THE INFLUENCE OF THE SOLAR RADIATION ON THE INTERIOR TEMPERATURE OF THE CAR[1]

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ABSTRACT

The evaluation and improvement of passengers comfort degree is a basic task of vehicle manufacturers. To achieve a high thermal comfort, most manufacturers provide a system for their cars to ensure ventilation, heating and cooling air in the cabin.

The purpose of this paper is to evaluate the temperature and humidity inside a moving car on the highway Pitesti - Bucharest. The software used for the numerical simulation is Theseus FE and the results obtained are compared with the values obtained for experimental tests.

Computer simulation was performed for a medium class car, moving at a speed of 120km/h on the highway Bucharest - Pitesti, at two time scales, while retaining the same sense of movement, i.e. from Pitesti to Bucharest. Values for exterior temperature and humidity, as well as for the sun position are dated July 24, 2009. Since Pitesti - Bucharest highway length is about 120km the numerical simulation time was considered 3600s.

Keywords: experimental data, numerical simulation, thermal comfort, moving sun

1. INTRODUCTION

We can consider that the environment is comfortable if there is no discomfort sensation. The first condition of comfort is to obtain a thermally neutral environment, for which a person does not feel any hot or cold.

The aim of the present study is to achieve a comparison between the results obtained experimentally and those obtained by numerical simulation.

Using a simplified model of the car can set different conclusions about the processes of heating/cooling and the quantity and distribution of air in the cabin.

One of the main reasons that led to accelerating the development time of a new product is the numerical simulation, which was used successfully in all areas of industry. Its advantages are represented by the speed, cost, and reliability.

Since three-dimensional simulation can be performed in different conditions, it helps us to obtain a good prediction of thermal comfort and better design of heating/cooling systems of the car.

2. EXPERIMENT SETUP AND RESULTS

The experiment was conducted on 24 July 2009 on the Bucharest - Pitesti highway and the aim was to evaluate the internal temperature at two

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different intervals, with and without the AC system on. The intervals choose for the simulations were 9:00-10:00 and 12:00-13:00.

Because we wanted to realize a comparison, the route was covered with two identical cars, one with the AC on and the other with the AC off.

In the experiment, the vehicle speed was about 120km/h, and since the length of the highway is about 120km, the time needed to complete the experiment was one hour and the direction of travel was from Pitesti to Bucharest.

The internal temperature was measured at passenger head level using a thermocouple type temperature transducer. Data acquisition was performed using WEB DAQ/100 system connected to a laptop computer. The thermocouple used was type K with temperature ranges between -100 and 300°C.

To study the temperature-time dependence, the data transfer from the acquisition system to computer was made every 60 seconds.

In both situations were the AC system has been used, its parameters were identical (temperature, flow, type).

The experimental values for the four cases considered are presented in Table 1, considering the Case 1 between the hours 9:00-10:00 and Case 2 between 12:00-13:00.

Table 1. Temperature values measured experimentally

Time[s]	Temperature Case 1 [°C]		Temperature Case 2 [°C]	
	AC ON	ACC OFF	ACC ON	ACC OFF
0	29.0	29.0	29.0	29.0
300	25.8	32.2	26.3	34.1
600	24.6	34.2	25.8	37.2
900	23.8	35.6	24.6	39.4
1200	22.8	36.8	23.7	40.8
1500	22.3	37.5	23.4	42.0
1800	22.2	38.3	23.2	42.9
2100	22.0	39.1	23.0	43.8
2400	21.8	39.9	22.9	44.2
2700	21.6	40.5	22.8	44.7
3000	21.6	41.3	22.7	45.0
3300	21.5	42.0	22.6	45.7
3600	21.4	42.6	22.6	46.0

The exterior temperature and humidity were measured using a Lufft Opus 10 thermo-hygrograph and were measured at the beginning and at the end of each simulations. The values are presented in Table 2.

Table 2. Measured values for temperature and humidity

Hour	Temperature[°C]	Relative humidity[%]
9:00(Pitesti)	30	31
10:00(Bucharest)	31	31
12:00(Pitesti)	32	28
13:00(Bucharest)	33	26

3. NUMERICAL SIMULATION

The software used for the simulation was Theseus-Fe 3.0, its benefits are represented by the short time needed to solve the problem, the good approximation of thermal comfort and heat transfer and the reliability of results.

3.1 Exterior boundary conditions

As exterior boundary conditions we will use data from tables 1 and 2, but we need also data about the sun position on the sky, sky temperature and the solar radiation intensity.

The sky temperature was estimated based on an algorithm using the following series of equations [1]:

$$T_{sky} = \varepsilon_s^{\frac{1}{4}} \cdot T_{ambient} \qquad (1)$$

where ε_s is the sky emissivity and $T_{ambient}$ is the ambient temperature measured in K.

$$\varepsilon_s = 0.787 + 0.764 \cdot \ln\left(\frac{T_{dew}}{273}\right) \cdot F_{cloud} \qquad (2)$$

where T_{dew} is the dewpoint temperature in K and F_{cloud} is the cloud cover factor.

$$F_{cloud} = 1.0 + 0.24 \cdot N - 0.035 \cdot N^2 + 0.00028 \cdot N^3 \qquad (3)$$

where N is the "tenths cloud cover", taking values from 0.0 to 1.0

The solar radiation intensity values are taken from [2] and they represent the characteristic values for the month of July. They are presented in Table 3 together with the values for sky temperature, ambient relative humidity and ambient temperature.

Table 3. Exterior boundary condition

Hour	Sun load [W/m^2]	Ambient temperature [°C]	Ambient relative humidity [%]	T_{sky} [°C]
9:00(Pitesti)	490	30	31	6,9
10:00(Bucharest)	592	31	31	7,9
12:00(Pitesti)	681	32	28	6,2
13:00(Bucharest)	657	33	26	5,2

Because we will simulate two different time intervals, we will need to find the sun position on the sky for each period, this being a date, geographical position and hour function.

We can find the values in tables, and considering the locations Pitesti and Bucharest with the geographical coordinates presented in Table 4 we will present in Table 5 the values that represent the sun position on the sky, the azimuth angle being reported to the geographical South[3].

Table 4. Geographical coordinates

City	Latitude N	Longitude E
Pitesti	44°51'	24°53'
Bucharest	44°26'	26°05'

Table 5. Sun position in geographical coordinates

Time	Pitesti		Bucharest	
	φ_{alt}	φ_{azi}	φ_{alt}	φ_{azi}
9:00	40,7°	283°		
10:00			51,6°	298,2°
12:00	64,3°	345,2°		
13:00			64,1°	20,7°

In Theseus FE, the azimuth angle represents the angle between the sun direction and the Ox axis of vehicle, as we can see in Figure 1.

In the considered experiment, the angle between the Pitesti - Bucharest highway and the axis that represents the geographical South and can be represented as a straight line with a inclination about 298°, this being represented in Figure 2.

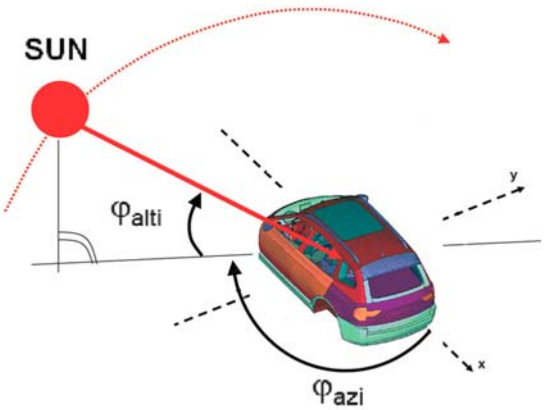


Figure 1. Sun position in Theseus FE

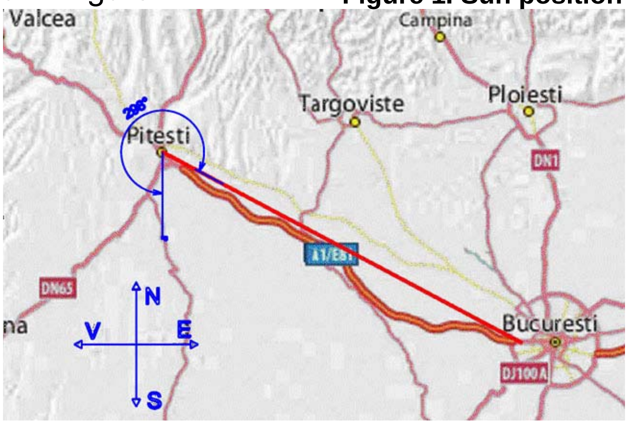


Figure 2.The geographical position of Pitesti-Bucharest highway

The equation used to calculate the azimuth angle needed for Theseus FE software is:

$$\varphi_{aziTH} = \pi - (\alpha - \varphi_{aziS}) \qquad (4)$$

where: φ_{aziTH} is the azimuth angle used in Theseus in degrees, α is the angle between the geographical south and the highway and φ_{aziS} the sun azimuth angle according to South axis.

Using the formula (4), an approximate angle of 298° and the values in Table 5, we will obtain the values needed in Theseus FE for the azimuth angle. Those are presented in Table 6.

Table 6. Sun position in Theseus FE

Time	Pitesti		Bucharest	
	φ_{alt}	φ_{azi}	φ_{alt}	φ_{azi}
9:00	40,7°	165		
10:00			51,6°	180,2°
12:00	64,3°	227°		
13:00			64,1°	262,7°

3.2 Model creation

For the numerical simulation we used the CAD model of the vehicle used in the tests, but, because we wanted to evaluate only the temperature of the cabin, we kept just the elements that compose the interior of the car.

Meshing of the model was made by Beta CAE ANSA software, obtaining a number of about 48000 elements with an average size of 20mm and distributed to 40 groups, each group being characterized by its material properties. A section in the thermal finite-element model is presented in Figure 3.

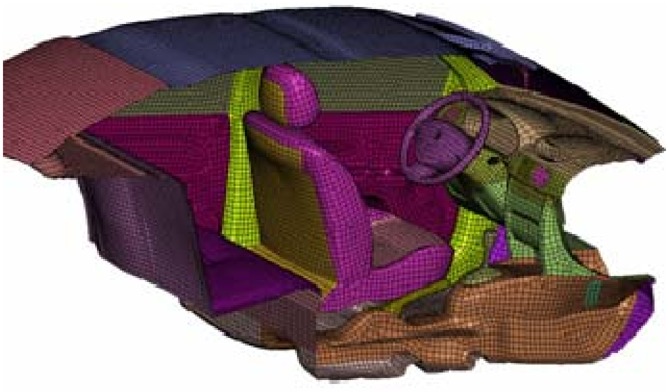


Figure 3. Section in the thermal finite-element model of the vehicle

3.3 Simulation set-up

The thermal model of the car was divided in three airzones, one that represent the interior of the car and the other two that represent the dashboard and the trunk. Their initial properties are presented in Table 7.

Table 7 Airzones initial conditions

Airzone	Volume[m^3]	Relative humidity[%]	Temperature[°C]
Interior	2,75	40	29
Dashboard	0.51	40	29
Trunk	0.20	40	29

The characteristics of the air conditioning system are presented in the following Table 8

Table 8. AC system characteristics

Time [s]	Air Temperature[°C]	Air Flow [m^3/s]
0	22,0	0,083
300	20,0	0,083
600	19,0	0,083
900	16,0	0,083
1200	14,0	0,083
1500	12,5	0,083
3600	12,5	0,083

The speed of the car is considered constant on the entire simulation and is 120km/h which converts to 33.33m/s.

4. RESULTS

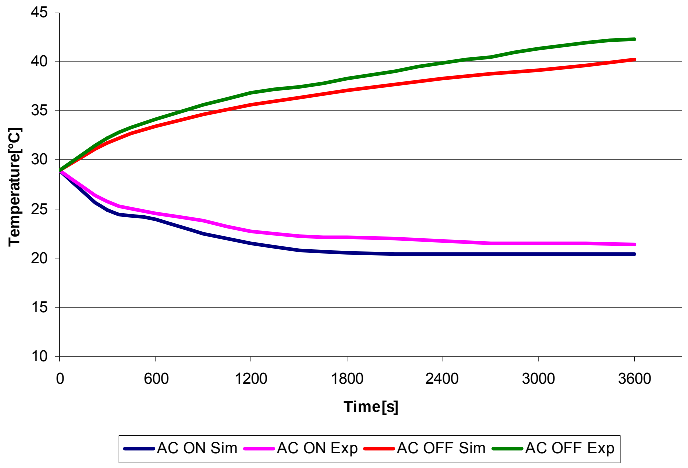
The results obtained in the numerical simulation are presented in Table 9, together with the results obtained experimentally.

In Graph 1 and Graph 2 are represented the temperature-time dependences in Case 1 and Case 2 respectively.

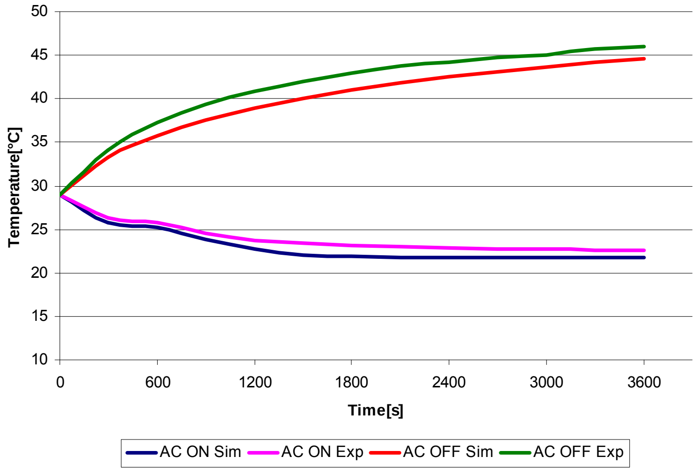
In Table 10 are presented average and maximum values for temperature on different components of the cabin.

Table 9. Comparison between experimental and numerical simulation results

Time	Case 1 - T[°C]				Case 2 - T[°C]			
	AC ON		AC OFF		AC ON		AC OFF	
	Sim	Exp	Sim	Exp	Sim	Exp	Sim	Exp
0	29	29	29	29	29	29	29	29
300	25	25.8	31.8	32.2	25.8	26.3	33.3	34.1
600	24.2	24.6	33.5	34.2	25.2	25.8	35.7	37.2
900	22.8	23.8	34.7	35.6	23.9	24.6	37.5	39.4
1200	21.6	22.8	35.6	36.8	22.8	23.7	38.9	40.8
1500	20.8	22.3	36.4	37.5	22.1	23.4	40	42
1800	20.6	22.2	37.1	38.3	21.9	23.2	41	42.9
2100	20.5	22	37.7	39.1	21.8	23	41.8	43.8
2400	20.4	21.8	38.3	39.9	21.8	22.9	42.5	44.2
2700	20.4	21.6	38.8	40.5	21.8	22.8	43.1	44.7
3000	20.4	21.6	39.2	41.3	21.8	22.7	43.7	45
3300	20.4	21.5	39.7	42	21.8	22.6	44.2	45.7
3600	20.4	21.4	40.2	42.6	21.8	22.6	44.6	46



Graph 1. Temperature-time dependence in Case 1

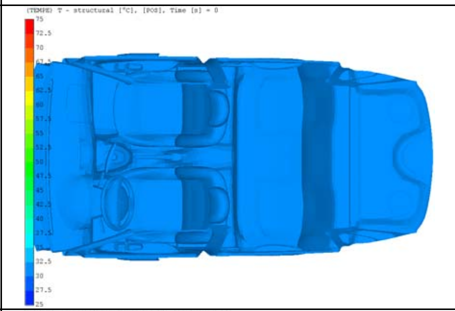
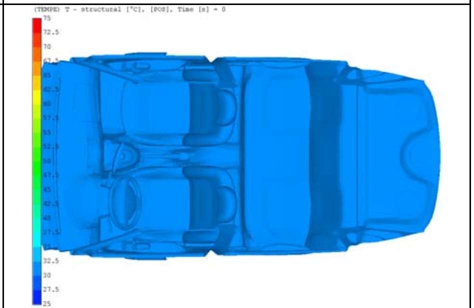
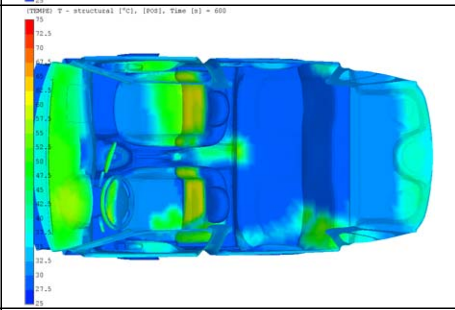
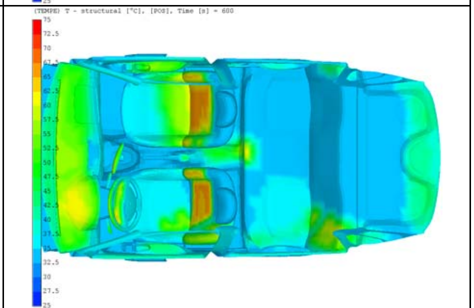
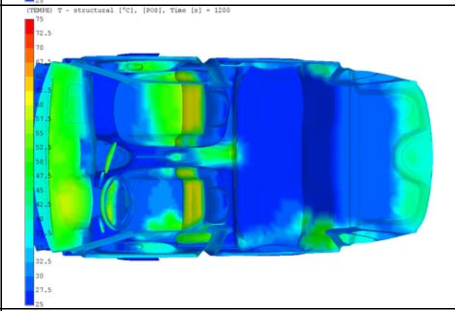
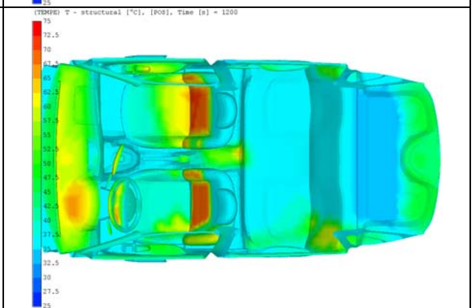
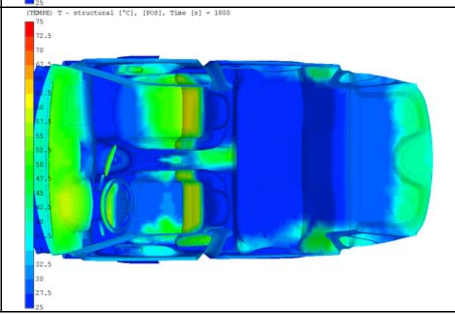
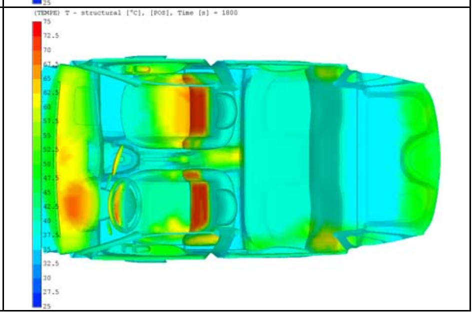


Graph 2. Temperature-time dependence in Case 2

Table 10. Maximum and average temperature on different cabin components after 3600s

	Case 1		Case 2	
	AC OFF	AC ON	AC OFF	AC ON
	$T_{max}/T_{average}$[°C]	$T_{max}/ T_{average}$[°C]	$T_{max}/ T_{average}$[°C]	$T_{max}/ T_{average}$ [°C]
Dashboard	70,1/53,6	58,3/40,4	73,5/61,1	59,7/46,0
Left seat	71,4/49,2	57,0/34,2	68,9/43,3	52,0/25,8
Right seat	72,9/54,6	58,2/39,2	74,7/57,5	58,1/40,6
St. wheel	67,9/43,5	54,2/28,5	70,5/49,3	55,1/32,0
Rear seat	60,8/41,9	45,8/24,4	75,8/50,5	58,2/25,0

In Figures 4 and 5 we can observe the temperature distribution with a time step of 600s on different components of the cabin.

Time	AC ON	AC OFF
0		
600		
1200		
1800		

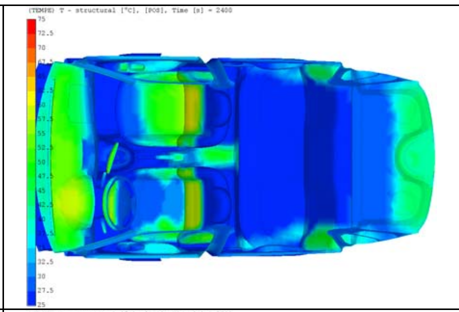
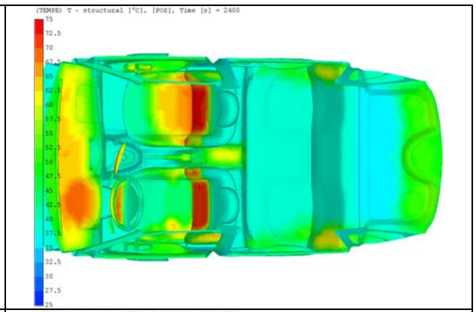
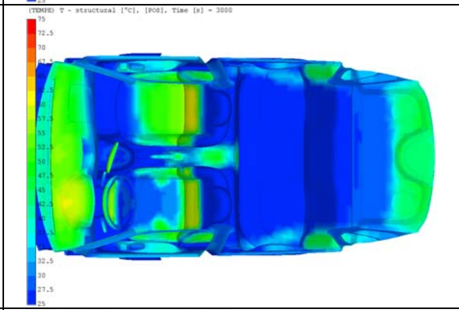
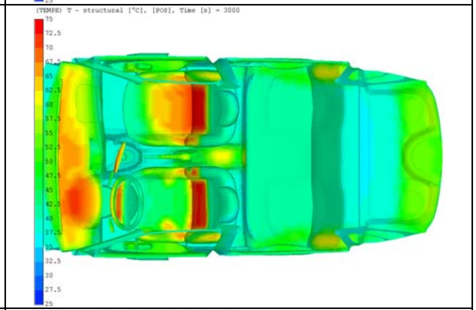
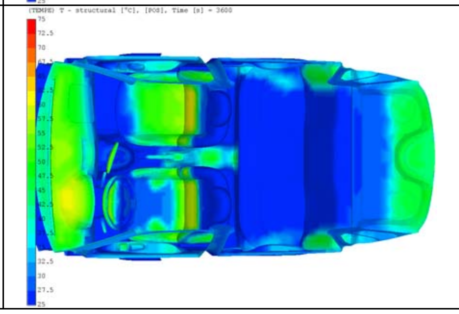
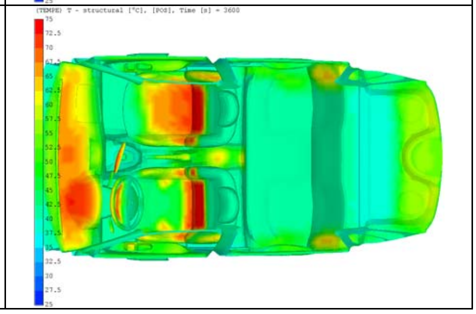
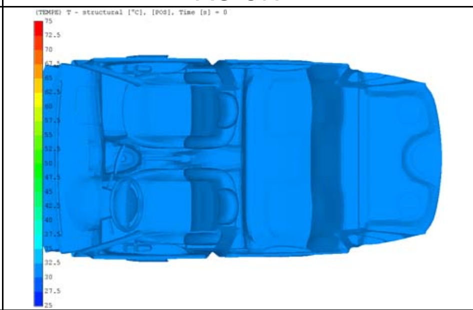
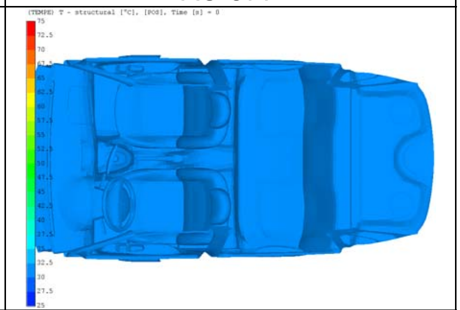
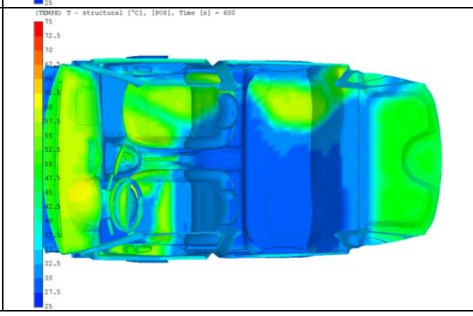
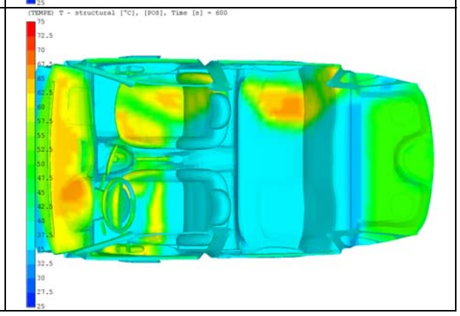
2400		
3000		
3600		

Figure 4. Temperature distribution on Case 1

Time	AC ON	AC OFF
0		
600		

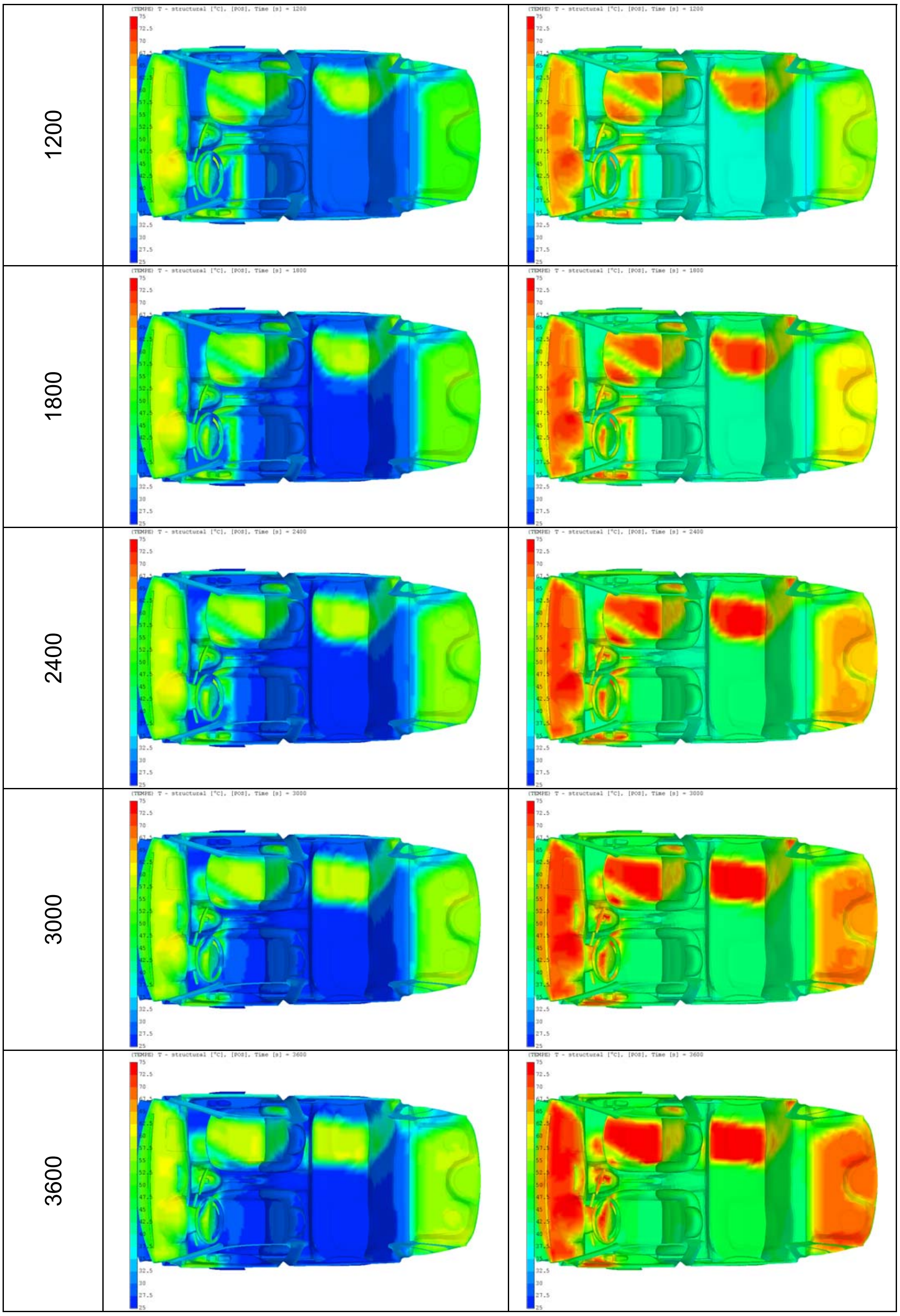


Figure 4. Temperature distribution on Case 2

5. CONCLUSION

As can be seen from the results presented above, values obtained from numerical simulation are close to those obtained experimentally. In this paper the authors have showed that is a correlation between the experimental data and the numerical simulation.

Following the results obtained in the four numerical simulations, we can observe a decrease of almost 50% in the interior temperature in the cases were we use air conditioning system over the cases we don't. Thus show us the big influence of the air conditioning system on obtaining a good thermal comfort.

Analyzing the cartographies we can observe also the influence of the sun position on the temperature of cabin components. In the first case, were the sun is in front of the car, the temperature on the front seats will be bigger compared to the temperature of the rear seats. In the second case, where the sun is on the front-right of the car the interior temperature of the right side is bigger than the interior temperature of the left side.

We can conclude that the numerical simulation is well done, because the values obtained experimentally for temperature are close to those obtained from numerical simulation for the interior of car.

6. REFERENCES

[1] http://ciks.cbt.nist.gov/bentz/nistir6551/node5.html

[2] Ivanescu Mariana, Tabacu Ion – "*Confortabilitate si ergonomie*", Editura Universitatii din Pitesti, 2007

[3] http://aa.usno.navy.mil/data/docs/AltAz.php

[4] Steven Daly – "*Automotive Air Conditioning and Climate Control Systems*", Elsevier, 2006

[5] P. Baker, M. Jenkins, S.Wagner, M. Ellinger – "*An Optimised Thermal Design and Development Process for Passenger Compartments*", EASC, Munich, Germany, 2009

[6] S. Paulke, M. Ellinger – "*Air Conditioning Cabin Simulation with Local Comfort Ratings of Passengers*", 2nd European Workshop on Mobile Air Conditioning and Auxiliary Systems, Torino, Italy, 2007

[7] S. Hong Rok, H. Pasthor – "A real time numerical analysis of vehicle cool-down performance", VTMS 8, ISBN 1843343487 , May 2007

[8] Theseus Fe – Theory Manual

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