Expertise of thermal environment in metallurgical complexes in Romania

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Abstract. Workplace microclimate is determined by temperature and humidity of air, air currents and caloric radiation of work environments. All microclimate factors act combined and simultaneously on the human body. Thermal comfort plays a decisive role in mental and physical abilities of workers, and decisively influences workplace performance of employees. In order to ensure the highest possible yield for workers, employers must regularly evaluate microclimate parameters by measurements. The paper presents a case study on the thermal environment of several metallurgical complexes in Romania, by calculating the PMV and PPD indices at various workplaces that are found in all studied units. After correlating the PMV and PPD indices for each workplace in particular, in all studied units, results were used to create a regression analysis that is expressed by a regression graph, in order to present as concise and objective as possible differences between the studied workplaces. Importance of the paper is outlined by the need to develop research in the field of Health and Safety at Work, in order to objectively assess working conditions in Romania and to develop new methods to ensure a proper work climate in order to maintain or increase the level of workers' productivity.

1 Introduction

In modern society, men (workers) spend most of their lives in their workplaces (closed, open or semi-open spaces). The main goal of organizations is to create comfortable thermal conditions for workers, at low energy costs [1]. The majority of population carries out their daily activities in an artificial environment for a period of 18 to 20 hours a day: at home, at work, in shops, in various places of recreation (restaurants, cafes, theatres, cinemas, galleries, etc.) [2].

Internationally, there is a concern that the work environment may affect workers' health, their performance and comfort during work thus leading to increased interest in studying and understanding the influence of indoor environments on humans [3]. Research based on experiments on large groups of people, maintained in environments with different characteristics, led to the conclusion that the state of thermal comfort can be achieved for different combinations of values of microclimatic parameters, in correlation with the nature of activity and clothing. Consequently, the state of comfort is a very technically-complex characteristic and can be negatively influenced by a multitude of factors. Individual

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performance is affected by work environment, ability and personal motivation. Work environment refers to: indoor climate, access to certain services and infrastructure, which separately and all-together affect health [4]. Thermo-physiological comfort is the basis of biological transformations activated by changes in microclimate parameters. A thermal environment can be characterized from a hygrothermal point of view by temperature of indoor air, temperature of the delimiting surfaces and, on the other hand, by humidity and speed of air. Ambient temperature and central body temperature are the active elements of human - environmental heat transfer [3]. The human body is endowed with a complex mechanism of thermal self-regulation driven by the hypothalamus, which compensates for the loss of excessive heat at low ambient temperatures and yields the accumulated surplus due to warm environments and intense metabolic and physical activities, achieving the necessary energy balance [5].

As more research has been conducted in the field, international standards and regulatory acts in the field of work safety have been developed regarding the quantification of physical microclimate parameters in specific qualitative indices that can objectively characterize the work environmen. These standards correlate physical and chemical parameters related to indoor air quality (purity), air temperature, average radiant temperature, relative humidity, air speed and information on worker's workload and body's degree of insulation from the outside environment (clothing) [4]. For production rooms, the notion of comfort is replaced by the notion of work efficiency, corresponding to activities carried out [Hameed, 2009]. Work conditions must ensure high-performance work and maintenance of good health [3].

The state of thermal comfort, managed by the mechanisms of metabolic self-regulation, is perceived individually, in relation to physiological peculiarities and conjunctural factors, i.e., certain workers respond differently to the same thermal environment (PMV). To delimit the percentage of dissatisfied people when PMV has a certain value, the PPD index (Predictable Percentage of Dissatisfied) was introduced. Physical indicators of indoor microclimate (air temperature, average radiation temperature, relative humidity and air speed) must be correlated with recommendations on thermal comfort indicators PMV and PPD limits provided by ISO 7730:2006. According to this regulation, the percentage of dissatisfaction for a certain PPD thermal environment must be less than 10% and the average predictable percentage $-0.5 < PMV < 0.5$.

According to SR EN ISO 7730:2006, thermal comfort is achieved by [6]:

- ensuring an average operating temperature, as a resultant of air temperature, delimiting surfaces, humidity and speed of air, in accordance with nature of activities and workers' clothing;
- limiting the asymmetry of radiant temperatures and temperature gradients to acceptable values;
- avoiding situations in which workers come in contact with too cold or too hot surfaces;
- avoiding drafts (limiting air speed);
- these requirements have to be met in both winter and summer conditions.

2 Methods and materials

Workplaces analysed in the research conducted on the analysis of thermal comfort indices of workers belong to organizations in Romania, in the field of steel casting and processing. Microclimate parameters of workplaces were determined by the staff of the Toxicology Laboratory within the National Institute for Research and Development - INSEMEX Petroșani. For each workplace analysed, the PMV and PPD indices were determined in order to objectively describe the workplace and to perform an analysis by correlating a job in normal conditions and several jobs in special conditions.

Regression analysis is a predictive modelling algorithm to predict the outcome of a variable and to identify variables (independent variables) that contribute to or depend on the outcome variable (target or dependent variable). It is a technique to find the relationship between independent and dependent variables, to produce the result.

PMV and PPD indices for the analysed workplaces were determined according to SR EN ISO 7730 which refers to analytical determination and interpretation of thermal comfort by calculating the PMV and PPD indices and specifying the local thermal comfort criteria. SR ISO 8756:1996 and SR EN ISO 7243:2018 were taken into account for processing data on temperature, pressure and humidity and estimating human thermal stress at work based on the WBGT index. Conclusions regarding the effects and influence of workplace microclimate on workers were summarized based on results obtained and by consulting the guide providing general aspects and methods of analysis used in industrial toxicology, developed by the Ministry of Health - National Institute of Public Health in 2016 and the guide for safety and health at work regarding workplaces, developed by the National Institute for Research - Development for Safety of Work "ALEXANDRU DARABONT" [7].

This method of assessing comfort consists of indices that can predict the thermal sensation felt by workers, for any combination of the four microclimatic parameters (t_i, t_{mr}, φ_i, v_i) and any level of activity and clothing. The body's predictable thermal sensation, as a whole, is evaluated by the PMV index only for values between +2 and –2 and the degree of discomfort (thermal dissatisfaction) is evaluated by the PPD index (eq. 2). For evaluation of the general thermal comfort in a room, the PMV - PPD model or the operating temperature are recommended, and verification can be done for parameters of the local thermal comfort: vertical temperature difference, temperature of considered surfaces and asymmetric radiation, which occurs if the temperature of buildings is much different from the average temperature of radiation.

The model for evaluating and verifying the thermal comfort in buildings was made based on the European standard ISO 7730 and the expression of the PMV index (eq. 1) established by Fanger is [6]:

$$PMV = [0.303 * \exp(-0.036 * M) + 0.028] \quad (1)$$

where: M is the metabolic energy produced by the human body in the unit of time

According to ISO 7730, the PMV index predicts the average value of voters of a large group of people on the 7-point thermal sensation scale (Fig. 1), based on the human's body thermal balance. Thermal balance is obtained when the internal heat production in the body is equal to the heat loss to the environment. In a moderate environment, the human thermoregulatory system will automatically try to change skin temperature and sweat secretion, to maintain thermal balance.

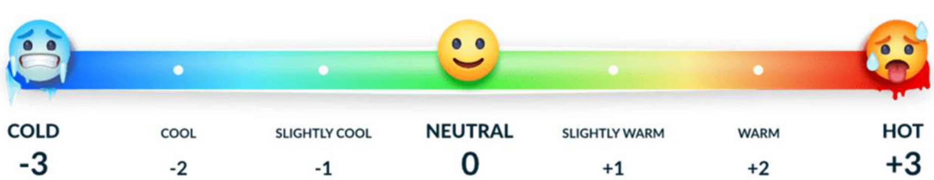

Fig. 1. Seven-point sensation scale according to SR EN ISO 7730 / 2006.

The PPD index (eq. 1) establishes a quantitative prediction of the percentage of thermally dissatisfied workers who feel too cold or too hot and is determined by the size of the PMV.

$$PPD = 100 – 95 \exp (– 0.03353 * PMV^4 – 0.2179PMV^2) \quad (2)$$

The relationship between PPD and PMV indices is represented graphically in figure 2 and is the combination of the six parameters (air temperature, average radiant temperature, humidity, velocity of air currents, metabolic rate and worker's clothing coefficient) necessary to determine the general degree of thermal comfort.

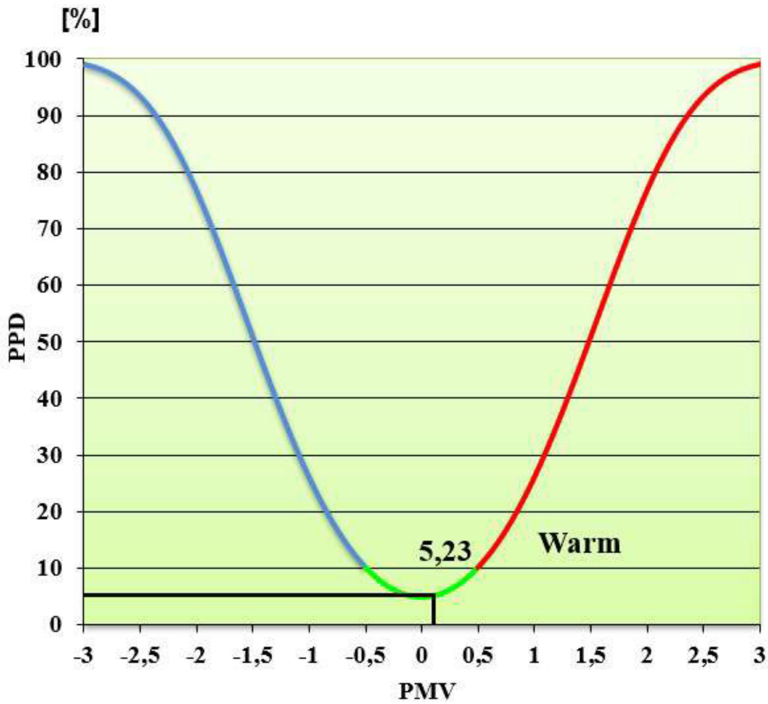

Fig. 2. Variation of PPD index according to PMV.

3 Results and discussions

Next, we named the 4 companies studied Steel factory - unit 1, Steel factory - unit 2, Steel factory - unit 3 and Steel factory - unit 4, in order to comply with the European norms on personal data. Results of microclimate determinations performed within the four companies, based on which we will calculate the PMV and PPD indices, are found in table 2 [8].

Using the results centralized in Table 1, the PMV and PPD indices were calculated according to SR EN ISO 7730. Parameters required for the calculation, such as metabolic energy production, mechanical working rate and basic insulation of clothing have been calculated according to Annexes A, B, C of the standard.

Results of PMV and PPD indices calculations for the 4 workplaces within the studied units are found in table 2.

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Table 1. Results of microclimate determinations.

No.	Place of determination	Air temperature [^{0}C]	Average radiant temperature [^{0}C]	lative air speed [m/s]	Relative humidity [%]
1.	Steel factory - unit 1	26.5	25.3	0.086	45.7
2.	Steel factory - unit 2	23.7	23.1	0.101	54.5
3.	Steel factory - unit 2	25.2	24.5	0.091	38.3
4.	Steel factory - unit 2	24.9	24.6	0.036	44.9
5.	Steel factory - unit 3	27.4	27.1	0.024	51.3
6.	Steel factory - unit 3	26.2	25.9	0.047	57.3
7.	Steel factory - unit 2	25.1	23.8	0.057	49.7
8.	Steel factory - unit 4	29.3	28.1	0.084	53.8
9.	Steel factory - unit 4	28.5	27.7	0.021	53.4
10.	Steel factory - unit 3	27.8	27.1	0.019	51.9
11.	Steel factory - unit 1	26.9	26.1	0.024	37.4
12.	Steel factory - unit 3	27.4	26.8	0.034	47.6

Table 2. Results of PMV and PPD calculations.

No.	Workplace	PMV index	PPD index [%]	PMV limits according to SR EN ISO 7730:2006	PPD limits according to SR EN ISO 7730:2006	Thermal sensation
1.	Steel factory - unit 1	1.17	33.8	-0.5 - +0.5	0% - 10%	Hot
2.	Steel factory - unit 2	0.70	15.3			Warm
3.	Steel factory - unit 2	0.89	21.7			Warm
4.	Steel factory - unit 2	0.95	24.2			Warm
5.	Steel factory - unit 3	1.52	52.2			Hot
6.	Steel factory - unit 3	1.32	41.5			Hot
7.	Steel factory - unit 2	0.94	23.6			Warm
8.	Steel factory - unit 4	1.83	68.8			Hot
9.	Steel factory - unit 4	1.72	63.2			Hot
10.	Steel factory - unit 3	1.57	55.0			Hot
11.	Steel factory - unit 1	1.25	37.8			Hot
12.	Steel factory - unit 3	1.46	48.9			Hot
13.	Office (ideal workplace)	0.2	5.0			Neutral

Ideal workplace PMV = 0.2 and PPD = 5 %

Results obtained were used to make a regression analysis of thermal comfort related to workplaces in the four studied units, an analysis which is graphically represented as follows:

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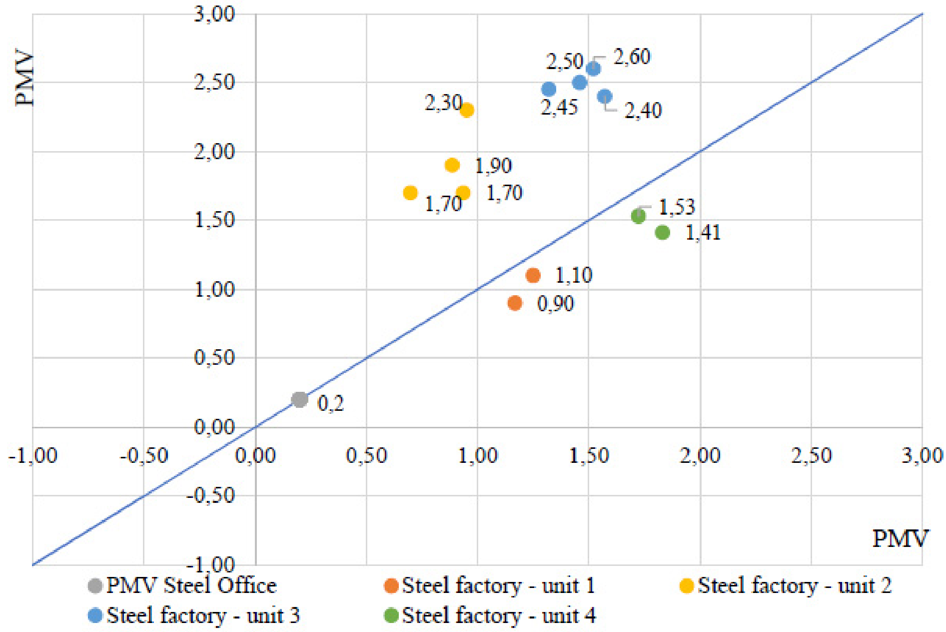

Fig. 3. PMV indexes for running bridge operators from Romania steel factories.

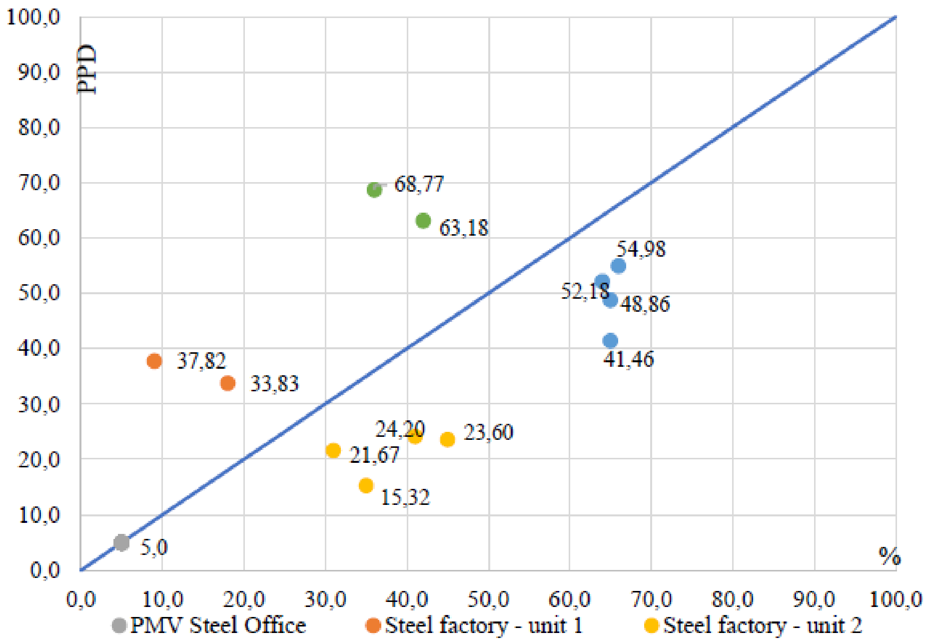

Fig. 4. PPD indexes for running bridge operators from Romania steel factories.

4 Conclusions

Following the analysis of results, the following can be stated:

1. Following the analysis of results, we observe that both the values of the PMV index and the values of the PPD index, are higher than the limit values established by SR EN ISO 7730: 2006.
2. We observe that the Predictable Percentage of Dissatisfied (PPD) for all studied workplaces, is positioned above the limit value of 10%, reaching a maximum value of 68.3%, which shows that thermal comfort is not satisfactory within the analysed workplaces, which can disrupt normal work pace and can lead to poor work performance.
3. The analysed jobs tend towards a work atmosphere with high temperatures, according to the analysis of the PMV indices, which is in all 3 cases between 1.7 -1.83, which can represent a health risk for workers.
4. In order to reduce the PMV and PPD values, in order to create favourable conditions for carrying out specific work activities within the analysed jobs, it is necessary to evaluate the opportunity of putting up efficient air conditioning installations and, subsequently, reanalysing the thermal comfort conditions of workers.

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