Agronomy Research **15**(5), 2236–2246, 2017
https://doi.org/10.15159/AR.17.037

Substantial factors influencing drivers' comfort in transportation

R. Zewdie[1,*] and P. Kic[2]

[1]Czech University of Life Sciences in Prague, Faculty of Engineering, Department of Vehicles and Ground Transport, Kamýcká 129, CZ165 00 Prague 6, Czech Republic
[2]Czech University of Life Sciences in Prague, Faculty of Engineering, Department of Technological equipment of buildings, Kamýcká 129, CZ165 00 Prague 6, Czech Republic
[*]Correspondence: zewdie@tf.czu.cz

Abstract. Research shows that driver stress is associated with workload and fatigue, and an inappropriate microclimate in the driving cabin can have an impact on overall driver's safety. The aim of this scientific study is to examine whether driver stress, across various urban and field drive conditions, can affect performance in a confined environment and whether the natural breathing process can also compound these effects and aggravate health hazards. This paper will address the influencing parameters associated with driver comfort of everyday job occupations in the urban communication network of Prague city public transport. In this research paper the authors will characterize cardinal components directly accountable to the safe operation elements; the concentration of carbon dioxide (CO_2) and the relative humidity (Rh_i) in the driving cabin, affecting the contentment of the drivers comfort while performing their duties. Similar inquiries were carried out on ventilation emphasis and air intake impact in drivers' cabin, recommending a design to minimize safety problems associated with comfort. Data on the concentration of carbon dioxide and internal relative humidity in the respective cabins have been collected carefully for detailed analysis. This research paper is the outcome of these findings.

Key words: driver, bus, tram, metro, microclimate, ventilation.

INTRODUCTION

Drivers in all transport categories, in the course of their daily operations, are affected by microclimate, which is determined by air temperature, air velocity, relative humidity, carbon dioxide and thermal radiation. The driver's exposure to a variety of temperatures whilst driving needs to be addressed for the safety and well-being of drivers in different climatic conditions, particularly in the driver's space, which has, so far, been given insufficient attention. The objective of this research is to examine the microclimate value measured in the driver's cabins in the professional city transport system. Microclimate in the driver's cabin significantly affects human thermal comfort; the cabin environment has an emphasis on thermal comfort not only for reasons of convenience, but also safety. It is necessary to ensure a suitable microclimate in the car cabin even in extreme operating conditions. The recommended values of microclimate in the cabin of the car, are according to researcher Vlk, (2003) as follows: Air temperature 18–22 °C and relative humidity 40–60%; air velocity 0.1 m s^{-1} at 18 °C and 0.4 m s^{-1} at 24 °C; air exchange per person (clean air): 25–50 m^3 h^{-1} of fresh air; maximal concentration of pollutants: 0.17% CO_2, 0.01% CO and 1 mg m^{-3} of dust. Scientific studies, Anderson, (1998) in the past have shown the effects of inappropriate working conditions on fatigue, which significantly applies to prolonged driver's working hours. A suitable microclimate is necessary and the systems must ensure it, as it is one of the most important safety features of vehicles.

The driver's cabin features a large flat windscreen. A small volume of air inside and relatively low heat insulation, result in a greater degree of influence on the operating conditions. If the temperature in a driver's cabin is below 17 °C, 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 °C, reactions slow down and the rate of physical tiredness accelerates. At a temperature above 30 °C, mental activity will worsen. Generally, drivers are sensitive to humid air because the human body uses evaporative cooling as the primary mechanism to regulate temperature. Under humid conditions, the rate at which perspiration evaporates on the skin is lower than it would be under arid conditions. Because human beings perceive the rate of heat transfer from the body rather than temperature itself, we feel warmer when the relative humidity is high than when it is low (Zewdie & Kic, 2016b).

Some drivers experience difficulty breathing in humid environments. Some cases may possibly be related to respiratory conditions, while others may be the product of performance anxiety disorder. In times of extreme stress, a driver may shake uncontrollably, hyperventilate (breathe faster and deeper than normal) or even vomit in response, causing sensations of numbness, faintness, and loss of concentration, among others (Gladyszewska, 2011). Air conditioning reduces discomfort in the summer not only by reducing temperature, but also by reducing humidity. In winter, heating cold outdoor air can decrease relative humidity levels indoor to below 30% leading to discomfort such as dry skin, cracked lips and excessive thirst (Zewdie & Kic, 2015).

Passenger transportation safety is a priority task and so maximum attention should be given to the comfort of drivers and their working conditions. Thermal comfort and preferable local microclimate conditions include the combination of local air velocity and temperature. Moreover, the system should be related to attaining and keeping local skin temperature within comfort range, which will give the 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* (Zewdie & Kic, 2015). The oversized windshield parameters unfortunately have become the reason for and contribute 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.

Generally, transport technology improvement is correlated to safety. In this research paper, the authors place a strong emphasis on an area that has not been well examined. Microclimate composition rate is an important index factor affecting the contentment of drivers in the cabin. Numerous researchers used different measurements to assess the driver workload under diverse driving conditions. The conclusions reached by monitoring measures support an objective and continuous analysis in a dynamically changing microclimate situation (Zewdie & Kic, 2016a).

A suitable microclimate is necessary and the systems must ensure a suitable microclimate as it is one of the most important safety features of vehicles. In a confined environment, our natural breathing process too can compound these effects and aggravate health hazards. In the course of breathing, we exhale CO_2, which can displace O_2 in an indoor environment such as a vehicle cabin, leaving the environment O_2 deficient. Such high CO_2 and low O_2 concentrations can cause adverse human health effects. Various independent studies, Galatsis et al. (2001) have also shown that through this process, the concentrations of O_2 and CO_2 may come to exceed safety limits. Interestingly, a study on fatal single vehicle crashes highlights that the vehicle is more likely to have closed windows and a heater on than to have fresh air and air conditioning fitted, Maroni et al. (1995). An O_2 deficient environment has been termed 'hazardous' when the O_2 concentration is less than 19.5%, Galatsis et al. (2000). Low O_2 levels can impair judgment, increase heart rate and impair muscular coordination. In the conclusion in their respective findings that thermal state of internal microclimate inside the drivers' cabins has a strong correlation with drivers' comfort which has influence on safety of drivers. The authors of this paper have confirmed the influences CO_2 and Rh_i based on collected data and statistical analysis, the airflow inside the cabin is crucial in removal of health hazardous pollutants generated by the driver himself.

MATERIALS AND METHODS

The authors carried out research on three public city transport modes; buses, trams and the subway cars (metros) accordingly. Detail category was denoted by the type of vehicles. For research implementation, the authors applied four buses Karosa KbN SOR, four trams Tatra T3 of surface transportation, which are Czech brands and four subway cars series 81-71M of Russian make for underground transportation; all modes of transportation were not air-conditioned. Data on the microclimate conditions in all drivers cabin were collected from measurement devices which were installed on the dashboard of the respective vehicles. 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 °C 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. The temperature sensor NTC type N with operative range from –30 to +100 °C with accuracy ± 0.01 K. and air humidity by capacitive sensors with operative range from 5 to 98% with accuracy ± 2% was installed. The concentration of CO_2 was measured by the sensor FY A600 with operative range 0–0.5% and accuracy ± 0.01%. All data was measured continuously and stored at intervals of one minute to the measurement instrument ALMEMO 2690–8 throughout the measurement process.

The data collections were carried out roughly in hot climate conditions in the summer of 2014 in the month 28^{th} and 29^{th} of August at an average external temperature $t_e = 25$ °C on buses 1 and 2. Buses 3 and 4 were measured at an average external temperature $t_e = 29$ °C. In July 7 and 8, 2015 at an average external temperature of $t_e = 28$ °C trams measurement was held. Similarly, on subway cars in June 2016 at noon with average subway platform temperature of $t_e = 20$ °C was measured. While data collecting process, the large side windows of buses and trams were open for ventilation whilst driving. Only subway car side windows were closed due to dust appearances in the tube. The drivers' cabin in all transport modes is bounded; drivers are limited and are not in contact with passengers. The duration of the measurement limited on the availability of the vehicles and capacity of the measuring devices. For buses measurement we had about 40 min, for trams about 50 min. and for subway car nearly 50 minute depending on the metro line, where the data collection was performed.

Assuming steady conditions, with a uniform distribution of pollutants in space the required volume air flow for ventilation V_c is calculated according to the Eq. (1).

$$V_c = \frac{M_p}{c_i - c_e} \tag{1}$$

where V_c – required volume air flow for ventilation, m^3 h^{-1}; M_p – mass flow of produced pollutant, uniformly leaking into the space, kg h^{-1}; c_e – concentration of pollutant in inlet air, kg m^{-3}, (usually is $c_e = 0$); c_i – concentration of pollutant in outlet air, kg m^{-3}, (usually considered OEL – Occupational Exposure Limits or MEL – Maximum Exposure Limits).

The data on CO_2 concentration, the thermal index composed of internal globe temperature t_g, and internal temperature t_i as well as internal relative humidity Rh_i are carefully collected for further analysis. The obtained results of CO_2 including relative humidity Rh_i were processed by Excel software and verified by statistical software (*Tukey HSD Test*). Different superscript letters (a, b, c, d) mean values in common are significantly different from each other in the rows of the (*ANOVA; Tukey HSD Test; $p \leq 0.05$*), e.g. if there are the same superscript letters in all the rows it means the differences between the values are not statistically significant at the significance level of 0.05.

RESULTS AND DISCUSSION

The mean values including standard deviation were calculated from the results of measurements for each internal and microclimatic parameter: internal temperature t_i (°C), internal relative humidity Rh_i (%), internal globe temperature t_g (°C), concentration of CO_2 (%) and calculated volume of ventilation air flow V_c (m^3 h^{-1}) in the driving cabin. The results of the measurement in the buses Karosa KbN SOR cabin are presented on Tables 1, 2., in trams Tatra T3 cabin on Tables 3, 4 and in subway cars 81–71M cabin on Tables 5, 6 respectively.

Table 1. The results of measurements indoor parameters in driving cabins of buses 1 & 2

Model			Bus Karosa (1)					Bus Karosa (2)		
Driver			1					2		
Parameter Units	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c m^3 h^{-1}	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c m^3 h^{-1}
Mean	0.040	33.5	30.4	26.5	224.2	0.043	46.5	35.1	31.5	158.2
± SD	0.006	2.0	3.8	1.0	95.6	0.010	0.6	1.9	1.6	133.7
Minimum	0.033	26.2	25.5	24.9	44.2	0.035	45.3	31.9	29.2	41.6
Maximum	0.065	39.5	38.7	30.1	471.4	0.069	48.1	37.4	34.9	707.5
Median	0.033	33.7	29.3	26.4	235.7	0.043	46.5	35.5	31.1	128.6

The results of the measurement in the bus Karosa (1) cabin, Table 1, shows that the mean value of CO_2 is a normal recommended. The value of the intake fresh air V_c

approaches to 224.2 m^3 h^{-1}, which is more than fourfold compared to the recommended range V_c = 25–50 m^3 h^{-1}. At the maximum value of CO_2, the fresh air intake reaches more than nine fold compared to the recommended range, i.e. V_c = 471.4 m^3 h^{-1}.

The result of the measurement in the Karosa (2) cabin, Table 1, indicates that the mean value of CO_2 is at the recommended value despite the high globe temperature t_g and internal temperature t_i. The internal relative humidity Rh_i records the acceptable value with the ventilation air flow V_c = 158.2 m^3 h^{-1} is adequate. The driver apparently felt comfortable even though the temperature t_i = 34.9 °C and t_g = 35.1 °C. The amount of CO_2 concentration was within the normal recommended range. The authors believe that, due to the maximum fresh air flow which reached fourteen fold V_c = 707.5 m^3 h^{-1} played a vital role for moderate internal relative humidity Rh_i = 40.1%.

Similar data were collected from the bus Karosa (3) cabin, Table 2. It demonstrates acceptable concentration of CO_2.The large amount of side window ventilation air flow V_c = 243.5 m^3 h^{-1}, which was twelve fold exhibits the contribution to low amount of internal relative humidity Rh_i and CO_2. The mean values of internal temperature t_i = 22.2 °C and the globe temperature t_g = 24.2 °C exposes that the measurement was held at a slight warm suitable summer days.

Table 2. The results of measurements indoor parameters in driving cabins of buses 3 & 4

Model			Bus Karosa (3)					Bus Karosa (4)		
Driver			3					4		
Parameter	CO_2	Rh_i	t_g	t_i	V_c	CO_2	Rh_i	t_g	t_i	V_c
Units	%	%	°C	°C	m^3 h^{-1}	%	%	°C	°C	m^3 h^{-1}
Mean	0.034	22.1	24.2	22.2	243.5	0.048	29.9	35.1	31.5	121.5
± SD	0.003	3.4	1.5	0.7	67.8	0.008	5.1	2.8	1.7	5.4
Minimum	0.033	14.0	20.7	20.7	83.2	0.033	19.9	29.7	27.7	44.2
Maximum	0.050	27.3	26.6	23.9	471.4	0.083	40.1	40.9	34.7	353.6
Median	0.033	22.5	24.0	22.1	235.7	0.050	27.8	35.3	31.5	94.3

The result of the measurement on bus Karosa (4) Table 2, demonstrates the mean values CO_2 and Rh_i are within the accepted range. The ventilation air flow V_c = 121.5 m^3 h^{-1}; all values at internal temperature t_i = 31.5 °C and extremely high internal globe temperature t_g = 35.1 °C. In this measurement, it was observed that the maximum concentration of CO_2 which is higher than the mean value and the ventilation air flow V_c = 353.6 m^3 h^{-1} has reached four fold.

The results obtained from buses through measurement and mathematical assessments, the authors denote that the extreme high fresh air intake through ventilation V_c has immense temperature impact in the driver's cabin. The large side windows ventilation may play significant role for the substantial part of the ventilation performance.

Fig. 1. Demonstrates the values of CO_2 concentration in buses 2 and 3 driver cabins. From the Figure, it is clearly seen that all mean values are within the recommended margin. Interestingly, the courses of the graphs demonstrate the driver's preference of fresh air intake V_c for ventilation. Bus 3 in Fig. 1, indicates that the driver had a small break at 7^{th}, 24^{th} and 32^{th} minutes and the value of CO_2 corresponds to collected data.

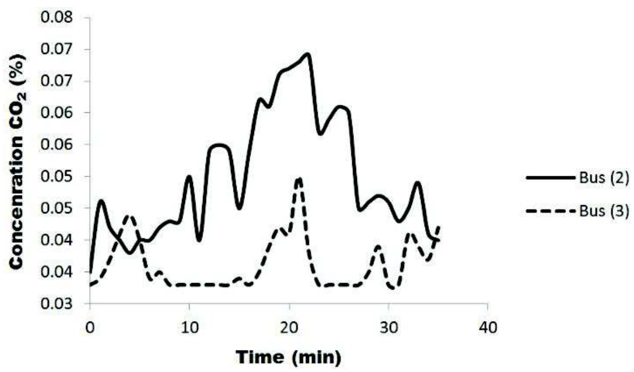

Figure 1. The dynamics of CO_2 concentrations in driving cabins of the buses 2 and 3

Obtained data through measurement of Tram T3 (1), from Table 3, shows that the mean value of CO_2 is at a normal recommended range due to a slightly more air flow which is $V_c = 189$ m^3 h^{-1} where as Rh_i which indicates insufficient internal humidity. Throughout the course of measurement it happens to be a very slight increase of CO_2, at $V_c = 0.083$ m^3 h^{-1}.The internal temperature t_i and the globe temperature t_g values indicate that the ventilation was sevenfold, $V_c = 353.6$ m^3 h^{-1}. Both values indicate that the measurement was held at a mild summer and increased to hot climate.

Table 3. The results of measurements indoor parameters in driving cabins of the trams 1 & 2

Model	T3 (1)					T3 (2)				
Driver	5					6				
Parameter	CO_2	Rh_i	t_g	t_i	V_c	CO_2	Rhi	t_g	t_i	V_c
Units	%	%	°C	°C	m^3 h^{-1}	%	%	°C	°C	m^3 h^{-1}
Mean	0.048	20.3	22.0	20.9	189.0	0.052	28.7	17.9	17.5	88.5
± SD	0.013	4.2	2.5	2.9	90.7	0.009	3.1	0.1	0.2	49.8
Minimum	0.033	13.1	19.4	19.4	48.8	0.033	24.6	17.7	17.1	29.5
Maximum	0.083	27.7	30.5	30.2	353.6	0.081	34.2	18.1	17.9	353.6
Median	0.046	20.2	21.2	19.9	202.0	0.051	27.8	18.0	17.6	78.6

The result of the measurement of Tram T3 (2), on Table 3, shows that the data collection was held on a mild summer time. All mean values are in a recommended range except the internal relative humidity which was a slightly lower than normal value. At maximum value of CO_2 registered, $Rh_i = 34.2\%$ has reached the acceptable value and fresh ventilation intake air value $V_c = 353.6$ m^3 h^{-1} extended seven fold.

The results obtained from Tram T3 and third participant of the research indicated on Table 4, clearly shows that all mean values are in ideal ranges of the recommended values. Even though, the maximum value of CO_2 scored a slightly more the mean value, it still satisfy the acceptable range.

The case for Tram T3, fourth participant, Table 4, demonstrates an increased mean values of $CO_2 = 0.113\%$, $t_g = 33.2$ °C and $t_i = 31.6$ °C. The maximum value of $CO_2 = 0.174\%$ was slightly higher than the recommended 0.170%. The internal temperature $t_i = 40$ °C and globe temperature $t_g = 39.9$ °C have identical maximum values, which indicates as an extreme hot summer period. The maximum fresh intake air $V_c = 94.3$ m^3 h^{-1} was insufficient to moderate the acceptable internal temperature. From the values obtained the authors assume the cause for higher measured values to improper ventilation and small sized side ventilation windows of the tram.

Table 4. The results of indoor parameters' measurements in driving cabins of the trams 3 & 4

Model			T3 (3)					T3 (4)		
Driver			7					8		
Parametr Units	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c $m^3\ h^{-1}$	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c $m^3\ h^{-1}$
Mean	0.072	70.4	19.4	19.2	46.4	0.113	59.4	33.2	31.6	28.0
± SD	0.022	1.6	1.0	1.0	32.7	0.045	4.4	3.3	3.6	20.1
Minimum	0.033	67.7	18.3	18.2	19.1	0.048	47.0	28.9	27.6	10.0
Maximum	0.107	75.1	21.2	21.3	157.1	0.174	65.7	39.9	40.0	94.3
Median	0.073	70.2	18.9	18.8	33.3	0.114	59.9	33.4	29.9	17.5

Figs 2 and 3, demonstrate the impact of fresh air intake for ventilation V_c and concentration of CO_2 pollutant in driving cabins for two different trams; Tram 3 and 4. From the values of both graphs, it is clearly indicated as fresh air intake for ventilation has a significant impact on the pollutant concentration in the driving cabins.

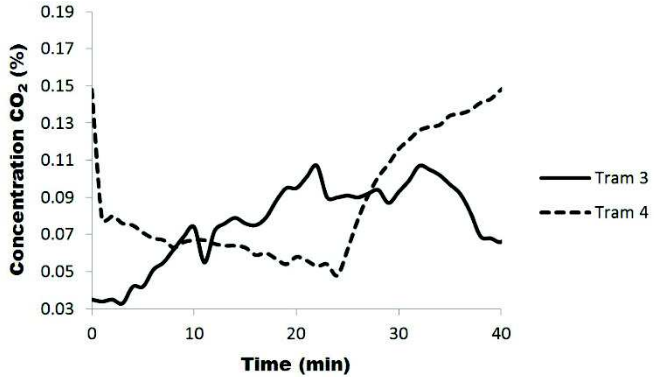

Figure 2. The dynamics of measured CO_2 concentration in drivers' cabins of the trams 3 and 4.

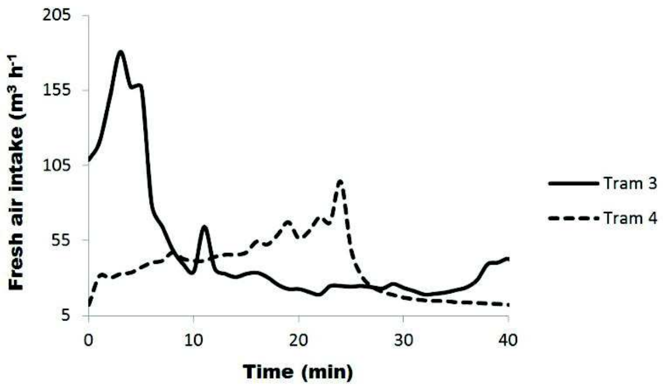

Figure 3. The dynamics of fresh air intake for ventilation in driving cabins of the tram 3 and 4.

Generally, most of subway cars transport operates underground. The data collection was held from the subway cars operating underground subway routes, where the influence of direct radiation temperature t_g (°C) and external temperature t_e (°C) do not play significant role. The data collected on subway cars M1 (1), Table 5, it is clearly shown that the mean values CO_2 and Internal relative humidity Rh_i and fresh air intake ventilation value V_c = 41 m^3 h^{-1} is within the recommended values all at suitable internal climate condition. The maximum value of CO_2 = 0.153% was a slight higher and has appeared on the margin of a tolerable value.

Table 5. The results of indoor parameters' measurements in driving cabins of the subway cars 1 & 2

Model			M1 (1)					M1 (2)		
Driver			9					10		
Parameter Units	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c m^3 h^{-1}	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c m^3 h^{-1}
Mean	0.076	56.8	22.2	21.7	41.0	0.082	63.7	23.9	23.7	82,5
± SD	0.025	2.1	0.4	0.4	18.1	0.029	1.8	0.8	0.2	52,8
Minimum	0.043	53.5	21.5	20.5	11.8	0.035	60.7	27.0	23.3	26,4
Maximum	0.153	60.5	22.8	22.1	88.4	0.140	68.5	26.6	24.1	176,8
Median	0.069	57.1	22.0	21.7	39.3	0.081	64.1	23.8	23.5	59,0

The attributes obtained for subway car M1 (2) on Table 5, shows the identical trends of mean values as subway car M1 (1). All mean values correspond to the recommended ranges. A slight increase of maximum value of CO_2 was observed. The relative internal humidity Rh_i, globe internal temperature t_g, internal temperature t_i and the fresh air intake ventilation V_c = 82.5 m^3 h^{-1} are all at the recommended values.

The case of the research on subway car M1 participant number three, on Table 6, clearly shows that the mean value is CO_2 and all other mean values corresponds to the acceptable ranges. On the maximum value of CO_2, the authors witnessed an increase, whereas the rest of other maximum values remain in accepted ranges.

The fourth participant of the subway car driving cabin M1 (4), Table 6, the mean value of CO_2 = 0.101% which means the mean values remained enjoyable. For the maximum values of all parameters, more or less stays at the recommended level.

Table 6. The results of indoor parameters' measurements in driving cabins of the subway cars 3 & 4

Model			M1 (3)					M1 (4)		
Driver			11					12		
Parametr Units	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c m^3 h^{-1}	CO_2 %	Rh_i %	t_g °C	t_i °C	V_c m^3 h^{-1}
Mean	0.087	60.4	25.6	23.6	37.1	0.101	58.4	22.7	22.2	32.0
± SD	0.022	1.3	0.3	0.1	32.4	0.042	4.0	0.4	0.4	20.5
Minimum	0.042	57.8	23.2	23.5	17.0	0.048	47.0	22.5	21.5	10.3
Maximum	0.116	62.0	24.0	23.8	157.1	0.170	64.7	23.1	22.8	94.3
Median	0.094	60.8	23.6	23.6	23.2	0.079	58.0	21.8	22.0	30.8

The collection of internal cabin data indicates that the CO_2 and RH_i to be similar. The same applies to the internal globe temperature t_g and internal temperature t_i.

Interestly, there happened to be higher concentration of CO_2 in driving cabins of all four subway cars. The authors only assume that the high concentration of CO_2 was caused by insufficient ventilation and probably due to the prevention of excess dust concentration in the subways tube.

From the behaviour of functions plotted on Fig. 5, the concentration of CO_2 in subway cars 3 and 4 cabins differs. At the initial stage, at 3rd and 4th minute the graph; it is clearly shown that both cabins are insufficiently ventilated. Cabin for subway car 4 slightly exceeded the recommended value CO_2 = 0.170%. In general, subway cars cabin ventilation system is improper and inadequate. The authors of this research have a close talk with the drivers and the management of the institution concerning the ventilation system.

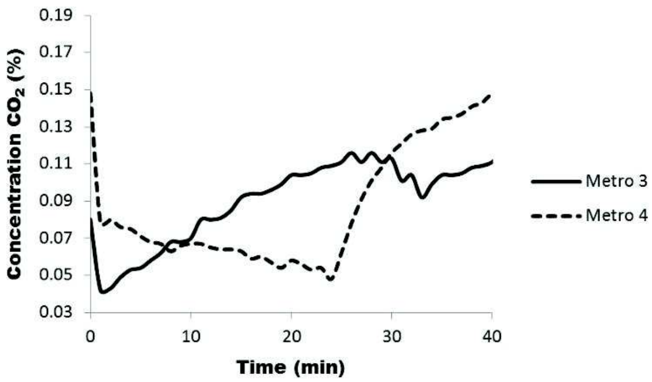

Figure 5. The dynamics of CO_2 concentration in the drivers' cabins of the subway car engines 3 and 4.

Table 7 shows the statistically significant data obtained for comparison in all twelve transport driving cabins. The data are mean value ±SD. Different letters (a, b, c, d) in the subscript are the sign of high significant differences *(Tukey HSD Test; p ≤ 0.05)*.

Table 7. Statistical parameters of CO_2 and Rh_i in driving cabins of the buses, trams and subway cars

Vehicle	pollutant unit	CO_2 % ± SD	Rh*i* % ± SD
	1	0.040 ± 0.060[a]	33.5 ± 2.0[a]
	2	0.043 ± 0.010[b]	46.5 ± 0.6[b]
	3	0.034 ± 0.003[c]	22.1 ± 3.4[c]
	4	0.048 ± 0.008[b]	29.9 ± 5.1[d]
	1	0.048 ± 0.013[a]	20.3 ± 4.2[a]
	2	0.052 ± 0.009[a]	28.7 ± 3.1[b]
	3	0.072 ± 0.022[b]	70.4 ± 1.6[c]
	4	0.113 ± 0.045[c]	59.4 ± 4.4[d]
	1	0.076 ± 0.025[a]	56.8 ± 2.1[a]
	2	0.082 ± 0.029[a]	63.7 ± 1.8[b]
	3	0.087 ± 0.022[a,b]	60.4 ± 1.3[c]
	4	0.101 ± 0.042[b]	58.4 ± 4.0[d]

± SD – Standard deviation; Different superscript letters (a, b, c, d) mean values in common are significantly different from each other in the rows of the (*ANOVA; Tukey HSD Test; p ≤ 0.05*).

Based on the result of measurement and statistical evaluation of the lowest concentration of CO_2 level measured was in the bus 3; $CO_2 = 0.034\%$. For the comparison, the CO_2 level in the cabin of the tram 1 was $CO_2 = 0.048\%$ and for the subway car 1 was $CO_2 = 0.076\%$. The lowest relative humidity Rh_i was measured again in cabin bus 3, $CO_2 = 22.1\%$.

The highest concentration was measured in the drivers cabin of tram 4, $CO_2 = 0.113\%$, compared to bus 4, $CO_2 = 0.048\%$ and underground car (metro) where $CO_2 = 0.101\%$. Similarly, the highest level of Rh_i was measured in cabin tram 3 where $Rh_i = 70.4\%$; followed by subway car 2, $Rh_i = 63.7\%$ and subway car 3, where $Rh_i = 60.4\%$. The CO_2 concentration difference between buses 2 and 4 is not statistically significant. The relative humidity Rh_i between buses the differences are statistically significant.

The difference between CO_2 concentrations in tram 1 and 2 is not statistically significant. The CO_2 concentration in trams 3 and 4 are significantly higher. Relative humidity Rh_i in all trams are significantly different.

The differences of CO_2 concentration in subway cars 1, 2 and 3 are not statistically significant; the CO_2 differences between subway cars 3 and 4 are statistically significant. Differences of relative humidity Rh_i in all four subways cars are statistically significant.

In this research paper, the findings demonstrated that the concentration of CO_2 was the lowest in all buses and approaches the external CO_2 level. The level of the relative humidity Rh_i was at the minimum and hazardous to health problem. Both parameters were influenced by the large side windows where a considerable amount of air flow while driving had strong impact on thermal state. The higher concentration of CO_2 was registered in Subway car cabins which were caused by insufficient ventilation. This research paper verifies the early investigations carried out by Vlk (2003) and Zewdie & Kic (2015; 2016a and 2016b).The measurement method extends the principle of early warning and the presence of harmful substances in the driver's cab and safety adjustments at the intervals in the work process. The measurements would be extended in different seasons and different types of vehicles. The authors were obliged to stick by only public transport research.

CONCLUSION

The internal conditions in the cabin of the surface transport mode i.e. the buses and the trams are strongly influenced by solar radiation, particularly with a larger proportion of cabin glazing. Based on the result of the measurements in the bus maximum internal temperatures have occurred in Buses Karosa (2) t_i and Karosa (4) t_i. The internal relative humidity was in the normal recommended values Rh_i and very low CO_2 concentrations. The internal global temperature t_g in case Karosa (1) increased to t_g in Karosa (2). This indicates, the influence of solar radiation has increased rapidly compared to the internal temperature in all four Karosa buses. Despite the increase in internal temperatures, interestingly, the contents of CO_2 and the relative humidity Rh_i, correspond to the recommended values.

Data from the Trams Tatra T3 measurements also reveals the major influence of radiation on Tram (4). The maximum concentration of CO_2 which is slightly higher than the recommended 0.170% and the Rh_i shows that the drivers cabin was insufficiently ventilated. Surprisingly, all other tram values are within the accepted ranges. Though out the course of data collection, Tram and Bus drivers had open the large side windows. The low concentration of CO_2 and relative humidity Rh_i could be explained by the huge amount of fresh air intakes for ventilation, V_c.

The nature and specific characteristics of subway car transportation differ from the surface means of transportation. Due to the large amount of dust concentration in the subways, which was a result of the crumbling concrete surface, the drivers were not willing to open the side window for ventilation. The results indicate that the high concentration of CO_2 in the drivers' cabin has appeared on the margin of a tolerable value. Divers should ventilate sufficiently even in colder outdoor conditions to let in fresh air (O_2) and exhaust the polluted air (CO_2 and odours).

REFERENCES

Low humidity health effects 2014. *http://articles.mercola.com/sites/articles/archive*. Accessed 20.12.2016

Anderson, J. 1998. Transport Ministers Attack Driver Fatigue. Media Release—Australian Commonwealth Department of Transport and Regional Services.

Galatsis, K., Wlodarski, W. & McDonald, S. 2000. *Vehicle cabin air quality monitor for fatigue and suicide prevention.* Proceedings of the society of Automotive Engineers exposition. Detroit, USA

Galatsis, K., Wlodarski, W., Wells, B. & McDonald, S. 2001. SAE Transactions Journal of Passenger Car Mechanical Systems.

Gladyszewska, K. 2011. Concentrations of carbon dioxide in a car. Transportation Volume 16, Issue 2, Elsevier. pp. 166–171.

Maroni, M., Seifert, B. & Lindvall, T. 1995. Indoor Air Quality. Monographs. Vol. 3. Elsevier. Amsterdam, pp. 13–19.

Vlk, F. 2003. *Stavba motorových vozidel*: Osobní automobile, autobusy, nákladní automobily, jizdní soupravy, ergonomika, biomechanika, struktura, kolize a materiály. (Construction of motor vehicles: cars, buses, trucks, trains, ergonomics, biomechanics, structure, collision and materials). Brno: (In Czech)

Zewdie, R. & Kic, P. 2015. Selected factors affecting microclimatic conditions in drivers Cabin. In: *14th International Scientific Conference on Engineering for Rural Development*. Latvia University of Agriculture. Jelgava. pp. 61–66.

Zewdie, R. & Kic, P. 2016a.Transport route segments and stress effect on drivers. *Agronomy Research* **14**, 269–279.

Zewdie, R. & Kic, P. 2016b. Microclimate in drivers cabin of combine harvesters. In: *6th International Scientific Conference on Trends in Agricultural Engineering.* Faculty of Engineering, CULS. Prague. pp. 743–748.