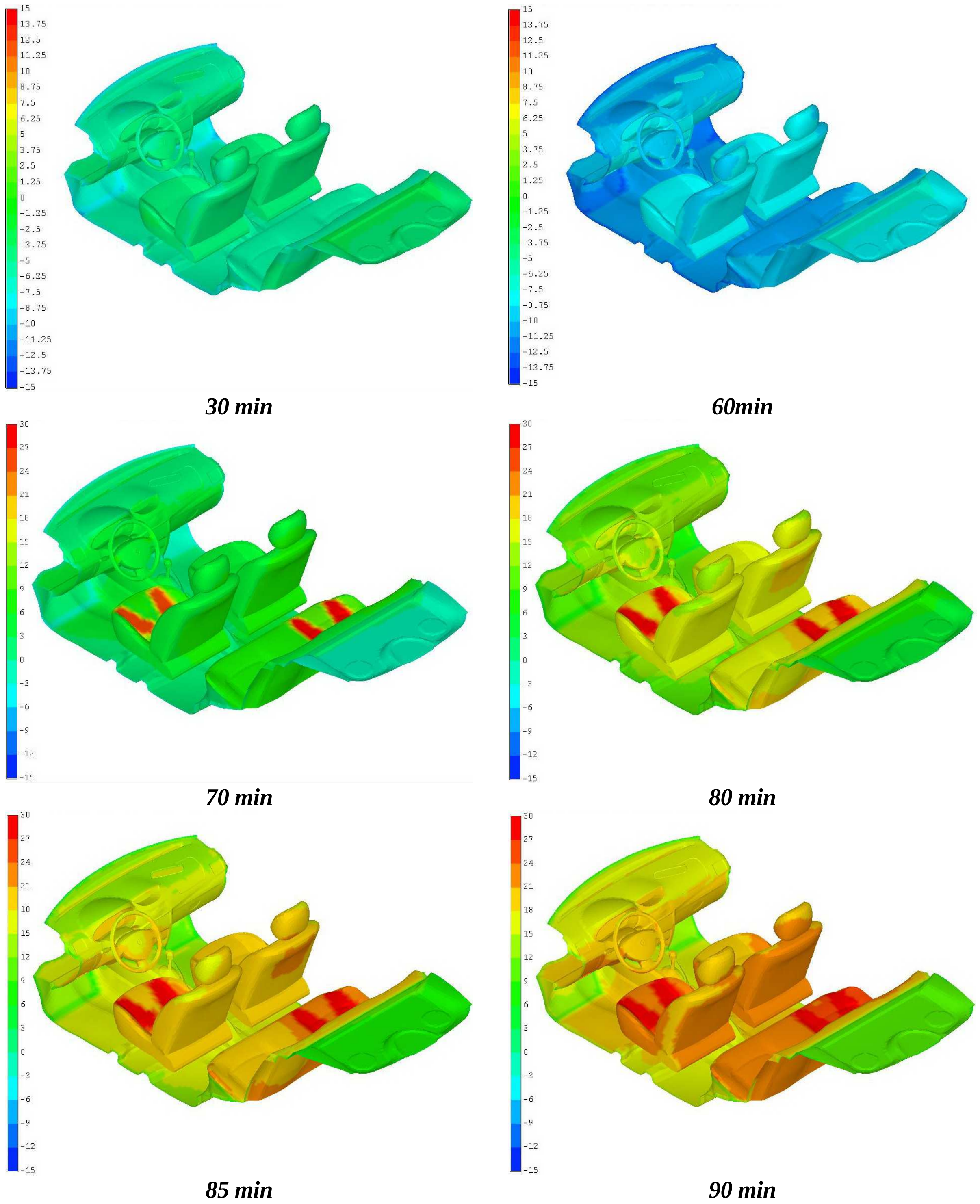

Figure 7. Temperature distribution inside the cockpit

In table 8 is presented the comfort scale according to ISO 7730 standard, and in figure 8 shows the distribution of the comfort index for each segment of manikin body after 80, 85 and 90 minutes, using the same comfort scale[1], [2].

Value	1	2	3	4	5
Sensation	Too cold (*uncomfortable*)	Cold (*comfortable*)	Neutral	Warm (*comfortable*)	Too warm (*uncomfortable*)

Table 8. The comfort indexes according to ISO 7730 standard

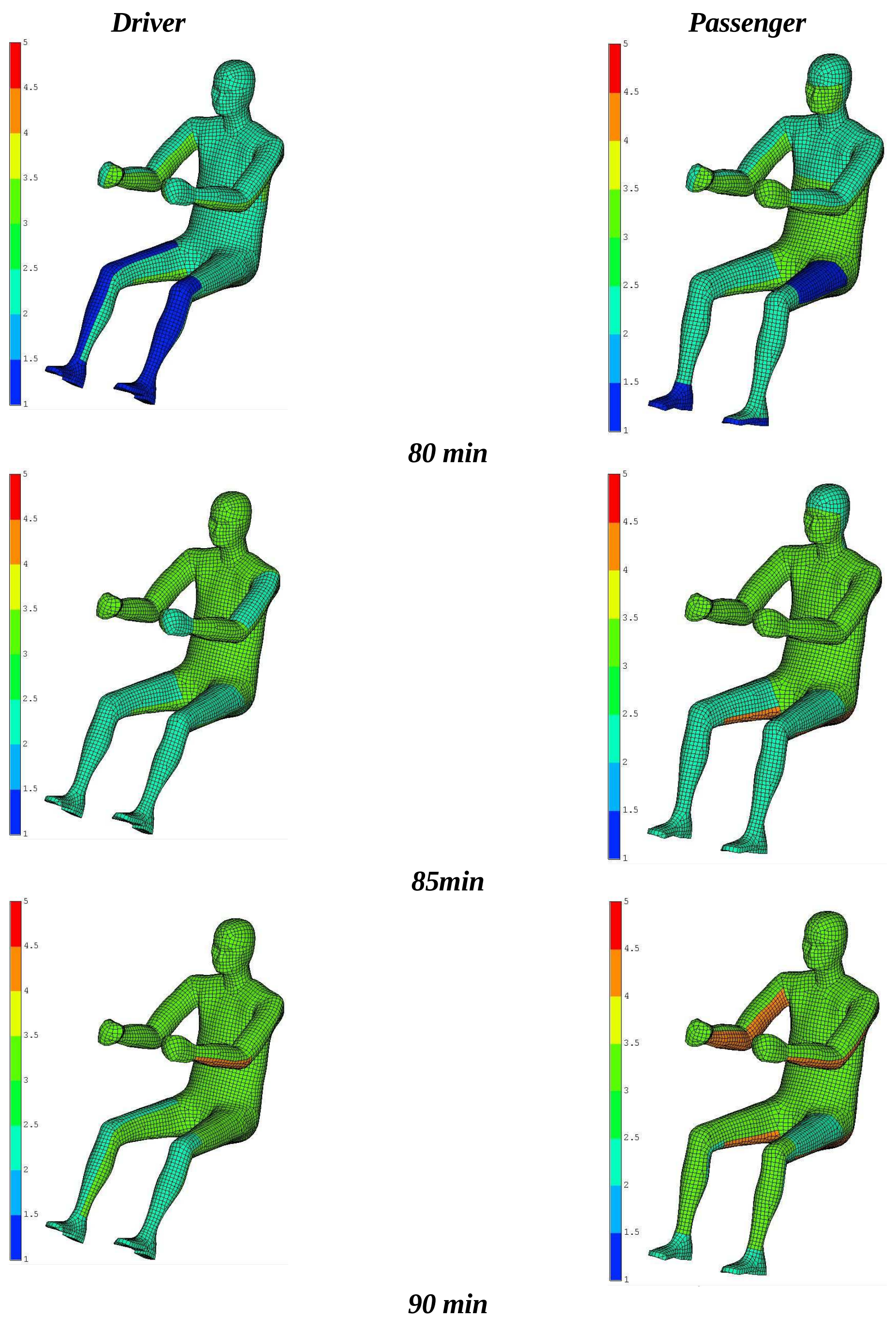

Figure 8. Comfort index on driver and passenger at different time steps according to ISO 7730

Analyzing the images in figure 8, we can observe that although the global thermal comfort is reached after 20 minutes, there are regions that will feel cold for the driver and the passenger after the same 20 minutes. The regions are the right tight, the calves and the feets for the driver and the left tight for the rear passenger. At the end of the simulation, the driver and the passenger will be characterized by a neutral comfort state, with some exception, given by the arms, which will feel warm and can give a local discomfort, both for the driver and the passenger.

CONCLUSIONS

The climate in the car cockpit is very inhomogeneous. The varying boundary conditions and the influence of air temperature and velocity from the vehicle heating system create a climate that may vary considerably in space and time.
Looking at the cartographies, we can observe the influence of the ground on the temperatures inside the car.
Although, the start temperature is 0°C, after 60 minutes of exposure in cold weather, the air temperature inside the cockpit descends to -12°C, and on some components of the interior will reach even -15°C. After the start of the heating system, the temperature inside the cockpit rise rapidly and after about 3 minutes it is greater than 0°C.
The target temperature for the comfort in winter is 22°C, and in our case, we will reach it just before 20 minutes after they are put inside the car. We can conclude that the heating system used in this car will satisfy the demands of customers regarding the time needed to reach the target temperature.
Looking at the comfort indexes, in tables 6 and 7 and figure 8 we can observe that the rear passenger will reach the thermal comfort faster than the driver. Also, this is reached in about 20 minutes after the passengers are put in the car.
Because the interior temperature will rise to 26.6°C after 90 minutes, the passengers will begin to feel warm, but still comfortable.
The use of Theseus-Fe helps us to evaluate the comfort indices in every moment and in any given situation.
The accuracy of the temperature distribution prediction inside the cockpit is crucial to the success of numerical simulation.

ACKNOWLEDGEMENT

The authors would like to thank to P+Z Engineering Gmbh, Germany for providing us the Theseus-Fe software (http://www.theseus-fe.com).

REFERENCES

[1] Baker, M., Jenkins, M., Wagner, S., Ellinger, M. – “Am optimized Thermal Design and Development Process for Passenger Compartments”, EASC, Munich, Germany, 2009;
[2] Fiala D. – “Dynamic Simulation of Human Heat Transfer and Thermal Comfort” – PhD Thesis, 1998, De Montfort University, Leicester;
[3] Hong Rok, S., Pasthor, H. – “A Real Time Numerical Analysis of Vehicle Cool-Down Performance”, VTMS 8, ISBN 1843343487, May 2007;
[4] Ivanescu, M., Tabacu, I. – “Comfortabilitate si Ergonomie”, Editura Universitatii din Pitesti, 2007, ISBN 978-973-690-2,330;
[5] Ivanescu, M., Tabacu. St., Tabacu, I., Vieru, I. – “The Calculation of the Comfort Indices, PMV and PPD, depending on different parameters”, SMAT 2008, Craiova, ISBN 978-606-510-253-8;
[6] Ivanescu, M., Neacsu, C., Tabacu, St., Tabacu, I. – “The Human Thermal Comfort Evaluation Inside the Passenger Compartment” – FISITA World Automotive Congress 2010, Budapest, Hungary, F2010-C-044;
[7] Nilsson, H. – “Thermal comfort evaluation with virtual manikin method”, International Journal of Building and Environment 42(2007), 4000-4005, 2007;
[8] Neacsu, C., Ivanescu, M., Tabacu, I. – “The Influence of the Solar Radiation on the Interior Temperature of the Car”, ESFA 2009, Bucharest, 2009;
[9] Neacsu, C., Ivanescu, M., Tabacu, I. – “ The influence of the Glass Material on the Car Passenger Thermal comfort”, University of Pitesti Scientific Bulletin XV, no 19, 2009;
[10] *** Theseus Fe Users Guide