SELECTED FACTORS AFFECTING MICROCLIMATIC CONDITIONS IN DRIVER'S CABIN

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Abstract. The driver's cabin should be comfortable, whilst being both ergonomically and climatically bearable. In this paper, the authors surveyed the real situation in the driver's cabin. The driver's exposure to a variety of temperatures whilst driving needs to be addressed as a feedback for automotive manufacturers to be considered as part of safety precautions. Large areas of the windshield and side windows of the monitored vehicles have direct solar radiation, which affect the variation of microclimates which cause stress on a driver. This paper examines the effect of the thermal state of the environment for both internal and external values obtained from the measuring devices. From each vehicle relevant data have been collected for detailed analysis. The outcome of the data is represented by respective graphs. Considerable effect was inflicted by the total volume of each cabin and glazed areas of the specific vehicle. The authors gave priority and considerable emphasis to the change in the thermal state to be one of the predominant indicators in monitoring the factors affecting microclimatic conditions.

Keywords: BGHI, fatigue, indoor air quality, radiation, THI, windshield.

Introduction

Drivers of all categories starting with personal, intercity, urban, freight haulage and rail transport in daily operation mode are affected by microclimate. The driver's exposure to a variety of temperatures whilst driving needs to be addressed as a feedback for automotive manufacturers. The safety and well-being of drivers in different climatic conditions, particularly in the driver's space is so far given insufficient attention. Microclimate in the driver's cabin significantly affects the human thermal comfort. The cabin environment has an emphasis on thermal comfort not only for reasons of convenience, but also safety. Scientific studies in the past have shown the effects of inappropriate working conditions on fatigue, which significantly applies to prolonged driver's working hours mainly to professionals [1].

A suitable microclimate is necessary and the systems must ensure a suitable microclimate as it is one of the most important safety features of the vehicles. The driver's cabin features a large flat glass, a small volume of air inside and relatively low heat insulation, resulting in a greater degree of influence on the operating conditions. Microclimate is determined by air temperature, air velocity, relative humidity and thermal radiation. If the temperature in a driver's cabin is below 17 ºC, the body starts to cool down; resulting in a reduction of efficiency and a risk of muscle fatigue. In addition, inaccuracy and constraints of movements are observed. If the temperature is above 25 ºC, reactions slow down and physical tiredness quickens. At a temperature above 30 ºC, mental activity will worsen.

Microclimate in the car cabin is formed on the basis of heat exchange between the exterior cabin and the surrounding environment. Microclimate in the driver's cabin is influenced by external factors: weather (clouds, rain, weather conditions), orientation of the vehicle relative to the sun, time of day, speed (affects convective heat exchange of the car with the surroundings), geometry of the car (the glazed area), material properties of interior and exterior: transmissivity, reflexivity, absorptivity, heat capacity, thermal conductivity, etc., air conditioning settings like temperature, humidity, and air flow and number of people inside the vehicle or a cabin (consumption of O_2, production of heat, humidity, CO_2 and odours). Suitable microclimate in the car cabin is necessary to ensure even during extreme operating conditions.

The recommended values of microclimate in the cabin of the car are according to [2] as follows.

- Air temperature 18-22 ºC and relative humidity 40-60 %;
- Air velocity 0.1 $m.s^{-1}$ at 18 ºC and 0.4 $m \cdot s^{-1}$ at 24 ºC;
- Air exchange per person (clean air): 25-50 $m^3 \cdot h^{-1}$ of fresh air;
- Maximal concentration of pollutants: 0.17 % CO_2, 0.01 %, CO and 1 $mg \cdot m^{-3}$ of dust.

Passenger transportation safety is a priority task and should be given maximum attention to the comfort of drivers and their working conditions. The workload is significantly higher for “afternoon” and “morning” peak hours in connection with both higher utilisation of buses and more traffic congestion. During these two peak times, most of the accidents, both at work and in itinerary, also occurred by physical and mental load as well as time pressure and emotional stress [3]. Thermal comfort and preferable local microclimate conditions include the combination of local air velocity and temperature. Moreover, the system should be related to attain and keep local skin temperature within comfort range, which will give sensation of thermal comfort, penetrate natural airflow around the body, avoid draught or eye irritation, and supply the breathing zone with fresh clean air. In other words, avoiding discomfort is not a guarantee that thermal comfort will be obtained, and vice versa [4]. The priority related to active safety has been partially shown on a research paper; there is a very high percentage of cases, when professional drivers of commercial vehicles are involved in road traffic accidents having committed various infringements of social legislation requirements before the crash occurrence. Most parts of the identified offences have been classified as very serious infringements, indicating a possible considerable threat to the road traffic safety [5; 6].

This paradigm will continue as time goes on as far as the need arises in technological improvement. The oversized windshield parameters unfortunately have become the reason for the consequences and attribute to the problems associated with increased solar radiation in summer and the formation of moisture (related to humidity) inside in winter due to dew point temperature.

Materials and methods

In this paper, the authors examined two vehicles: city bus and tram related to microclimate conditions in the driver’s cabin. A general model for bus transport Czech brand articulated Karosa KbN was a preferred selection as being a predominant Prague city bus transportation system (Fig. 1).The other key role player for Prague transportation system is also a Czech brand Tram T3 (Fig. 2). The influence of the size and shape of the front and side windows (windshields), this impacts not only radiation as the driver’s cabin was the centre of the research in the above two means of transport systems.

Fig. 1. **Measuring devices situated in bus driver’s cabin**

Fig. 2. **Measuring devices situated in tram T3 driver’s cabin**

All data collected correspond to the actual microclimatic condition in the driver's cabins; buses, trams respectively. The volume of each cabin was taken into consideration (bus 2.25 m^3, glazed surfaces of windows and doors comprise approximately 40 % of the surface of the cab; and tram 2.17 m^3, glazed surfaces are about 20 % of the surface of the cab). The experiment was conducted in summer in the mild climate month of August. This period was chosen deliberately because of fewer passengers being transported in the city transportation system during annual holidays and vacations.

Relevant data were collected from measurement devices which are installed on the dashboard of the bus and tram. The thermal comfort in the space was continuously measured by globe temperature (measured by globe thermometer FPA 805 GTS with operative range from –50 to +200 ºC with accuracy ± 0.01 K and diameter of 0.15 m) together with temperature and humidity of surrounding air measured by sensor FH A646–21 including the temperature sensor NTC type N with operative range from -30 to +100 ºC with accuracy ± 0.01 K, and air humidity by capacitive sensors with operative range from 5 to 98 % with accuracy ± 2 %. The concentration of CO_2 was measured by the sensor FY A600 with operative range 0-0.5 % and accuracy ± 0.01 %. All data were measured continuously and stored at intervals of one minute to the measuring instrument ALMEMO 2690–8 during the measurement (approximately from 80 to 120 minutes).

The Czech government health protection regulation [7] determines the conditions for the protection of health related to light manual work such as driving under normal operating conditions. Under this regulation, for particular metabolic energy output 81-105 $W.m^{-2}$, the recommended operating temperature is 20 ± 2 ºC and relative humidity to be 30-70 %.

Thermal state of the internal environment can be described by applying the index of temperature and humidity (THI). This index is widely used to describe the heat stress, and it is also a key indicator of the environmental conditions of stress, temperature [8-10]. According to the definitions used in the Czech republic the THI is determined by the following equation:

$$\mathrm{THI} = 0.8 \cdot t_i + \frac{(t_i - 14.4) \cdot \mathrm{RH_i}}{100} + 46.4 \tag{1}$$

where THI – temperature–humidity index;
t_i – internal temperature of air, ºC;
RH_i – internal relative humidity of air, %.

For THI evaluation, the following limit values are applied. If the THI ≤ 65 it means comfort state; if the THI is from 66 to 79 it means alert state, prolonged exposure occurs fatigue; and if the THI ≥ 80 it means discomfort, if the THI ≥ 84 it is dangerous, the heat stress is highly probable if the activity continues.

To determine the influence of solar radiation the BGHI (black globe-humidity index) can be calculated according to the equation (2):

$$\mathrm{BGHI} = 0.8 \cdot t_g + \frac{(t_g - 14.4) \cdot \mathrm{RH_i}}{100} + 46.4 \tag{2}$$

where BGHI – black globe–humidity index;
t_g – globe temperature, ºC.

Results and discussion

The average values including standard deviation were calculated from the results of measurements for each of external and microclimatic parameters: external temperature t_e, external relative humidity RH_e, internal temperature t_i, internal globe temperature t_g, internal relative humidity RH_i, THI, BGHI and concentration of CO_2.

The results of the measurement in the bus cabin during the morning are presented in Table 1, afternoon measurements are in Table 2. The results of the measurement in the tram cabin during the morning are presented in Table 3, afternoon measurements are in Table 4. Examples of the course of the THI and BGHI calculated from the internal parameters measured during the morning, afternoon measurements in the bus cabin are shown in Figures 3 and 4.

Table 1

Indoor parameters in cabin of bus during the morning

Parameter	t_e	RH_e	t_i	t_g	RH_i	THI	BGHI	CO_2
Units	ºC	%	ºC	ºC	%	-	-	%
Mean value	15.4	53.6	22.22	24.19	39.8	67.3	69.7	0.041
Standard deviation	0.5	3.4	0.62	1.25	1.3	0.68	1.5	0.009
Minimum	13.9	48.7	20.65	20.69	36.1	65.54	65.4	0.033
Maximum	16.4	60.8	23.91	26.57	44.5	68.96	72.4	0.075
Median	15.8	51.2	22.14	23.97	39.8	67.18	69.5	0.037

Table 2

Indoor parameters in cabin of bus during the afternoon

Parameter	t_e	RH_e	t_i	t_g	RH_i	THI	BGHI	CO_2
Units	ºC	%	ºC	ºC	%	-	-	%
Mean value	19.5	33.6	29.98	29.88	22.1	73.7	73.7	0.034
Standard deviation	0.4	0.51	2.72	1.30	2.8	2.3	1.5	0.002
Minimum	18.6	32.9	25.95	26.73	14.0	70.1	70.3	0.033
Maximum	20.3	36.0	38.99	33.12	27.3	81.3	77.7	0.050
Median	19.7	33.3	29.04	29.52	22.5	73.0	73.7	0.033

Table 3

Indoor parameters in cabin of tram during the morning

Parameter	t_e	RH_e	t_i	t_g	RH_i	THI	BGHI	CO_2
Units	ºC	%	ºC	ºC	%	-	-	%
Mean value	12.5	92.6	18.37	18.67	71.6	63.9	64.3	0.068
Standard deviation	0.2	0.1	0.86	0.82	4.0	1.1	1.1	0.018
Minimum	12.1	92.5	17.09	17.66	57.4	32.1	63.0	0.033
Maximum	12.9	92.8	21.27	21.22	81.2	67.4	67.5	0.107
Median	12.4	92.6	18.17	18.34	72.5	63.7	63.9	0.068

Table 4

Indoor parameters in cabin of tram during the afternoon

Parameter	t_e	RH_e	t_i	t_g	RH_i	THI	BGHI	CO_2
Units	ºC	%	ºC	ºC	%	-	-	%
Mean value	13.9	91.6	21.35	22.31	65.4	67.7	69.2	0.047
Standard deviation	0.1	0.4	2.44	1.93	7.3	2.6	2.0	0.010
Minimum	13.8	90.4	19.37	19.25	40.0	65.4	65.2	0.033
Maximum	14.1	92.3	30.18	30.50	75.1	76.9	77.3	0.083
Median	13.9	91.7	19.91	21.25	69.4	66.2	68.0	0.044

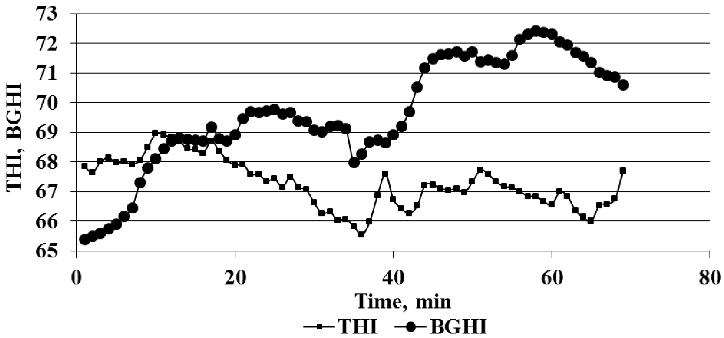

Fig. 3. **Course of THI and BGHI calulated from the morning measurement in bus cabin**

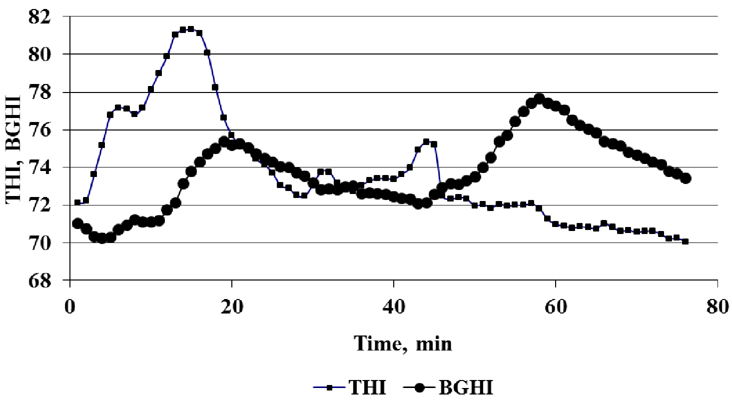

Fig. 4. **Course of THI and BGHI calulated from the afternoon measurement in bus cabin**

The results of the measurement in the bus cabin during the morning (Tab. 1) show that at the time of mild summer outdoor environment the parameters inside the cabin were in the optimum parameters, only slightly higher CO_2 values indicated that the ventilation was insufficient. After about 40 minutes when the outside temperature in the morning increased and intensified the effect of solar radiation, there was internal air temperature increased, which resulted in a higher value of the BGHI (Fig. 3).

The afternoon measurements (Tab. 2, Fig. 4) in the cabin showed that the ventilation was generally insufficient, particularly in the first 20 minutes, when the value exceeded THI 80. High air temperatures and high values of the THI and BGHI show heat discomfort inside the cabin.

The measurements in the tram cabin (Tabs. 3 and 4) were colder and moister when exposed to the summer weather. Average air temperatures were at optimal levels. Higher CO_2 levels, however, show a lack of ventilation of the tram.

Conclusions

1. The internal conditions in the cabin of bus or tram are strongly influenced by solar radiation, especially at a larger proportion of cabin glazing. Based on the result of the morning measurements in the bus higher temperatures have occurred, for example global temperature t_g from 20.7 ºC to 26.6 ºC. The internal temperature t_i from 20.7 ºC to 23.9 ºC. This indicates that the influence of solar radiation has increased rapidly compared to the internal temperature.
2. Measurement evaluation applying the THI and BGHI indexes also reveals the major influence of radiation. E.g., on bus measurements the mean value of the THI is 67.3 and the BGHI mean value 69.7. Similarly, in the afternoon tram measurements indicate that the THI 60.7 and the BGHI 69.2.
3. In the lower outside air, temperatures can reduce the influence of solar radiation by adequate ventilation of the cabin.
4. In the higher outside air, temperatures can maintain the recommended air temperature inside only using the cooling (air conditioning) of air.
5. Drivers should ventilate sufficiently even in colder outdoor conditions to let in the fresh air (O_2) and exhaust the polluted air (CO_2 and odours). Based on the results of the measurement, a slightly higher concentration of CO_2 has occurred. For the bus 0.075 %, and in the tram 0.107 %.

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