MICROCLIMATE IN DRIVERS' CABIN OF COMBINE HARVESTERS

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Abstract
Ergonomically and climatically bearable drivers and operators' cabin correlate thermal comfort. Comfortable drivers and operators are supposed to guarantee better performances. Activity performance in relation to operators' exposure to temperature variety whilst driving was surveyed through measurements the authentic environmental circumstances in the driver's cabin. Cluttering side and windshield are constantly evolving irrespective to the direct solar radiation, which affect the variation of microclimates, especially in hot summer time and eventually cause stress on a driver. For the research implementation, the related data collection of microclimate conditions in driver's cabin in three farm machineries, specifically three combine harvesters of three different brands were monitored. Farm machinery operators' cabin microclimate and heart rate variables relevant data are collected for detail analysis. This research paper is the outcome of the findings.

Key words: heart rate**,** microclimate, safety, stress, thermal comfort.

INTRODUCTION

The comfort of drivers in different climatic conditions, particularly in the driver's space is so far given insufficient attention. A research on thermal comfort and related issues are undervalued. Generally, drivers of all mode of transport system in daily operation are affected by microclimate. Particularly, operators of mobile power equipment like drivers of agricultural machinery, earthmoving machines, and road and highways maintenances machines are exposed to the direct intervention of summer sun exposure, and other inconvenient weather conditions. Microclimate in the driver's cabin significantly affects the human thermal comfort which is one of the core issues of this paper. The cabin environment has an emphasis on thermal comfort not only for reasons of convenience, but also safety.

Radiation temperature, which surrounds the driver in which there would be radiative heat flow between the surface of the body and the surrounding areas. With the increase of humidity partial pressure of water vapor rises, this causes the rate of evaporation of sweat from the body of a driver leading to discomfort. On the contrary, very low humid air, the driver's mucous membranes of the eyes dry and dust formation increases. Air velocity is an important factor that influences suitable temperature inside. High air velocity can cause undesirable cooling of the body; especially during long exposure to the driver causing speed airflow excessively stresses to the organism and the cabin may not be designed for long stays drivers. Recommended values of microclimate in the cabin of the car according to VLK (2003) are: air temperature 18–22 ºC 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; maximum concentration of pollutants 0.17 % of CO_2, 0.01 % of CO and 1 $mg{\cdot}m^{-3}$ of dust.

Scientific studies have shown the effects of inappropriate working condition on fatigue, which significantly applies to prolonged drivers working hours. Human factors research shows that driver stress is associated with workload and fatigue, and is constructs that can have an impact on overall driver safety. Furthermore, a heart rate variability analysis was particularly applicable for this research as it is a strong indicator of mental stress or workload caused by driving tasks (MULDER, 1992). Numerous researchers used different measurement to assess driver workload under diverse driving conditions. The conclusions made by monitoring physiological based measures support an objective and continuous analysis in a dynamically changing situation (LI ET AL. 2004). Researchers JORNA (1993) and APPARIES ET AL. (1998) came to a conclusion that the relationship between safety and stress depends on the route conditions and work load. Furthermore, measurements of the heart are the most practical for application in the driving domain as it least interferes with driving performance (HARTLEY ET AL., 1994). Specific research has not yet well expended to ensure the mental and physical workload and its impact on farm machine operators.

The objective of the finding is to examine operators engaged on rural, bumpy, uneven, rough pavements, dusty, muddy and stubble farm fields. Frequent steering, reducing speed, monitoring various operations different devices while driving in short intervals, long working hours denote a significant degrade in driver performance. Due all these performances, farm machine operators are exposed to whole body vibration which leads to swift fatigue compared to acceptable and normal operating conditions, surfaces and pavements. In order to fully understand the complexity of the relationship between surface characteristics and driver behaviours, this paper closely examines various yet realistic uneven, rough, up and down drives, turns, breaking and accelerating and other working related conditions, influences of driving behaviours, physical strength of the operators playing a leading role on dimensions of stress. Generally, unexpected events are correlated to impaired driver cognition due to fatigue, stress, or mental workload (LI ET AL., 1995). Therefore, by evaluating stress as a form of distraction, this paper addresses the comfort of farm field surface conditions.

Measurements of driver stress can be objectively captured using physiological measures. Physiological measurements can be used to quantify changes in the body's state (NISKANEN ET AL., 2004). These measurements can include skin conductivity, cardiac, neurological, muscle, and respiratory activity. Many studies have concluded that during periods of increased stress, it tends to be an increase in the values of heart rate and the low to high frequency ratio (SLOAN ET AL., 1994; LEE ET AL., 2007; PARTIN ET AL., 2006; ZHAO ET AL., 2010). Similar research findings published ZEWDIE AND KIC (2015), ZEWDIE AND KIC (2016), shows the impacts of the microclimate conditions in drivers cabin plays a significant role on the stress and changes in heart rate variability. 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. The objective of this research paper is to investigate presumptions: if the heart rate variance depends on the operational performances and physical conditions of each operators; the air conditioner in the driver's cabin has affects the thermal comfort and affects the quality of microclimate and presents analysis among those measured parameters the influential and significant in terms of thermal comfort to operators.

MATERIALS AND METHODS

The authors performed the research on three farm machines (combine harvesters) drivers cabins of two agricultural enterprises at Eastern and Southern Bohemia farming fields cultivating on areas of nearly 2500 ha each. Three combine harvesters, Claas 450, German brand, air conditioned (AC) and East Bohemian farm enterprise property, Massey Ferguson (AC), UK brand and Fortschritt E 517, East German brand (non AC) both belonging to South Bohemian enterprise with their respective operators were at the disposition for the research performance.

For the heart rate measurement, the authors used the Polar measuring sensors package which is the brand of Kempele, Finland. The operators put on a sensor (Polar RS800CX) around the body and computer device on the wrist of the driver to record the heart rate variability (HRV). The package of the measuring instrument consists of four parts of Polar brand. Data detected (heart rate of the driver of the farm machinery) stored in Polar RS800CX are transformed through infra port to a personal computer for further processing and analysis. The Czech government health protection regulation 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 $W \cdot m^{-2}$, the recommended operating temperature is 20 ± 2 °C 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.

Data on the microclimate conditions in the farm machinery operator's cabin were collected from measurement devices which are installed on the dashboard of the respective farm machinery. 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 °C 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 °C, 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 %. For the sound measurement, a Digital Sound Level Meter (Unitest 93411, produce of BHA GmbH, Klottertal, Germany) with measuring range 30–135 dB, accuracy ± 2 dB and resolution 0.1 dB was applied. All data were measured continuously and stored at intervals of one minute to the measuring instrument ALMEMO 2690–8, which is the product of Ahlborn Mess-und Regelungstechnik GmbH, Holzkirchen, Germany.

This research work and measurements were carried out in July 22, and August 5 to 6, 2015 which were extreme hot summer days. When the research was performed there was a continuous hot climatic condition (the external temperature reached about 35 °C ± 2 °C). The data of 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 microclimate including noises LA (dB) in the cabin and heart rate measurements were processed by Excel software and verified by statistical software Statistica 12 (*ANOVA and TUKEY HSD Test*). Different superscript letters (a, b, c) mean values in common are significantly different from each other in the rows of the table (*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

Principal results of microclimate and heart rate measurements in all three combine harvesters cabin MF, Claas 450 and E 517 are summarized and presented in Tab. 1 which represents the CO_2 pollutant, the thermal index, noise level, relative humidity in operator's cabin and the heart rate of the operators. Tab. 2 shows the statistically significant data obtained for comparison in all three driving cabins. The data are means ± SD. Different letters (a, b, c) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test; $P \leq 0.05$*).

Tab. 1. – Determined microclimate in cabin and noise values, data in the table are means ± SD

Parameter	**Unit**	**MF**	**Claas 450**	**E 517**
CO_2	(%)	0.51 ± 0.24^a	0.14 ± 0.05^b	0.05 ± 0.01^c
t_g	(°C)	31.0 ± 1.4^a	27.2 ± 3.5^b	41.1 ± 2.1^c
t_i	(°C)	24.0 ± 1.7^a	25.3 ± 2.1^b	39.1 ± 1.2^c
RH_i	(°C)	23.5 ± 2.7^a	34.0 ± 3.4^b	28.2 ± 1.3^c
LA	**dB**	74.7 ± 5.1^a	80.6 ± 5.2^b	86.6 ± 1.5^c

Tab.2. – Selected detail microclimate comparison parameters

	CO_2 (ppm)			RH_i (%)		
Harvester	**MF**	**Claas 450**	**E 517**	**MF**	**Claas 450**	**E 517**
Average	5,100	1,210	490	23.5	33.8	28.2
Median	5,000	1,280	490	23.7	33.4	28.2
Maximum	9,290	1,840	660	30.4	41.0	30.8
Minimum	1,020	350	350	18.4	24.9	25.3
St. Devia.	2,400	500	100	2.70	3.42	1.30

Tab.3. – Operators heart rates on selected segments, data in the table are means ± SD

		MF	**Claas 450**	**E 517**
Segment		**HR ± SD**	**HR ± SD**	**HR ± SD**
Field ride		93 ± 3.8^a	94 ± 3.8^a	88 ± 4.2^a
Downhill drive		101 ± 5.3^a	109 ± 6.5^a	102 ± 5.1^a
Uphill drive		85 ± 4.1^a	87 ± 3.9^a	94 ± 3.3^a
Stop		96 ± 5.9^a	115 ± 6.0^b	110 ± 5.6^c

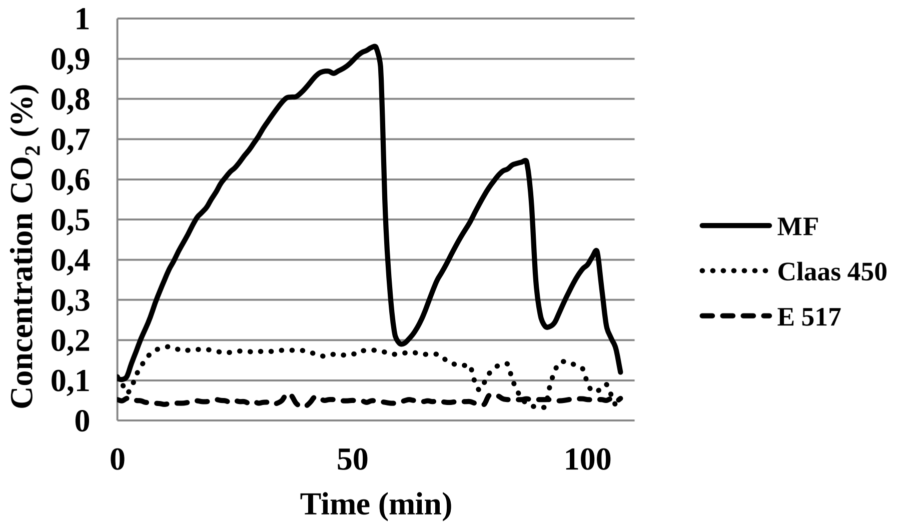

Fig. 1. – Measured concentration of CO_2 in the operators' cabin

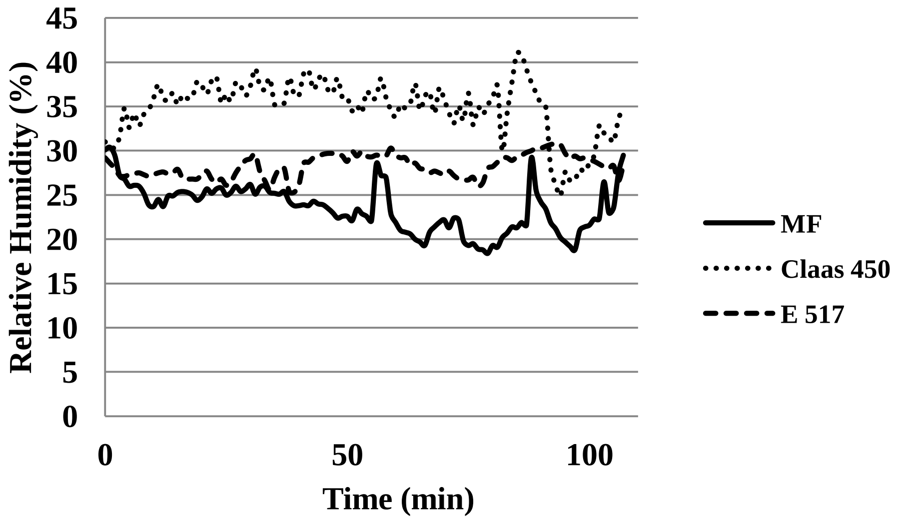

Fig. 2. – Measured relative humidity inside the operators cabin

Based on the result of the measurements Tab. 1 and Tab. 2, in the combine harvester cabin the internal temperatures were different. Tinted glass of the wind shield and side windows of the combine harvester had a noticeable influence in reducing the radiation. Law radiation temperature t_g and internal temperature t_i has been observed on both tinted glass and air conditioned harvesters (t_g = 31.0 °C, t_i = 24.0 °C) in MF harvester cabin and t_g = 27.3 °C, t_i = 25.3 °C in Claas 450 harvester cabin). Strong radiation effect has been observed and measured by globe thermometers t_g on E 517 combine harvester cabin due to clear glass of the wind shield and side windows; i. e. t_g = 41.1 °C and the internal temperature t_i raised to 39.1 °C. This indicates that the influence of solar radiation has increased compared to the internal temperature t_i, which is against regulation in relation to the directive on health supervisor (Government Regulation 361/2007 of Czech Republic, 2007). From the measurements evaluation, the inner temperatures can reduce the influence of solar radiation by adequate ventilation of the operators driving cabin. To maintain the recommended air temperature inside the cabin, operators are recommended to use air conditioning and frequent ventilation.

The results on Tab. 3 demonstrate the changes in heart rate variability on all three farm machine operators depending on the feature of the farm field and their actual performance. On the operator E 517 (22 years old and 75 kg), it is clearly seen that he has the lowest average heart rate (88 ± 4.1) has been registered at the field drive segment. MF (40 years old and 95 kg) and Claas 450 (48 years old 115 kg) operators scored the lowest heart rate on uphill drive (85 ± 4.1 and 87 ± 3.9 respectively). On all operators, the highest heart rate was observed at downhill drive (MF 101 ± 5.5, Claas 450 – 109 ± 6.5, and E 517-102 ± 5.1). At the stop segment, operators E 517 and Claas 450 had defects and frequent telephone calls from their respective despatchers due to pulleys release and malfunctions of the cooling system (E 517) and threshing cylinder (Claas 450). Both scored high heart rate (Claas 450 – 115 ± 6.0 and E 517 – 110 ± 5.6). Significant increase of heart rate was observed at downhill drive and farm field drives on all three operators. The highest heart rate increase of combine harvester operator was registered on a cell phone call from the despatcher related to defects (E 517) by 128 % and operator of Claas 450 due to threshing cylinder defect (131 %). Frequent turns during harvest performance had significant influence to heart rate fluctuations with the increase of 125 % on combine harvester operators by average. A profound increase in heart rate was observed while refilling water to the radiator of harvester E 517 due to the leak of cooling system (130 %). Often pulley failure had factors in the increase in heart rate to the operator E 517 (131 %). Braking performance due to deceleration has played as well significant heart rate value changes (127 %) in average.

CONCLUSIONS

The results on Fig. 1 and Fig. 2 indicate proofs on two hypotheses: the air conditioner in the driver's cabin positively affects the microclimate. If the air conditioner is not functioning as it is expected, it may be hazardous. This has a significant impact on the thermal comfort of the operator (the driver). Maladjustment or non-inspected air conditioner may worsen some parameters of microclimate conditions in the drivers' cabin especially if the blowhole is not properly functioning.

Drivers are recommended to 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 maximum pollutant concentration CO_2 (0.929 % = 9,290 ppm) has been observed in harvester operator of MF cabin which is air conditioned. On the fitted function Fig. 1, it is clearly seen the fluctuating curve observed which may be caused due to incorrect function of ventilation or occasional door opening for communication with the truck driver. The obtained result shows that the maximum amount of CO_2 has exceeded fivefold (9,290 ppm); which is hazardous to the operator's health (VLK, 2003). Slight increase of CO_2 concentration was observed in Claas 450 operator's cabin (0.185 = 1,850 ppm) throughout the course of the harvest performance. The maximum tolerable level of concentration of CO_2 has been sustained. In the combine harvester cabin E 517 the CO_2 pollutant level was the least (max. 0.066 % = 660 ppm). Separate propeller ventilator was fixed for additional ventilation due to extreme outside temperature (35 °C) extra to the ventilation set by the manufacturer. This may cause the concentration of CO_2 to the accepted level. The highest concentration of noise was measured in the E 517 harvester's cabin (86.6 ± 1.5°). This could be due to opened ventilation window throughout the course of harvest.

The lowest relative humidity was observed again in the cabin of MF (23.5 %) by average; for a temperature of 18–22 °C recommended relative humidity is 40–60 % (VLK, 2003). The Claas 450 harvester cabin again scored the better value of relative humidity (33.8 %) by average; in harvester E 517 driver's cabin, it was observed a little below the level of the recommended value (28.3 %) by average. From the values measured the authors strongly recommend ventilation in driver's cabin even if the farm machineries are equipped with air condition.

The outcome of this extensive research provides a comprehensive view of the most important parameters related to microclimate problems in drivers or operators encountering in their respective cabins, and analyses the most influential not deeply examined scientific field which are not given adequate consideration.

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