THERMAL COMFORT ASSESSMENT USING HUMAN SUBJECTS

PhD Student Danca P., Lecturer PhD Vartires A.

CAMBI Research Centre, Technical University of Civil Engineering Bucharest, Faculty of Building Services
66, Pache Protopopescu Blvd, sector 2, 021414, Bucharest, Romania
danca.paul09@gmail.com,vartires2@gmail.com

Abstract: *The objective of the present study is to experimentally investigate the thermal comfort inside a car cabin. During the experimental campaign the occupants filled out questionnaires on the thermal sensation vote. The questionnaire contained questions about the local and global state of comfort and were performed according to ISO 14505-3 / 2006 and ISO 10551 / 2001. Each experimental session lasted 30 minutes and each occupant completed four questionnaires as follows: a questionnaire at the entrance in the car cabin, and afterwards one questionnaire every 10 minutes.*

Keywords: THERMAL COMFORT, AUTOMOTIVE, HUMAN SUBJECTS (PASSENGERS), QUESTIONNAIRES, THERMAL ENVIRONMENT

1. Introduction

Thermal comfort in vehicles has gained more importance in recent years, one of the main reasons being that time spent by people inside car's cabins has increased considerably. Optimization of fuel consumption is one of the major issues in the current geopolitical context. European directives adopted emission reduction targets for greenhouse gas emissions in 2020 at a rate of 20% compared to 1990 emissions [1], thus contributing to the promotion of clean and energy efficient vehicles.

The present work is dedicated to the study of cold thermal environments in car through a subjective assessment based on an individual questionnaire which aims to describe thermal sensation felt by occupants. Nowadays vehicles represent a necessity. Unfortunately, thermal comfort in cabin has not been developed simultaneously with this necessity [2].

2. Method

The objective of the present study is to experimentally investigate the thermal comfort inside a car cabin. The evaluation was conducted in the cold season, in Bucharest in a Renault Duster SUV (Sport Utility Vehicle). Several measurements were conducted being used a large number of human subjects

The main methods for assessing thermal comfort are the following:

- Subjective methods - utilizes subjective scales to determine the sensation felt by the human body. In this case the correctness of the results depends heavily on knowledge and understanding sensations scale used.
- Objective methods – are those models which quantifies physical or physical state using measurements instruments.

The thermal sensation can be predicted but existing thermal comfort standards, e.g. ISO 7730/2005 [3] are based on experiences where people spend longer time. The standard ISO 10551/2001 [4] covers the construction and use of thermal sensation scales and proposes a set of specifications on direct experts assessment of thermal comfort/discomfort expressed by persons subjected to various degrees of thermal stress. This approach has been done in order to supplement the objective measurements with the aim of receiving reliable and comparative data on the subjective aspects of thermal comfort/discomfort. Thermal scales as proposed in the standard have used and questioned in following order:

- Perceptual (How do you feel now? e.g. hot);
- Affective (How do you find it? e.g. comfortable);
- Preference (How would you prefer to be? e.g. cooler);
- Acceptance (acceptable/unacceptable);
- Tolerance (Is the environment tolerable?)

The thermal sensation scale is a 7-degree two-pole scale, comprising a central neutral point and two times 3 degrees of increasing intensity. The central point of indifference corresponds to the absence of hot and cold sensation. The scale corresponds to ISO 14505-3/2006 [5] scale used frequently and the results obtained can be compared to the other studies

The scales of comfortable and stickiness are asymmetrical 4-degree scale, the effect lacking from the base, these two being negative. These scales balance each other, for example, you cannot feel comfortable if you're sticky (sweaty).

Preference scales is used when the occupants express how they would prefer to be the indoor environment. Again the scale will validate the answer of thermal sensation scales previously used.

The ISO 14505-3 gives guidelines and specifies a standard test method for the assessment, using human subjects, of thermal comfort in vehicles. The questionnaire used in our study made corresponding to indicates from ISO 14505-3 and it is in Fig. 1.

Evaluation of thermal environments in vehicles – subjective questionnaire

Session: ……………………
Date: ……………………
Time: ……………………
Age: ……………………
Sex: Male / Female
The place occupied in the car:

The driver seat	
Place the right driver	
Place behind the driver	
Place the right rear of the driver	

Please rate on these scales how you fell now:

1. Thermal sensation scale

		1	2	3	4	5	6	7	8	9	10	11
	Whole body	Head	Trunk		Arms	Upper legs		Lower legs		Feet	Ankles	Neck
			Front	Rear		Front	Rear	Front	Rear			
+3 Hot												
+2 Warm												
+1 Slightly warm												
0 Neutral												
-1 Slightly cool												
-2 Cool												
-3 Cold												

2. Thermal discomfort scale

		1	2	3	4	5	6	7	8	9	10	11
	Whole body	Head	Trunk		Arms	Upper legs		Lower legs		Feet	Ankles	Neck
			Front	Rear		Front	Rear	Front	Rear			
3 Very uncomfortable												
2 Uncomfortable												
1 Slightly uncomfortable												
0 Comfortable												

Fig. 1*:Subjective questionnaire for evaluation of thermal environments in vehicles*

3. Stickiness scale

3 Very sticky	
2 Sticky	
1 Slightly sticky	
0 Not sticky	

4. Please rate on the scale how you would like to be now in vehicle inside:

Much warmer	Warmer	Slightly warmer	No change	Slightly cooler	Cooler	Much cooler
+3	+2	+1	0	-1	-2	-3

5. Please indicate how acceptable you find this thermal environment now:

☐ Acceptable ☐ Unacceptable

6. Please indicate how satisfied you are with this thermal environment now:

☐ Satisfied ☐ Dissatisfied

7. Please indicate other aspects that should be specified:

....

Fig. 1:*Subjective questionnaire for evaluation of thermal environments in vehicles (continuation)*

All measuring campaigns have been made with air flow discharged from the dashboard vents and the footwells, and with ventilation speed on 1st position, as shown in the following figure (Fig. 2).

Fig. 2*: Control panel of Duster vehicle*

Fig. 3*: Photos of Renault Duster prototype*

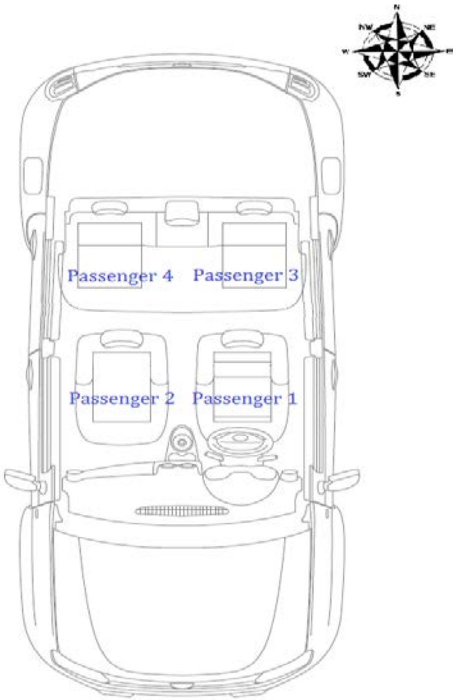


Fig. 4*: Schematic location of passengers in the cabin*

Some pictures of the prototype car can be shown in Fig. 3,4.

Survey questionnaires were given to the occupants and a total number of 96 questionnaires were completed and the time for filling the questionnaire was about 2-3 minutes. The general information requested by questionnaire was: date and time of filling, information about the person who had completed the questionnaire (age and sex). For the assessment of the thermal sensation the subjects had to choose an option on the 7-points rating scale and they also had to choose the thermal preference at the time of filling out the questionnaire. They had to answer about the acceptability of the thermal environment and about local thermal discomfort. Based on the questionnaires we could estimate the Thermal Sensation Vote (TSV). The persons interviewed have been informed briefly about reasons for the questionnaire.

As a particularity, uncomfortable and thermal sensation scales were made also for 11 parts of human body: head, front torso, back torso, arms, front and back thighs, front lower legs, back lower legs, foot, ankles and neck.

Surveyed people have been given 4 questionnaires, the first being completed at the entry of the car (minute 0), the other 3 being filled out every 10 minutes. Each session time took 30 minutes.

3. Results and discussions

Regarding the subjects surveyed, 67% are males and 33% are females, with ages between 20 and 40 years.

Although outside temperature was slightly over 0°C and air temperature control button, from heating and ventilation console, was on a neutral position, the passengers thermal sensation vote for the whole body was +3 (hot) in a proportion of 20% (Fig. 5, 7).

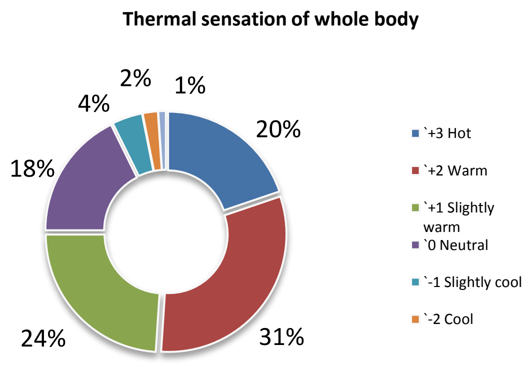


Fig. 5: *Thermal sensation of whole body*

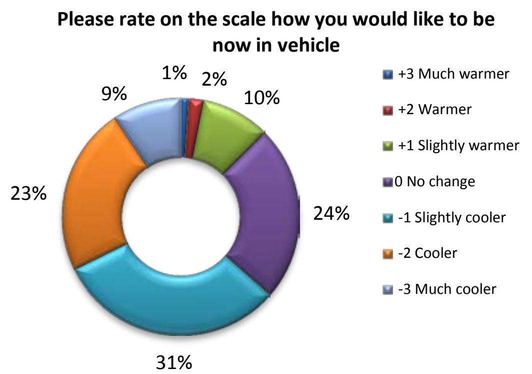


Fig. 6: *Preference votes of the passengers*

The percentage of persons who felt comfortable was only 29%, while 17% felt uncomfortable.

Uncomfortable sensation was felt most intensely at the head, 24% of votes being for very uncomfortable (Fig. 6). On the other hand, ankles sensation was comfortable for 51% of the occupants.

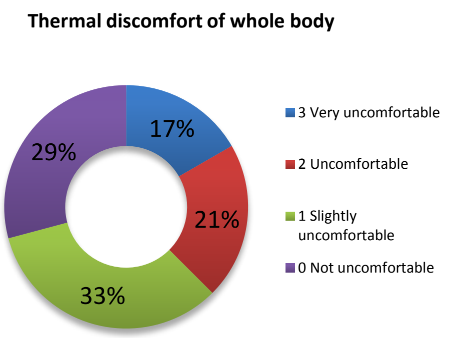
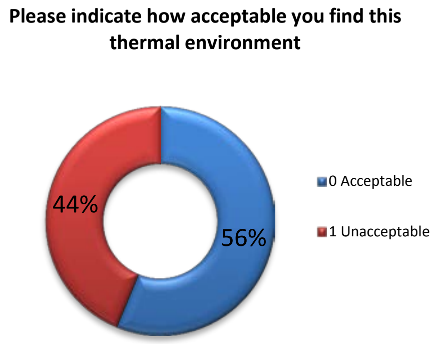
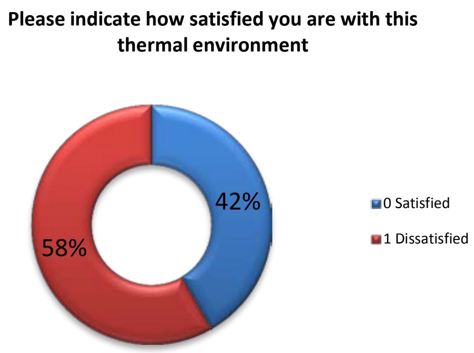


Fig. 7: *Thermal discomfort scale*



a)

Over 50% of the interviewed persons votes, thermal environment is acceptable, but dissatisfied, desiring a cooler environment (Fig. 8a, b).



b)

Fig. 8: *a) acceptability scale; b) satisfied scale*

For this study we calculated an mean of clothing insulation considering clothing was composed of: T-shirt – 0.09 clo; Normal trousers: 0.25 clo; Sweater: 0.28 clo; Coat: 0.6 clo; Socks: 0.02 clo and boots: 0.1 clo. Total thermal insulation – 1.34 clo.

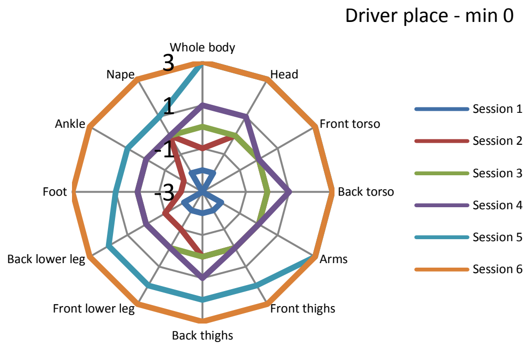
Mean TSV computed for whole body are in Table 1.

Table 1: *Mean TSV values*

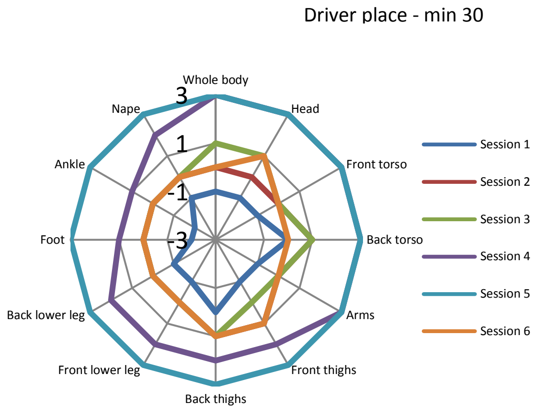
Nr. Pass/ Nr. Minute	minute 0	minute 10	minute 20	minute 30
Passenger 1	0,67	0,67	0,67	1,00
Passenger 2	0,50	0,50	1,50	2,00
Passenger 3	**1,17**	**1,67**	**2,17**	**2,50**
Passenger 4	1,00	1,17	1,67	1,83

TSV-mean value was calculated and the results validate what is written ISO 7730/2005 for certain values of indoor environment [3, 6] (metabolic rate, clothing insulation, air temperature, mean radiant temperature, relative air velocity, water vapors partial pressure), values of TSV must be between (-2…+2).

The passenger from front right place of the car at the end of every session (minute 30) have the mean calculated TSV value +2.5, justified by the fact that the solar radiation was more intense along measurements, and the warm air flow discharged from the dashboard vents were directed to the passenger. Back passengers expressed a thermal sensation similar to the front right passenger, mean TSV in +2.



a)

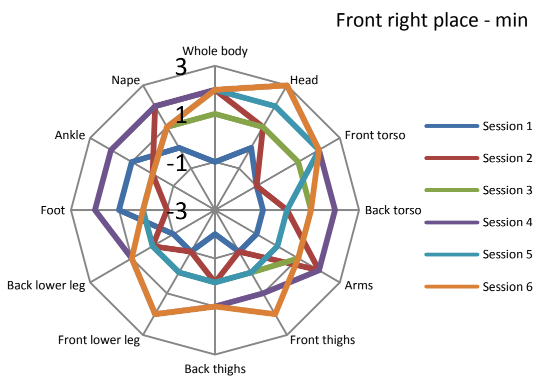


b)

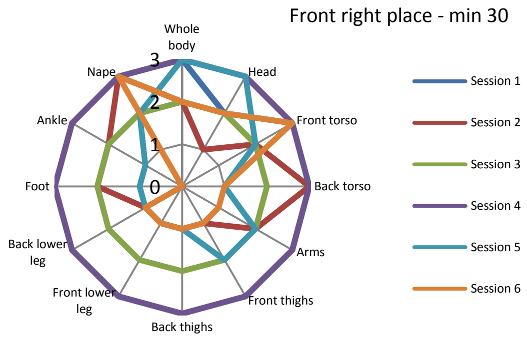
Fig. 9: *TSV evolution for passenger 1 a) at minute 0; b) at minute 30*

The graphs in Fig. 9-10 highlights expressed subjective character of thermal sensation of every occupant. Are presented the global thermal sensation of the passengers from the front of vehicle at the beginning and at the end of the measurement sessions. Be observed that one passenger has expressed a positive thermal sensation global and local on scale for most tests, except for the first session when measuring thermal sensation it was mainly cold.

Place from front right of the car was the worst place in terms of thermal sensation felt. Right from the beginning of measuring sessions the local and global thermal feeling was expressed (-2 ... 0), and from session 4 thermal sensation was felt strongly purporting to +3 because of the influence of direct sun radiation.



a)



b)

Fig. 10: *TSV evolution for passenger 2 a) at minute 0; b) at minute 30*

4. Conclusion

This paper is focused on the transient non-uniform environment inside the automotive passenger compartment. The thermal sensation of an automotive passenger is affected by the surrounding environment. The major characteristics of the automobile environment that complicate the determination of passenger thermal comfort are the transient nature and non-uniformity of the passenger compartment thermal/fluid conditions as well as the necessity of large windows which allow the variability of the exterior solar radiation conditions to have a significant influence. These are in addition to the psychological as well as physiological differences among passengers that also play a significant role.

Acknowledgements

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