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EVALUATION OF THERMO-HYGRIC MICROCLIMATE PARAMETERS IN THE WORK ENVIRONMENT

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Thermo-hygric microclimate evaluation and planning is important for improving quality of work environment and protecting employees' health. The thermo-hygric microclimate objective evaluation is performed by measuring its physical parameters. It is a part of a comprehensive microclimate of internal environment. This article introduces elementary thermo-hygric parameters and their measurement and evaluation methods and informs about sources of their limit values. Human body emits its own metabolic heat and affects the final body temperature therefore it is necessary to know what the emitted amount is. There is also information about recommended ways to determine human's emitted metabolic heat in this article.
Key words: metabolic heat, measuring, Index WBGT (Wet Bulb Globe Temperature), optimisation.

Vrednovanje termo-higroskopskih mikroklimatskih parametara u radnom okolišu. Procjena i planiranje termo-higroskopskih uvjeta važni su za poboljšanje radnih uvjeta i zdravlje djelatnika. Vrednovanje termo-higroskopskih uvjeta provedeno je mjerenjem fizičkih parametara, koji su dio cjelokupne mikroklime interijera. Ovim radom su predstavljeni osnovni termo-higroskopski parametri, njihovo mjerenje i procjena metoda te pregled informacija o dozvoljenim vrijednostima. Ljudsko tijelo emitira vlastitu metaboličku toplinu koja utječe na ukupnu tjelesnu temperature, zbog čega je znati emitirane količine topline. Također su u ovom radu iznesene informacije o preporučenim načinima određivanja emitirane metaboličke topline ljudskog tijela.
Ključne riječi: metabolička toplina, mjerenje, indeks temperature mokrog termometra, WBGT (Wet Bulb Globe Temperature), optimalizacija.

INTRODUCTION

The thermo-hygric comfort is a state of environment in which heat and hygric flow affects people [1]. One of the most important factors affecting the overall balance on human body burden is presence of heat and cold. To determine the degree of physical human body burden it is also necessary to consider several factors of thermo-hygric microclimate. It is well known that the more negative factors are present in environment (safety factors, ionizing radiation, Roentgen radiation, air purity, toxic substances, biological factors, thermal radiation, electromagnetic radiation, lighting, vibrations) the more negative impact they will have on the workers health [2].

For shaping optimal thermo-hygric microclimate model it is important to know limiting physical human body burden values and which technological equipment is present in certain work environment.

Basic thermo-hygric microclimate parameters

The thermo-hygric microclimate is a part of global climate in work environment. It is formed by heat and humidity flows (heat and steam) [1]. Basic parameters of thermo-hygric microclimate and their definitions are listed in Table 1.

Table 1. Basic thermo-hygric internal microclimate parameters
Table 1. Osnovni termo-higrički parametri mikroklime interijera

Parameter	**Identification symbol**	**Unit**	**Characteristics**
Air temperature	t_a	(°C)	Temperature of the indoor air without the affects of heat radiant from the surrounding areas. It is called the dry temperature [3].
The mean radiation temperature	t_r	(°C)	Homogenous temperature of surrounding areas in which the heat exchanged by radiation between the surface of the human body and the surrounding areas is the same as in a real heterogeneous environment [3].
Speed of air flow	v_a	(ms^{-1})	Is a quantity determined by amount and direction of flow. It characterise the movement of air in the space [3].
Resulting temperature measured by ball thermometer	t_g	(°C)	Known as the temperature of black ball or otherwise known as global temperature. It is an indicator of thermal condition of inner space covering the influence of recent air temperature (t_a), temperature of the surrounding areas (t_r) and air flow speed (v_a) [3].
Wet thermometer temperature	t_{wn}	(°C)	Psychrometric wet temperature is measured by wet valve thermometer [3].
Operational temperature	t_o	(°C)	Joint temperature of closed black space, where would happen change of the same amount of heat caused by convection and radiation as in real homogenous environment [3].
Relative humidity	R_h	(%)	Ratio between the partial pressure of water vapour in the air and saturated water vapour pressure at the same temperature and same total pressure [4].
Radiation intensity	I	(Wm^{-2})	It describes the heat exchange by radiation between the surface area of space and the human body. It is an effective heat flux shared by radiation [4].

As necessary, overall clothing insulation R_{cl} (m^2KW^{-1}), surface temperature t_s (°C) and other necessary values are specified.

Determination of the human body energy expenditure

To determine the impact of thermo-hygric microclimate parameters on human health, and thus evaluate the thermal load it is essential to determine a total energy expenditure of the human body or the metabolic heat gross amount, q_M (Wm^{-2}).

Total energy expenditure of the human body (Fig. 1) includes a primary heat generation (basal metabolism), energy expenditure from physical activity (the metabolic heat net amount) and the mental work (Fig. 1) [5].

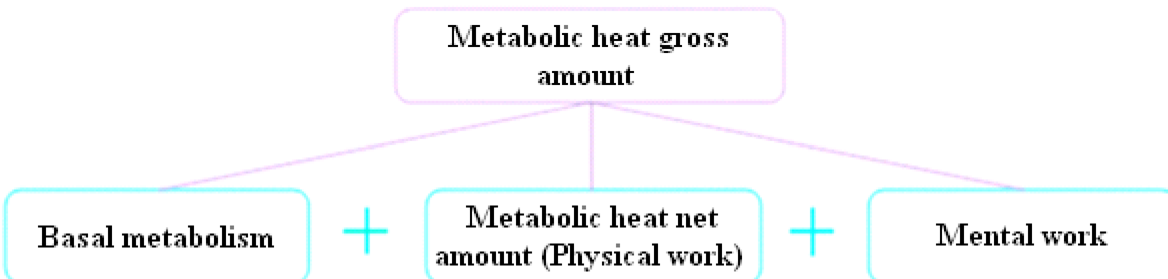

Figure 1. Total energy expenditure of the human body
Slika 1. Ukupna potrošnja energije ljudskog tijela

Basal metabolism is measured either by the direct method in energometers (special completely thermal insulated chambers, for measuring the amount of work done by human muscles) or by simpler indirect method (calculating of the amount of oxygen consumed).

The indirect ergometrics supposes that the amount of oxygen consumed corresponds to the current human's emitted metabolic heat. After inhaling of the atmospheric air, exhailed air goes to a analyzer bag. The basal metabolism depends on the age, gender, body surface (m^2), body weight, height and can be determined from tables. [6].

To determine the burden from physical activity the values such as heart beats per minute, increased blood pressure and respiratory rate are used. Direct determination of total energy expenditure during work activities is possible and ways are shown in Table 2.

Table 2. Direct determination of total energy expenditure during work activities
Tablica 2. Direktno određivanje ukupne potrošnje energije tijekom radnog vremena

No.	Possible ways of finding the total energy expenditure during work activities
1.	Estimated energy output from the reference tables according to the type of activity, occupation, and by body position. Values show net energy output and omit the value of basal metabolism.
2.	Calculation of energy expenditure using the reference tables. It is important to know the temporal distribution of work tasks during work hours. Procedures and methodology were described in detail in I. and II. in Appendix No.11 in Acta Hygienica, Epidemiologica et Microbiologica from the year 1978 [6].
3.	Calculation of energy expenditure values from the heart rate. Regression equation between heart rate and energy expenditure are used. This method should be used when load is put on large muscle groups and no large share of the static, thermal and mental stress is present.
4.	Determination of energy expenditure using heart rate measuring device that measures heart rate and total (gross) energy expenditure during physical load.
5.	Determination of energy expenditure using WBGT (wet bulb globe temperature) according to EN 27243.

Although the reference data are obtained by actual measurement, calculations and estimations are always just indicative.

Wet Bulb Globe Temperature index

The Wet Bulb Globe Temperature index (WBGT index) is a composite temperature used to estimate the effect of temperature, humidity, wind speed (wind chill) and solar radiation on humans. It is used by industrial hygienists, athletes, and the military to determine appropriate exposure levels to high temperatures.

Wet bulb and ball thermometers or WBGT are used for taking and evaluating temperature parameters from extremely hot or cold operations. Obtained results should be considered only for informational purposes [7].

Index WBGT combines the temperature values from wet bulb thermometer (t_{wn}), the resulting temperature from ball thermometer (t_g), and air temperature (t_a). WBGT index is calculated for buildings and outdoor spaces with and without the impact of solar radiation. Measurements are carried out by the sensor (Fig. 2 a).

Suitable measuring devices are connected to the sensor and directly calculate WBGT (Fig. 2 b). Measured or calculated WBGT values are then shown on display (Fig. 2 c) and are compared with reference values presented in tables for people who are acclimatized or not acclimatized to heat.

a) b) c)

a) Sensor WBGT, b) Measuring device, c) Display readings from the measuring device

Figure 2. Measuring of WBGT index
Slika 2. MjerenjeWBGT indeksa a) sensor WBGT; b) mjerni instrument; c) očitavanje mjerenja

Thermo-hygric microclimate measurements

Table 3. Custom measuring of thermo-hygric microclimate parameters
Tablica 3. Uobičajeno mjerenje termo-higričkih mikroklimatskih parametara

No.	Parameter	Ways of measuring thermal-hygric microclimate parameters
1.	Air temperature t_a (°C)	Obtained by measuring the physical quantities which are continuous functions: the length of the solid, liquid volume, electrical resistance, electromotive force. Air temperature measuring devices can be divided in groups: [4] expansion, electric and thermomanometric.
2.	Mean radiation temperature t_r (°C)	The mean radiation temperature t_r (°C) can be measured by devices which allow the integration of the mean value from total radiation from the uneven surface [4]. It is measured by black ball thermometer, double ball radiometry, sensor at constant air temperature or is calculated from the radiation temperature of surrounded areas.
3.	Airflow speed v_a (ms^{-1})	In general, it can be obtained from omnidirectional sensor which is sensitive to the speed in any direction and with three-dimensional sensor that measures the individual components of airflow velocity along three mutually perpendicular axes [4].
4.	Resulting temperature measured by ball thermometer t_g (°C)	Obtained by black ball thermometer or stereothermometer.
5.	Wet thermometer temperature t_{wn} (°C)	Read from psychrometric diagram or measured by valve wet thermometer. Psychrometric wet temperature (t_{wn}) should not be confused with natural wet temperature t_{vn} (°C) which is measured by naturally cooled wet thermometer [4].
6.	Operational temperature t_o (°C)	It is measured by the sensor which diameter is estimated according to ISO 7730, or by calculation.
7.	Relative air humidity R_h (%)	It is measured by capacitive meter and aspiration psychrometer. It is determined from psychrometric diagram, nomogram or is calculated.
8.	Radiation intensity I (W.m^{-2})	It is determined by instruments that measure the thermal radiation in (W.m^{-2}) or it is calculated.

In general measured physical parameters change in time. We must have in mind these changes during measurements. Methods used for measuring parameters linked with thermal-hygric microclimate are listed in Tab. 3.

DISCUSION

Microclimatic conditions can be divided into optimal, acceptable and tolerable groups [3]. The environment can be considered bio-climatically homogeneous if the variables are practically uniform at the certain moment around a person [7]. Thermal environment may change in the horizontal or vertical position. It is therefore necessary to take into account how long a person works in a certain place. If the environment is heterogeneous (heat or cold radiation sources are present, air flow velocity changes are significant etc.), variables must be measured in several places and around the workers head, stomach and ankles [4]. The above-mentioned parameters of thermo-hygric microclimate can also be measured simultaneously (during 8 hour working shift, 6 hour measurement with regular 30 min. break must be performed) at different locations using multiple sensors connected to several devices.

Height for placing sensor, weight coefficients for calculating the average values of physical quantities, standard conditions determining time constants of sensors and measuring heights for physical variables of environment are specified in EN ISO 7726.

Optimization of thermo-hygric microclimate is done by air conditioning; ventilation and heating, depending on hot and cold days or on total body heat produced by employee.

Optimization could be done by removing the source of heat or cold, with the exception of working areas which require special thermal conditions and workplaces where loads of heat and cold are result of technological process. Heat load can be reduced by providing adequate working time, working area with a place for break, training courses for employers and employee to learn and inform of occupational safety, health and ergonomics, personal protective equipment, protective clothing and drinking, reducing unnecessary physical activity. The other way how to reduce thermal load is the acclimatization of workers. It is a process of physiological adaptation of workers to changes in the work environment, such as humidity, temperature, light etc. It is performed by gradual prolongation of working time in the work environment. The most effective way of protection from heat or cold is a combination of mentioned solutions.

CONCLUSION

Technological advances have allowed that in developed countries, fewer people are actually exposed to heavy physical work. Nevertheless, particularly adverse working conditions exist in the industrial workplaces [2]. Therefore, the optimal design of thermo-hygric microclimate parameters are important for creating a healthy working environment for newly created or already existing workplaces where microclimate conditions are unsatisfactory.

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REFERENCES

[1] J. Pajtik, J. Borota, Work and living environment, Technical University of Zvolen, Zvolen, 1992.

[2] E. Lumnitzer, M. Badida, M. Romanova, Assessment of the environmental quality, Faculty of mechanical engineering, Technical University of Košice, Elfa s.r.o., Košice, 2007.

[3] The order of Ministry of health of the Slovak Republic no. 544/2007 local codex.

[4] EN ISO 7726 Ergonomics of the thermal environment: Instruments for measuring physical quantities, 7-30.

[5] D. Hamar, J. Lipkova, Fyziológia telesných cvičení. Physiology of the body exercises, Comenius University in Bratislava, 2001. Pages 50-60.

[6] http://matej.gaya.sk/Diplomova praca Matej Pauliny 2009. 31-57.

[7] EN 27243 Hot environments. Estimation of the heat stress on working man, based on the WBGT index (wet bulb globe temperature), 7-10.