THE THERMAL COMFORT IN THE SURFACE PUBLIC TRANSPORT FROM BUCHAREST DURING THE SUMMER PERIOD

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ABSTRACT. – The thermal comfort during the summer period inside the surface public transport from Bucharest. The studies of human biometeorology are few at national level and the existing ones target especially housing or office buildings. This paper aims instead the surface public transport, represented by three categories of vehicles (bus, trolleybus and tram), from a city with over two million passengers per day with this transportation type. The study covers the warm season of the year, because this is the period with the most intense thermal discomfort, due to the excessive daytime heating of the air inside the transport vehicles. This paper is based on the expeditionary measurements undertaken inside seven vehicle models, selected depending on their share in the public transport fleet. A certain transport route was selected for each of those models, and the measurements were performed in certain days, depending on their meteorological characteristics. The study revealed that the construction features of the analyzed vehicles are decisive for the thermal discomfort level of passengers.

Keywords: thermal comfort, thermal discomfort, vehicle model, biometeorological index, air temperature.

1. INTRODUCTION

Regia Autonomã de Transport Bucureşti (RATB) is the company that provides the surface public transport in Bucharest. At the beginning of 2011, it operated 125 routes totaling a length of 1,196 km double track on a network with a length of 509 km double track. The total number of passengers was about 760 million in 2010, resulting in an average of almost 2.1 million passengers per day. RATB owned in September 2011 an auto fleet composed of 1,014 buses, 502 trams and 302 trolleybuses represented by 15 constructive types (five models of buses, six models of trams and four models of trolleybuses) (www.ratb.ro/statistici).

2. DATA AND METHODS

This study is based on the measurements made with specialized equipment inside seven vehicle models operated by RATB and selected based on their share in the auto fleet, which had to exceed 1 % (table 1). In this way, only the models

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accessible to a large number of passengers were taken into account, while the ones represented by only a few or even one single vehicle were excluded. Each of the vehicle models were studied on a certain portion from a single transport route (table 1). The routes were chosen based on their passenger traffic, being preferred those that connect the central area of the city to the very densely populated peripheral residential areas. Also, the selected routes had to intersect in the same area of the city, or to have common portions, which allowed the analysis of several types of vehicles in a single day. All the measurements for each of the selected routes were performed in the same sector located between two preset stations and in vehicles moving in the same direction.

Table 1. ***The vehicle models included in the study***

Vehicle category	Vehicle model	Share in the auto fleet owned by RATB (%)	Route selected	Observations
Bus	Mercedes – Benz Citaro O530 Euro 3 (Citaro 1)	27.5	336	Fig. 1
	Mercedes – Benz Citaro O530 Euro 4 (Citaro 2)	27.5	601	Very similar in appearance to Citaro 1
Trolleybus	Ikarus 415T	11.0	66	Fig. 2
	Iveco Citelis Irisbus	5.5	69	Fig. 3
Tram	V3A – 93	17.8	11	Fig. 4
	V3A – 93 – CH – PPC	2.5	41	Fig. 5
	Tatra T4R	6.4	25	Fig. 6

Fig. 1. ***Citaro 1***

Fig. 2. ***Ikarus 415T***

Fig. 3. ***Iveco Citelis Irisbus***

Fig.4. ***V3A – 93***

Fig. 5. ***V3A – 93 – CH – PPC***

Fig. 6. ***Tatra T4R***

The data collection campaigns were conducted over four days in the period between July and September 2011. The study targeted the summer period, and so it took place in two types of days with characteristic temperatures for this season, namely two summer days (during which the maximum air temperature reaches or exceeds 25 °C) and two tropical days (during which the maximum air temperature

reaches or exceeds 30 °C). The days included in the study were selected by the maximum air temperature measured at Bucureşti Bãneasa weather station the summer days having a value between 27 °C and 28 °C, and the tropical ones a value between 32 °C and 33 °C. The purpose of two days from each type was to compare the micrometeorological features inside all the analyzed vehicle models, given the impossibility to actually make the measurements for all the seven models in the same day. The selected days from each type are similar in terms of meteorological parameters measured at Bucureşti Bãneasa, paying particular attention to the mean, maximum and minimum air temperature. In order to study them in both types of days, all the seven vehicle models mentioned were divided into two groups, namely the buses and trolleybuses group and the trams group. The measurements undertaken in one day took into account a single group.

The measurements were performed during the time interval between 07:00 and 20:00, resulting eleven sets of values for the vehicles included in the first group and ten sets of values for those in the second group. They were conducted cyclically, being followed the same sequence: routes 66, 69, 336 and 601 for the first group and routes 41, 25 and 11 for the second one. The period between two successive measurements for the same route ranges from 45 to 105 minutes, mainly because of the variation during the day of the succession interval for the RATB vehicles. In order to facilitate the analysis of the data obtained from the collection campaigns, the values are considered to be measured at the half time of each hour (for example, the values obtained between 9:00 and 9:45 are considered at 9:30).

The measurements were performed in the middle of each of the seven vehicle models studied, during their movement, at a height of about one meter from the floor. The meteorological parameters determined were the dry and the wet bulb air temperature and the relative humidity. Those parameters were obtained with Kestrel 3500 Pocket Weather Meter device by Nielsen – Kellerman Company. The thermal comfort in each of the studied vehicle models was evaluated based on three biometeorological indices calculated by specific formulas that included the meteorological parameters measured for this study (table 2). The level of thermal comfort or discomfort of the passengers was determined depending on the values obtained for those indices during the data collection campaigns.

Table 2. ***The biometeorological indices used in this study (data source: Ionac and Ciulache, 2008)***

Index	Symbol	Measurement unit	Conditions of application	Formula
Thom discomfort index	DI Th	°C	21 °C < Tdry < 47 °C	DI Thom = 0.4 * (Tdry + Twet) + 4.8
Relative strain index	RSI	Units	Tdry > 26 °C	RSI = (Tdry – 21) / (58 – e) e = (RH * E) / 100 $E = 6.112 * 10^{(7.5 * Tdry / (237.7 + Tdry))}$
Summer Simmer Index	SSI	°F °C	22 °C < Tdry < 53 °C	SSI (°F) = 1.98 * (Tdry – (0.55 – 0.0055 * RH) * (Tdry – 58)) – 56.83 SSI (°C) = (5 / 9) * (SSI (°F) – 32)
Significance of symbols: Tdry : dry bulb temperature (°C)			RH : relative humidity (%) e : true vapor pressure (hPa)	Twet : wet bulb temperature (°C) E : saturation vapor pressure (hPa)

3. RESULTS

The mean temperature inside the public transport vehicles varies depending on the type of day for the same vehicle model and on the constructive features of the seven vehicle models for the same type of day (table 3).

Table 3. ***The mean air temperature inside the studied vehicle types***

Vehicle category	Vehicle model	Mean temperature (°C)	
		Summer day	Tropical day
Bus	Mercedes – Benz Citaro O530 Euro 3 (Citaro 1)	28.6	33.7
	Mercedes – Benz Citaro O530 Euro 4 (Citaro 2)	27.0	28.6
Trolleybus	Ikarus 415T	28.0	32.3
	Iveco Citelis Irisbus	28.0	32.3
Tram	V3A – 93	29.8	33.3
	V3A – 93 – CH – PPC	29.9	32.9
	Tatra T4R	30.2	33.7

The lowest values for the same type of day are specific to Citaro 2 bus, the only vehicle model operated by RATB equipped with air – conditioning system in the passenger cabin. The highest values are specific to Tatra T4R tram in both types of days and to Citaro 1 bus in the tropical day. The first one is in this situation mainly because of the heat generated by the electric motor located under a large part of the passenger cabin, due to the reduced dimensions of this vehicle compared to other trams. Considering the absence of a proper thermal insulation between the cabin and the motor, a large part of the produced heat is transferred inside the vehicle. Citaro 1, although, except the air – conditioning system, it is very similar to Citaro 2 regarding its constructive features, has the highest mean temperature in the tropical day, fact explained by the insufficient ventilation of the air inside it due to the small opening created by the mobile parts of the windows. This factor is added to the greenhouse effect from inside this vehicle, favored by the predominance of glass in the construction of the vehicle lateral sides, aspect valid for all the transport vehicles operated by RATB.

The air temperature variation within the same vehicle model differs between the two types of days considered, regarding mainly the moment of the day when the maximum is found and also the values of the temperatures measured at the same time of day. The evolution curves for all vehicle models from the same type of day are similar (fig. 7, fig. 8, fig. 9, fig. 10).

The minimum temperature inside all the studied vehicle models is typical to the beginning of the data collection days, being found around 07:30. The maximum temperature is observed earlier in the summed days compared with the tropical days, being generally found between 12:30 and 14:30 in the first case, and between 15:30 and 16:30 in the second one. In the summer days, the air inside the vehicles heats up continuously until noon, cooling down slowly after that, while in the tropical days the heating continues in the afternoon, the dropping of the temperatures being delayed for a few hours. The temperature measured inside the same vehicle at approximately the same hour is higher in the tropical day than in the summer day with about 3° – 5° C for the vehicles in the buses and trolleybuses

group, and about 4° – 6° C for the ones in the trams group. The highest temperatures recorded reach 37.6° C for Citaro 1 bus during the tropical day and 34.3° C for V3A – 93 – CH – PPC tram during the summer day.

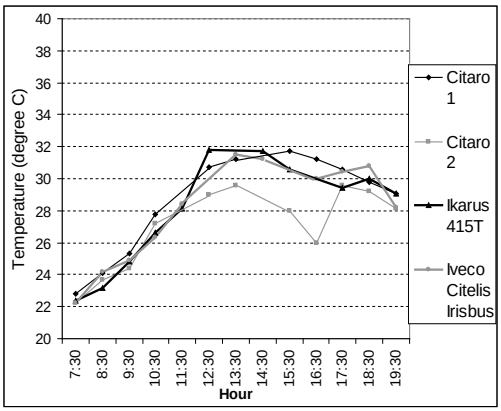

Fig. 7. ***The air temperature variation inside the vehicles from the buses and trolleybuses group in the summer day***

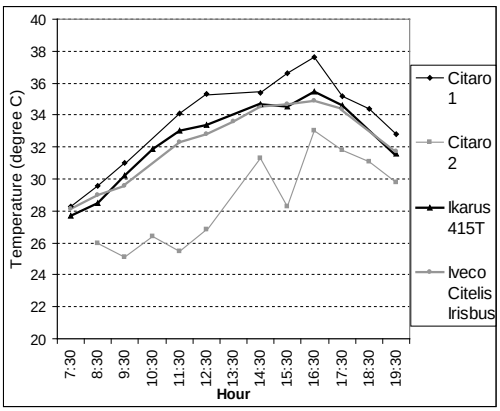

Fig. 8. ***The air temperature variation inside the vehicles from the buses and trolleybuses group in the tropical day***

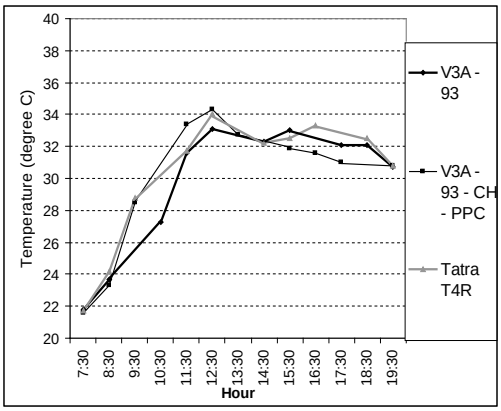

Fig. 9. ***The air temperature variation inside the vehicles from the trams group in the summer day***

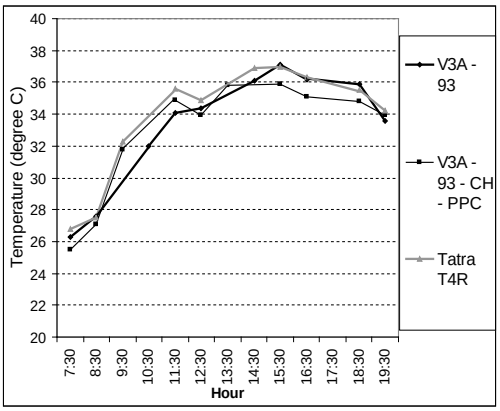

Fig. 10. ***The air temperature variation inside the vehicles from the trams group in the tropical day***

Citaro 2 bus does not have the thermal characteristics of the rest of the analyzed vehicle models, because of its air – conditioning system. When the system is functional, the temperatures inside this vehicle are significantly lower than those measured at approximately the same hour in other models. Depending on the cooling power of the system set by the driver, some vehicles of the same model have higher temperatures than others, fact that explains the evolution of the temperature as a broken line, with local minimum and maximum points (fig. 8).

The biometeorological characteristics of the analyzed vehicle models are summarized in table 4. The level of discomfort is illustrated by a five color scale. The blank spots indicate an hour when no measurements were made or when the conditions of application for a certain index were not met.

Table 4. ***The biometeorological characteristics of the studied vehicle models***

Index	Hour												
	07:30	**08:30**	**09:30**	**10:30**	**11:30**	**12:30**	**13:30**	**14:30**	**15:30**	**16:30**	**17:30**	**18:30**	**19:30**
	Mercedes – Benz Citaro O530 Euro 3 (Citaro 1)												
DI Th	20.32	20.92	21.68	23.88		24.72	24.68		25.84	25.48	24.12	24.40	24.04
RSI				0.17		0.22	0.23		0.27	0.24	0.21	0.20	0.19
SSI	26.26	27.78	29.09	33.19		34.78	34.67		36.97	35.77	33.59	34.15	33.57
DI Th	25.76	26.28	26.84		28.56	29.92		29.32	29.80	30.28	29.04	28.48	27.36
RSI	0.23	0.27	0.31		0.40	0.48		0.43	0.50	0.52	0.42	0.41	0.34
SSI	37.21	38.19	39.66		42.02	***44.39***		42.93	***44.81***	***45.17***	42.44	42.44	40.00
	Mercedes – Benz Citaro O530 Euro 4 (Citaro 2)												
DI Th	19.64	20.76	20.92	22.64		23.32	23.68		22.68	21.60	23.52	23.32	22.88
RSI				0.14		0.17	0.19		0.15	0.11	0.19	0.18	0.16
SSI	25.25	27.43	27.77	31.09		32.17	32.90		31.25	29.15	32.57	32.26	31.52
DI Th		24.40	22.60	23.00	23.12	23.28		25.92	24.28	27.40	26.00	25.36	24.64
RSI		0.15		0.13		0.15		0.27	0.19	0.31	0.28	0.25	0.21
SSI		33.81	30.44	31.74	31.16	32.72		37.18	34.34	38.66	37.47	36.18	34.49
	Ikarus 415T												
DI Th	19.96	20.32	21.44	22.40	23.44	25.48		24.52	24.12		23.76	23.48	23.36
RSI				0.13	0.16	0.25		0.23	0.21		0.19	0.19	0.18
SSI	25.70	26.64	28.75	30.58	32.42	35.96		34.33	33.59		33.15	32.71	32.46
DI Th	25.36	25.56	26.48	27.28	27.96	27.92		28.84	28.16	29.48	28.24		26.56
RSI	0.21	0.23	0.28	0.33	0.39	0.38		0.38	0.38	0.47	0.43		0.29
SSI	36.37	36.92	38.44	40.08	42.10	41.66		41.32	41.27	43.99	42.94		38.52
	Iveco Citelis Irisbus												
DI Th	19.60	21.40	21.24	22.04	23.64		25.76	24.68		23.68	23.96	24.44	22.96
RSI				0.12	0.17		0.26	0.23		0.19	0.20	0.22	0.16
SSI	25.08	28.45	28.55	29.92	32.81		36.70	34.67		32.88	33.36	34.37	31.50
DI Th	25.20	25.96	26.12		27.64	28.32	28.20	28.24	28.12	28.80	28.64		26.40
RSI	0.23	0.25	0.25		0.38	0.39	0.38	0.39	0.41	0.42	0.39		0.29
SSI	37.32	37.88	37.53		41.83	42.00	41.53	41.71	42.20	42.48	41.57		38.09
	V3A – 93												
DI Th	20.20	21.40		23.40	25.68	26.80		26.20	26.76		25.72	25.96	25.24
RSI				0.15	0.26	0.31		0.28	0.30		0.26	0.27	0.24
SSI		28.44		32.48	36.65	38.79		37.36	38.46		36.53	36.72	35.66
DI Th	23.52	24.48		26.60	27.88	27.68		29.52	29.28	29.00		29.04	27.40
RSI	0.14	0.18		0.31	0.36	0.35		0.46	0.44	0.42		0.44	0.34
SSI	32.76	34.48		39.08	40.74	40.27		43.65	43.02	42.60		43.15	39.86
	V3A – 93 – CH – PPC												
DI Th	20.08	21.16	24.40		26.72	27.08	26.52		26.00	25.92	25.32		25.68
RSI			0.19		0.31	0.33	0.29		0.27	0.27	0.24		0.25
SSI		28.22	34.32		38.56	39.28	37.87		37.23	37.02	36.05		36.86
DI Th	23.04	24.04	26.56		28.68	28.00	28.76		29.12	28.84		28.40	28.36
RSI		0.16	0.30		0.42	0.38	0.41		0.45	0.44		0.39	0.39
SSI	31.52	33.72	38.80		42.48	41.53	42.32		43.38	43.20		41.68	41.95
	Tatra T4R												
DI Th	20.20	21.84	24.60		25.84	27.56		26.04	26.24	26.96		26.24	25.08
RSI			0.20		0.27	0.35		0.28	0.28	0.32		0.28	0.24
SSI		29.20	34.90		36.97	40.39		37.62	37.62	39.26		37.62	35.61
DI Th	24.20	24.48	27.40		29.08	28.40		29.72	29.40	29.16		29.08	27.80
RSI	0.16	0.18	0.34		0.44	0.40		0.48	0.44	0.44		0.44	0.36
SSI	33.94	34.47	40.28		43.21	41.81		***44.24***	43.14	42.97		43.07	40.44

Significance of colors:

20.08	Comfort	27.08	Increased discomfort	For each vehicle model, the first three sets of values are for the summer day ant the other three are for the tropical day
21.16	Slightly discomfort	***44.24***	Risk of heat shock	
26.72	Moderate discomfort		No data	

The thermal discomfort is higher in the tropical day by comparison with the summer day for all the seven vehicle models, fact that stands to reason if the thermal differences found inside the vehicles from one type of day to another are taken into account. The summer day usually has a slightly or moderate discomfort, while the tropical day has many cases of increased discomfort. Those differences are more visible for Citaro 1 bus and the vehicles in the trolleybuses group, and less visible for other models.

Comparing the situation observed for all of the seven vehicle models in the same type of day, Citaro 2 bus stands out with the lowest degree of thermal discomfort in both days. The differences from the other models are higher in the tropical day, when the air – conditioning system was functional in all of the studied vehicles, than in the summer day, when the system functioned only in two cases (at 15:30 and 16:30). The highest degree of thermal discomfort is specific to Tatra T4R tram in the summer day and to Citaro 1 bus in the tropical day. These two vehicles are the only ones with cases of the highest level of discomfort possible for SSI, namely the risk of heat shock, which is almost inevitable for susceptible individuals (elderly, children, persons with cardiovascular or respiratory diseases). This level does not appear for DI Thom, because the obtained values are not high enough, and does not exist at all for RSI, in which case the highest level is represented by the increased discomfort.

Although the two bus models analyzed in this paper are almost identical regarding their constructive features, they are very different in terms of thermal comfort, fact that indicates the importance of the air – conditioning system in reducing the level of discomfort, especially when it functions properly. The two models of trolleybuses are similar regarding their biometeorological characteristics, although they have very different constructive features. However, Iveco Citelis Irisbus has slightly more cases of increased discomfort than Ikarus 415T. All the tram models have a higher general thermal discomfort level than the other vehicles, except Citaro 1. The differences between the three models are insignificant in the tropical day, but they become important in the summer day, Tatra T4R having the highest and V3A – 93 the lowest level of discomfort.

The evolution during the summer day of the biometeorological features of the studied vehicle models is characterized by the presence of the thermal comfort in the first one or two hours and of the maximum discomfort in the time interval between 12:30 and 15:30. The cases of thermal comfort are almost absent in the tropical day, when the observation period begins with a slightly or even a moderate discomfort and the highest values of the biometeorological indices are found between 14:30 and 16:30. This time intervals are comparable with those in which is found the maximum air temperature from inside the vehicles.

The results of this study have common points with other similar researches published in the international literature. The thermal comfort can be maintained in the air – conditioned vehicles if the device is set in accordance with outdoor weather conditions, while the level of discomfort from the non air – conditioned vehicles depends mostly on the external environmental factors (Shek and Chan,

2008). The air – conditioned vehicles can achieve and maintain the human comfort zone at a faster rate by controlling the relative humidity level during the cooling process (Alahmer et al. 2012). The non air – conditioned vehicles are characterized by high levels of discomfort due to three main factors: high air temperature, strong solar radiation and low air movement and ventilation (Lin et al. 2010). The efficiency of the air ventilation process depends on the windows features (number, position and dimensions of the mobile parts) and on the speed of the vehicle. The outside air enters the vehicle from the rear windows, moves forward relative to the bus at about 1/10 the vehicle speed and exits through the front windows (Kale et al. 2007). The overall environmental discomfort depends also on the quality of the air from inside the vehicles, being increased by the high levels of CO_2 (especially during rush hours) and of suspended solids (which varies with the quantity of the external air that enters the vehicle) (Zhu et al. 2010).

4. CONCLUSIONS

The constructive features of the surface public transport vehicles are decisive for their micrometeorological and biometeorological characteristics. The only recommended transport vehicle in the summer season is Citaro 2 bus, because of its much lower thermal discomfort level by comparison with other models. However, even this bus can have an increased discomfort if the driver does not use the air – conditioning system at full capacity. The most not recommended vehicles are those that receive heat from the engine inside the passenger cabin or that are insufficiently ventilated, like Tatra T4R tram and Citaro 1 bus. The time of the day with the highest risk to passengers is between 12:30 and 16:30, while the recommended travel time is in the early hours of the day.

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