

**DETERMINATION OF HEAT LOAD BY WET BULB GLOBE TEMPERATURE  
IN WORKING ENVIRONMENT****KRÁLIKOVÁ Ružena***Faculty of Mechanical Engineering/Department of Process and Environmental Engineering, Technical  
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**Abstract:** Thermal load on people in general depends on the heat production in the human organism as a result of physical activity as well as environmental conditions which are affected by transfer of heat between human and the surrounding area. The resulting effect of metabolic exchanges which occur in work activities is the thermal load of organism. The paper deals with the evaluation of microclimatic conditions of the working environment of workers, who are exposed to the hot environment during their work.

**Key words:** working environment, microclimatic conditions, human, heat load

**Introduction**

Stress at workplace usually arises from an interaction of several risk factors. One of them may also be unsuitable climatic conditions. Thermal-moisture microclimate (TMM) is part of the overall microclimate in working environment, in which the most important factors are air temperature, middle temperature of the radiation, air moisture and air velocity.

At workplaces, where the values exceed acceptable microclimatic conditions due to the heat load from technological resources and at the rest of workplaces, where during extraordinary hot days work hours must be adjusted so that long-term and short-term viable TMM conditions are not exceeded. Acceptable microclimatic conditions are identified by long and short term tolerable load of the heat. Viable long-term heat load is limited by the amount of water excreted from the body through sweating and breathing, limit values for acclimated and non-acclimated employees are set out in decree [5]. Short-tolerable heat load is limited by the amount of stored heat in the body, that for acclimatized and non-acclimatized employees must not exceed  $180 \text{ kJ.m}^{-2}$ . This corresponds to a rise in core body temperature of  $0.8 \text{ K}$ , the rise of average skin temperature by  $3.5 \text{ K}$  and increase of heart rate to a maximum value of  $150 \text{ min}^{-1}$ .

Long and short periods of work acceptable at increased load of heat for men and women are determined by dependence on the energy intensity work class and the microclimatic conditions for acclimatized and non-acclimatized workers. Specific situation in the workplace is the thermal load from strong radiation from heat sources. In this case, the heat load for each exposed workplace using appropriate evaluation methods with the help of stereotemperature  $t_g$ , asymmetry in radiation temperature or by WBGT indicator [3]. In case of radiant heat sources where stereotemperature at workplace exceeds  $43^\circ\text{C}$  or radiance exceeds  $700 \text{ W.m}^{-2}$ , it is necessary to use protection against radiant heat.

**2. Bearable heat load**

From the basic data it is possible to determine heat load by Wet Bulb Globe Temperature (WBGT) indicator by measuring of parameters derived from the data. WBGT is one of empiric indicators representing heat load, to which an individual is exposed [3,4].

It represents a wet and ball thermometer temperatures, which combines natural ventilation temperature of the wet bulb thermometer  $t_{nv}$ , the resulting temperature of ball thermometer  $t_g$ , and air temperature  $t_a$ . WBGT indicator without the influence of solar radiation is calculated as:

$$WBGT = 0,7t_{nv} + 0,3t_g. \quad (1)$$

For WBGT indicator with solar radiation applies:

$$WBGT = 0,7t_{nv} + 0,2t_g + 0,1t_a. \quad (2)$$

Evaluation method of heat stress according to this indicator describes the standard STN ISO 7243 “Hot environment: Determination of worker’s thermal load ratio according to WBGT indicator” [3]. This evaluation method is considered only as a screening method. It is a compromise between the exact evaluation of the heat load and the effort to carry out control measurements in industrial applications.

Direct determination of the heat load by analysing data on heat exchange between men and the environment allows to accurately assess the load and to analyse ways of protection, which is very laborious and time consuming. It requires further detailed analysis and synthesis of data about working conditions in a hot environment and about individuals, especially when the acquired data exceed benchmarks of WBGT (see Table 1).

For reliable classification of the size of energy outgo it is necessary to make an objective measurement of energy outgo according to a detailed analysis of the activity. Reference values correspond to the level of exposure which workers can (under the conditions listed in Table 1) be exposed to without adverse effects on health, and these conditions should not cause accidents, as they were found no contra findings.

The introduction of methods for assessing the heat load by the WBGT indicator replace several methods of determining the heat load, because such indicator does not exist yet. Established international standard is suitable for use in industrial environments [3]. This standard is not suitable for assessing heat load during short time intervals, nor the evaluation of thermal comfort conditions. It is designed to assess the average effect of heat on men during the period of its effect and provides quick information.

**Table 1: Reference values of WBGT heatload**

No.	Energetic outgo		Reference value of WBGT			
	$q_M$ [W.m <sup>-2</sup> ]	M [W]	Person acclimatized on heat [°C]		Person not acclimatized on heat [°C]	
0	$M \leq 65$	$M \leq 117$	33		32	
1	$65 < M \leq 130$	$117 < M \leq 234$	30		29	
2	$130 < M \leq 200$	$234 < M \leq 360$	28		26	
3	$200 < M \leq 260$	$360 < M \leq 468$	No feeling of air moving	Feeling of air moving	No feeling of air moving	Feeling of air moving
			25	26	22	23
4	$M > 260$	$M > 468$	23	25	18	20

No. - energetic outgo class\* size according to character of work (0 - tranquility, 1 - low, 2 - medium,

3 - high, 4 - very high energetic outgo);  $q_M$  - energetic outgo per body unit [W.m<sup>-2</sup>]; M - total energetic outgo per standard person with body coverage of 1.8 m<sup>2</sup>

If reference benchmarks of heat load indicator are exceeded, it is necessary to lower heat load at workplace by appropriate technical measures or by organizational measures – determining the bearable work time. Setting the bearable work time can ensure compliance with viable long-term or short-term heat load. Indicative values of long and short term viable heat load are listed in the Annexes to the Decree [5].

### 3. Practical verification of measuring methodology

TMM has been the subject of measuring small foundry workplace, where a radiant heat sources were four furnaces. Measuring points (M1 to M4) were selected to represent place of residence of workers during the performance of their work. Measurement was carried out during a summer day with daytime temperatures from 18 to 29 °C in the morning time change.

Measured parameters were air temperature  $t_a$  (°C), the resulting spherical bulb temperature  $t_g$  (°C), wet bulb temperature  $t_{vn}$  (°C), air velocity  $v_a$  (m.s<sup>-1</sup>) and relative humidity  $R_h$  (%). Digital devices with a spherical sensor  $t_g$ ,  $t_{vn}$  triple-probe for sensing  $v_a$ ,  $R_h$ ,  $t_a$  were used.

Basic characteristics of the sample number of measured values (selective average  $\bar{x}$ , maximum, minimum and standard deviation of selection s) are listed in Table 2 and Table 3.

Using the scatter chart (Figure 1 - Figure 2) the measured values of the variables at different sites of measurement are shown.

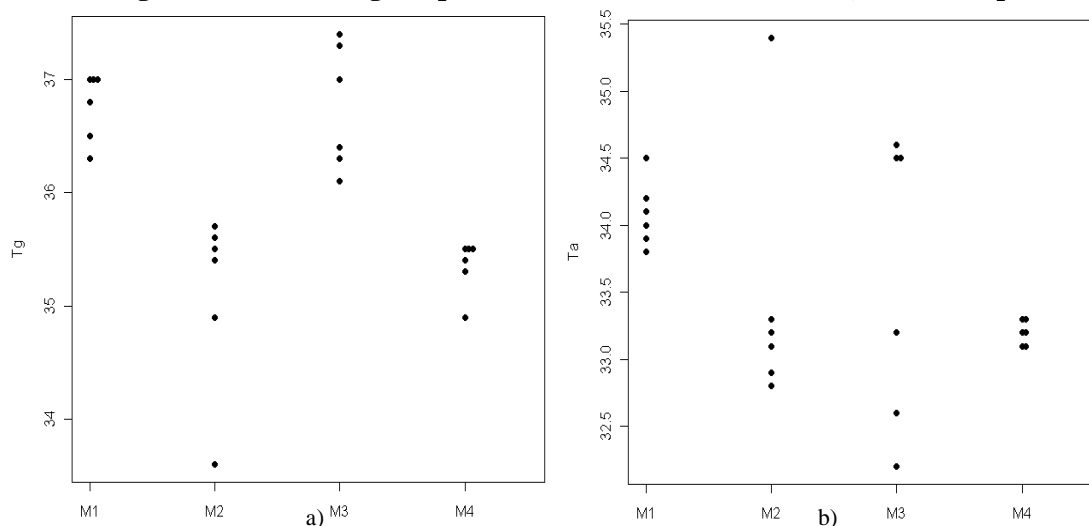
**Table 2: Descriptive statistics – Measuring points M1 and M2**

	M1				M2			
	min	$\bar{x}$	max	s	min	$\bar{x}$	max	s
$t_g$	36,3	36,7667	37,0	0,3011	33,6	35,1167	35,7	0,7935
$t_a$	33,8	34,083	34,5	0,2483	32,8	33,450	35,4	0,9731
$t_{vn}$	26,5	26,6667	26,90	0,1633	25,9	26,0333	26,30	0,1366
$v_a$	0,10	0,1433	0,22	0,0468	0,14	0,2350	0,32	4,2881
$R_h$	44,0	48,000	55,3	4,2881	44,7	46,750	51,8	2,5844

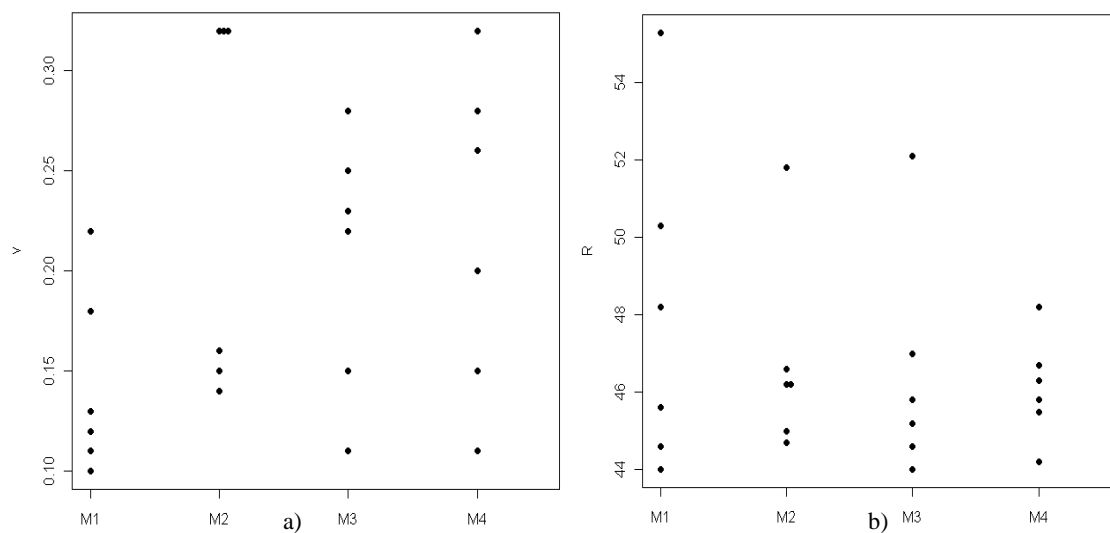
**Table 3: Descriptive statistics – Measuring points M3 and M4**

	M3				M4			
	min	$\bar{x}$	max	s	min	$\bar{x}$	max	s
$t_g$	36,1	36,7500	37,4	0,5541	34,9	35,3500	35,5	0,2345
$t_a$	32,2	33,600	34,6	1,0714	33,1	33,200	33,3	0,0894
$t_{vn}$	26,2	26,6333	27,00	0,3830	23,2	25,7667	26,30	1,2580
$v_a$	0,11	0,2067	0,28	0,0641	44,0	46,450	52,1	2,9541
$R_h$	0,11	0,2200	0,32	0,0807	44,2	46,117	48,2	1,3318

**Figure 1: a) Resulting temperature of the ball thermometer, b) Air temperature**



**Figure 2: a) Air velocity, b) Relative humidity**



The average median value of radiation temperature  $t_r$  (°C), operative temperature  $t_o$  (°C) and the intensity of radiation  $I$  (W.m<sup>-2</sup>) for each measuring point were obtained by relations (1), (2) and are listed in Table 4. These values significantly exceeded the limit values.

**Table 4: Values –  $t_r$ ,  $t_o$ ,  $I$**

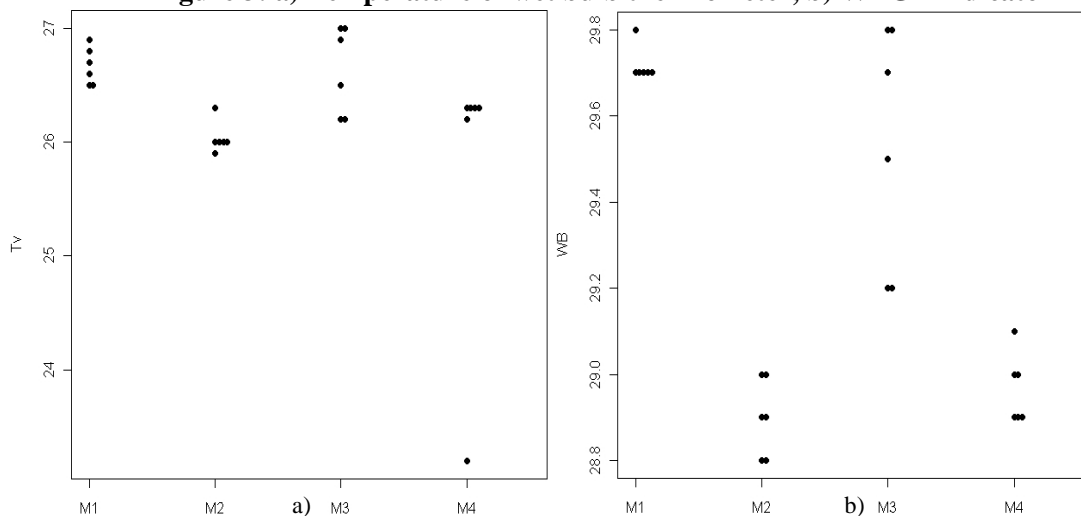
Measuring place	$t_r$ [°C]	$t_o$ [°C]	$I$ [W.m <sup>-2</sup> ]
M1	38,79	36,44	46,24
M2	36,83	35,14	32,69
M3	39,69	36,65	52,61
M4	37,47	35,34	37,08

Calculated values for WBGT indicator according to equation (2) for the individual measuring points are listed in Table 5. Scatter plots of measured values of wet bulb thermometer temperature and the calculated values of WBGT heat load are shown in Figure 3.

**Table 5: WBGT values for measuring points M1, M2, M3, M4**

Time	WBGT			
	M1	M2	M3	M4
9:00	29,73	28,88	29,47	29,03
10:00	29,72	28,84	29,23	26,89
11:00	29,86	28,28	29,17	28,88
12:00	29,72	29,03	29,93	28,93
13:00	29,50	28,85	30,09	29,06
14:00	29,65	28,67	30,12	29,06

**Figure 3: a) Temperature of wet bulb thermometer, b) WBGT indicator**



The values of the thermal load indicator by WBGT are compared with benchmark WBGT indicators, which are listed in Table 2. By comparing the values significant differences were found, on these basis it is necessary to draw the appropriate technical, health, organizational and other measures.

## Conclusions

Hot environment weakens the physical and mental performance. If the values of microclimatic variables are beyond the permissible values the work time must be adjusted in order to meet long-and short-term tolerable heat load. The most effective protection against heat load is combination of various methods - technical regulation or administrative regulation, and personal protective equipment (cooling, breathable clothes), water refreshment (hydration), breaks in work time. Acclimatization is another option – it is a result of physiological adaptation process. Acclimatization can be achieved either artificially by controlled repeated exposure in the acclimatization chamber, or naturally by progressive prolongation of intervals of performed work in hot environment. This work was supported by project APVV – 0432-12.

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