Industrial Health 2017, **55**, 437–443

Original Article

Application of Universal Thermal Climate Index (UTCI) for assessment of occupational heat stress in open-pit mines

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Received February 1, 2017 and accepted July 31, 2017
Published online in J-STAGE August 11, 2017

Abstract: The purpose of this article is to examine the applicability of Universal Thermal Climate Index (UTCI) index as an innovative index for evaluating of occupational heat stress in outdoor environments. 175 workers of 12 open-pit mines in Tehran, Iran were selected for this research study. First, the environmental variables such as air temperature, wet-bulb temperature, globe temperature, relative humidity and air flow rate were measured; then UTCI, wet-bulb globe temperature (WBGT) and heat stress index (HSI) indices were calculated. Simultaneously, physiological parameters including heart rate, oral temperature, tympanic temperature and skin temperature of workers were measured. UTCI and WBGT are positively significantly correlated with all environmental parameters ($p<0.03$), except for air velocity ($r<-0.39$; $p>0.05$). Moreover, a strong significant relationship was found between UTCI and WBGT ($r=0.95$; $p<0.001$). The significant positive correlations exist between physiological parameters including oral temperature, tympanic and skin temperatures and heart rate and both the UTCI and WBGT indices ($p<0.029$). The highest correlation coefficient has been found between the UTCI and physiological parameters. Due to the low humidity and air velocity (~<1 m/s) in understudied mines, UTCI index appears to be appropriate to assess the occupational heat stress in these outdoor workplaces.

Key words: Heat stress, UTCI, WBGT, HSI, Physiological parameters, Open-pit mines

Introduction

Heat is one of the work-related risk factors in both indoor (such as metal smelting industry and casting) and outdoor environment (open pit mine, farm, and construction sites)[1, 2]. Despite large numbers of workers employed

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in outdoor workplaces comparing to indoor environments, fewer studies have been conducted on them. Rising the temperature in these workplaces can be resulted from heat produced by both industrial processes and atmospheric heating during warm seasons[3, 4]. Indeed, heat is an inherent occupational hazardous agent in the outdoor workplaces especially in environment with a hot and dry climate. Moreover, it is hard to control heat stress using air-conditioning systems in such outdoor environments[4]. Mining operations face potentially health risks from improper climatic conditions. Heat sources in open-pit mines include sun light, blasting, electrical tools, and working machines like diesel engines[5, 6]. In Iran, a large number of mine workers are exposed to heat due to type of mining activity and weather conditions of Iran. Statistical Centre of Iran has reported that there were 6,206 open-pit mines, including 84,528 workers in 2012. Unfortunately, there are no precise data on number of workers exposed to heat stress in open-pit mines and also no comprehensive studies have been done to assess the heat stress in them[7, 8].

During the last century, many heat stress indices have been developed in different categories including empirical, rational and direct. For calculating these indices, it is required to measure some environmental parameters like dry, wet, and radiant temperatures and air velocity, some occupational factors like worker's metabolic rate, clothing insulation and physiological parameters like skin temperature, heart rate, deep body temperature, sweat rate and weight loss caused by sweating. Usually, special equipment is needed to measure them, besides this approach may be very complex and time-consuming, and sometimes measuring some indices (such as physiological strain index) may interfere with worker's activities[9, 10]. Wet-bulb globe temperature (WBGT) as an empirical index is assumed in International Organization for Standardization (ISO) as thermal stress index in job environments. It is a most widely used index which was developed by Yaglou and Minardinin[1, 11]. Standard ISO 7243 (Hot environments -- estimation of the heat stress on working man, based on the WBGT-index) offers different equations for calculating WBGT in indoor and outdoor environment[12−14].

Despite this, measurement of WBGT is so time-consuming and can be costly (from the viewpoint of the measurement equipment and manpower) for applying in small and medium-sized manufacturing enterprise. A careful calibration of the measurement sensors especially radiant temperature sensors is needed before measuring it and it takes a long time to reach thermal equilibrium between its sensors and ambient air. WBGT requires that the parameters such as clothing insulation (Clo), worker's metabolism rate have been estimated, and also there are some limitations for using WBGT in low air velocity or high humidity environment[15−17].

In 2011, a new heat stress index for using in outdoor thermal environment for public health purposes was presented by COST (a European Union program promoting Cooperation in Science and Technology) Action 730. It is assigned universal thermal climate index (UTCI)[18, 19]. UCTI index is derived from recent scientific advances in the field of human thermal physiology, biophysics and heat exchange theory. UTCI has a high sensitivity to small degree of variation in temperature, solar radiation, humidity and wind speed and it can be applicable in different types of climate. Therefore, this index provides the proper assessment of climate change on human health[20, 21]. UTCI categorize the thermal stress in 10 classes as an equivalent temperature ranging from −50 to +50°C, from extreme cold to extreme heat stress[5, 22].

The aim of the present study was to examine the applicability of UTCI index for assessing occupational heat stress in open-pit mines. For this purpose, WBGT as a standard widely used empirical index and heat stress index (HSI) as a common analytical index were measured to be a basis for comparison and validation of this applicability of UTCI. Since, the correlation between heat stress index and physiological parameters can be an important measure for evaluation of a heat stress index; the physiological responses such as oral temperature, the tympanic temperature, skin temperature and heart rate of exposed workers to heat were measured.

Subjects and Methods

All open-pit mines of three cities Pakdasht (6 mines), Shahr-e Qods (3 mines) and Damavand (3 mines) of Tehran province were selected for this cross-sectional study which was done in the summer of 2016. Tehran province has different climatic characteristics, for example, Damavand is located at an altitude of 2,000 meters above sea level and it has semi-humid weather with long cold winters. Pakdasht and Shahr-e Qods are located at altitudes lower than 1,000 meters above sea level. They have semi-arid climate with shorter winters and warmer summers[23].

Inclusion criteria for participants were being heat-acclimated, having no background of cardiovascular and kidney diseases, high blood pressure and fever and not being under any other special medical treatment. Subjects who had work experience less than 1 yr in the outdoor environment were excluded. A signed informed consent had been obtained from all participants and Ethical approval was granted by the Research Ethics Committee of Tehran University of Medical Sciences.

The mean of subject workload (metabolic rate) according ISO-8996[24] and thermal insulation of cloths according ISO-9920[25] were estimated from 264.2 to 313.33 watt and 0.79 Clo, respectively. In total, 175 workers with medium workload were simple randomly selected, participated in the study and they were studied in three different tasks.

A calibrated WBGT meter (Emerson Co., model TIS 10; Iran) was used to measuring the dry temperature, black-globe temperature, natural wet-bulb temperature and WBGT index. Relative humidity was measured by humidity meter (TES Electrical Electronic Corp, modelTES-1363; Taiwan). Air velocity was measured by hot wire anemometer (Standard Co., ST-8880; Hong Kong). These measurements were carried out based on the standard ISO 7243[12] and recorded at 9:00 am, 12:00 pm and 15:00.

Since the pilot measurement of environmental changes indicated no significant fluctuations of understudy environmental parameters, all measurements were conducted only at the waist height of workers according to their postures during doing work. The studied indices were calculated as follow:

WBGT index:

To calculate WBGT index in outdoor environment we used Equation 1:

$$WBGT_{outdoor} = 0.7T_{nw} + 0.2T_g + 0.1T_a \qquad \text{(Eq. 1)}$$

Where, T_{nw} is natural wet-bulb temperature, T_g is the black-globe temperature and T_a is the natural dry-bulb temperature. Also, a correction factor for clothing of workers was considered in WBGT calculations[1, 3].

HSI index:

The following equation was used to calculate the HSI;

$$HSI = \frac{Ereq}{Emax} \times 100 \qquad \text{(Eq. 2)}$$

Where, E_{req} is the thermal energy is required to be excreted from the body by evaporation to achieve thermal equilibrium.

$$E_{req} = M - R - C \qquad \text{(Eq. 3)}$$

Where, M is metabolic rate in w/m^2, R is radiation heat transfer (w/m^2) which is equal to:

R = 4.4 (35-MRT), C is convective heat transfer (w/m^2) which is equal to: C = 4.6 $V^{0.6}$ (35-T_a).

MRT is mean radiant temperature (°C), V is air velocity (m/s), Ta is dry temperature (°C), and E_{max} is maximum energy excreted from the body by evaporation in the working environment: E_{max} = 7 $V^{0.6}$ (56-Pa) (w/m^2), Pa is pressure of water vapor in air (mb)[2, 8].

UTCI index:

The UTCI can be presented in general function as bellow:

$$UTCI = f(T_a; T_{MRT}; V_a; RH) \qquad \text{(Eq. 4)}$$

Where T_a is air temperature, T_{MRT} is mean radiant temperature, V_a is wind speed and RH is relative humidity. UTCI was calculated according to study done by Blazejczyk *et al.* (2013)[26].

Simultaneously, physiological parameters were measured. For this purpose, a digital sublingual oral thermometer (Beurer, model FT09; Germany), non-contact thermometer (Microlife, model NC 120; China) and non-contact infrared thermometer (Microlife, model NC 150; China) for measurement of oral, tympanic membrane temperature as deep temperature and skin temperature were used, respectively. Heart (pulse) rate was measured by the wrist blood pressure monitor (Beurer, model BC60; Germany). Skin temperature was measured in four points of the body surface according to ISO 9886[27] and mean skin temperature was calculated as follows:

Mean skin temperature = (0.28 Right scapula) + (0.28 Neck) + (0.28 Right shin) + (0.16 Left hand) (Eq. 5).

All statistical analyses were performed using Microsoft Office Excel 2010 and SPSS statistical software (ver. 18). Significance level was set at 0.05.

Results

The mean age of participants was 36.8 ± 9.36 yr. Their mean duration of employment and body mass index were 6.61 ± 5 yr and 26.27 ± 4.36 kg/m^2, respectively. Table 1 presents measurement results of environmental, physiological parameters and heat stress indices in three measurement times. All environmental parameters, except for relative humidity, and all heat stress indices showed the increasing trend over the time in a day; however there were no significant changes in physiological parameters during the day. Daily mean and standard error of WBGT, UTCI and HSI was obtained 27.45 (0.37)°C, 37.52 (0.63)°C and 71.60 (3.16)%, respectively.

Table 1. Measurement results of environmental, physiological parameters and heat stress indices in three measurement times

Variable	9 AM	12 PM	15 PM	Daily average
Environmental parameters (Mean ± SD)				
Dry-bulb temperature (°C)	33.3 ± 3.9	38.7 ± 2.8	41 ± 3.6	37.7 ± 4.7
Natural wet bulb temperature (°C)	20.7 ± 2.7	22.2 ± 2.7	23.1 ± 2.4	22 ± 2.3
Black-globe temperature (°C)	36.8 ± 4.8	42.4 ± 3.6	44.3 ± 4.1	41.2 ± 5.3
Relative humidity (%)	20.5 ± 7.7	13.7 ± 6.4	12.5 ± 6.3	15.6 ± 7.2
Air velocity (m/s)	0.9 ± 0.42	1.06 ± 0.4	1.07 ± 0.4	1.02 ± 0.4
Mean radiant temperature (MRT) (°C)	39.2 ± 5.3	44.6 ± 4.4	46.4 ± 4.5	43.4 ± 60
Physiological parameters (Mean ± SD)				
Oral temperature (°C)	36.26 ± 0.47	36.4 ± 0.55	36.5 ± 0.47	36.37 ± 0.37
Aural temperature (°C)	35.51 ± 1.10	36.2 ± 0.82	36.55 ± 0.68	36.1 ± 0.67
Mean skintemperature(°C)	34.70 ± 1.60	35.46 ± 1.50	35.9 ± 1.30	35.35 ± 1.24
Heart rate (beat/min)	80.14 ± 13.90	79.37 ± 13.80	82.1 ± 13.70	80.53 ± 8.30
Heat stress indices (Mean ± SD)				
Wet-bulb globe temperature (WBGT) (°C)	25.25 ± 2.90	28 ± 2.40	29.12 ± 2.60	27.45 ± 2.90
Universal thermal climate index (UTCI) (°C)	32.80 ± 3.40	38.93 ± 3.60	40.83 ± 3.70	37.52 ± 4.90
Heat stress index (HSI) (%)	63.96 ± 25.70	73.84 ± 24	76.95 ± 24.70	71.60 ± 23

Table 2. Relationship betweenthe environmental and physiological parameters and for the heat stress indices

Variable		WBGT (°C)	UTCI (°C)	HSI (%)
Environmental parameters				
Dry-bulb temperature (°C)	R	0.910	0.983	0.258
	p-value	0.001	0.001	0.045
Natural wet bulb temperature (°C)	R	0.935	0.794	0.271
	p-value	0.001	0.001	0.033
Globe temperature (°C)	R	0.903	0.948	0.262
	p-value	0.001	0.001	0.001
Relative humidity (%)	R	0.343	0.288	0.214
	p-value	0.001	0.022	0.095
Air velocity (m/s)	R	−0.198	−0.234	0.019
	p-value	0.389	0.308	0.885
MRT (°C)	R	0.528	0.530	0.284
	p-value	0.001	0.001	0.025
Physiological parameters				
Oral temperature (°C)	R	0.474	0.514	0.291
	p-value	0.001	0.001	0.023
Aural temperature (°C)	R	0.474	0.506	0.037
	p-value	0.001	0.001	0.777
Mean skin temperature (°C)	R	0.457	0.502	0.279
	p-value	0.001	0.001	0.027
Heart rate (beat/min)	R	0.275	0.279	0.123
	p-value	0.029	0.025	0.343
Heat stress indices				
Wet-bulb globe temperature (WBGT) (°C)	R	1	0.950	0.214
	p-value		0.001	0.100
Universal Thermal Climate Index (UTCI) (°C)	R	0.950	1	0.133
	p-value	0.001		0.303
Heat stress index (HSI) (%)	R	0.214	0.133	1
	p-value	0.100	0.303	

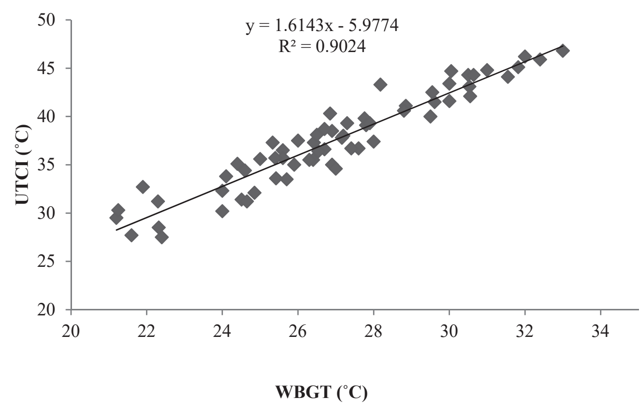

Fig. 1. Linear correlation graphof UTCI with WBGT index.

The relationships between heat stress indices and environmental and physiological parameters are shown in Table 2 (Pearson Correlation Coefficient test). UTCI and WBGT are significantly correlated with all environmental parameters ($p<0.03$), except for air velocity ($p>0.05$). There was weak negative relationship between both WBGT and UTCI with air velocity (r=−0.198 and r=−0.234, respectively). The highest correlation coefficient has been found between the WBGT and natural wet bulb temperature (r=0.935), UTCI and Dry-bulb temperature (r=0.983) and also between HSI and MRT (r=0.284; $p<0.03$). In comparison with other studied indices, UTCI had the highest correlation coefficient with environmental parameters.

In terms of physiological responses, the significant positive correlations exist between all physiological parameters and both the UTCI and WBGT indices ($p<0.03$). HSI was significantly correlated with oral and skin temperatures ($p<0.03$). The highest correlation coefficient has been found between the UTCI and physiological parameters.

A linear correlation between WBGT and UTCI is shown in Fig. 1. There were statistically significant relationship between UTCI and WBGT (r=0.950; $p<0.001$). There were weak positive correlations exist between HSI index with both WBGT (r=0.214; $p>0.05$) and UTCI (r=0.133; $p>0.05$).

Discussion

Improvement of safety and occupational health at workplaces has gotten so much attention in worldwide. Potential adverse health effects of undesirable climatic conditions accompanying with various job requirements such as working clothes, work load, working metabolism rate, long exposure, the use of personal protective equipment and lack of proper recreational facilities in outdoor workplaces, lead to incidence of heat stress, especially in the warm seasons. These workers suffer from disorders such as thermal weakness, muscle cramps, and heatstroke[2, 3]. The first step in management and prevention policies is a risk assessment and identification of individuals who are exposed to the heat stress. A useful tool for evaluating the heat stress in workplaces is using the heat stress indices. UTCI index is one of the valid assessment procedures which are applied for measurement of the heat stress in outdoor environment[19]. The aim of this study was to investigate the applicability of UTCI in the heat stress assessment of workers engaged in the open-pit mines.

According our finding, the significant relationships have been found between WBGT and UTCI with all environmental parameters, except for air velocity. Vatani *et al.* (2015) showed that the relationship between air velocity with both UTCI and WBGT is negative and both Bröde *et al.* (2013) and Blazejczyk *et al.* (2012) findings indicated that UTCI is less applicable for assessing the environment with high air velocity[19, 20, 22]. Moreover, there was a strong significant correlation between UTCI and WBGT indices. However, the weak positive correlations were seen between both WBGT and UTCI with HSI index. Vatani *et al.* (2015) showed that there is the significant correlation between UTCI and WBGT indices[19]. They are indicated that UTCI is appropriate for assessing the environments with low air velocity (~ < 1 m/s)[19]. Kampmann *et al.* (2012) found that a strong correlation between WBGT and UTCI indices in high humid environments, but in low humid environments, there is a significant difference between two indices[28]. Due to the low relative humidity and air velocity which are measured in this study and also a high correlation which is found between UTCI and WBGT, it seems that UTCI may be appropriate index to assess the occupational heat stress in these outdoor environments with low humidity and air velocity.

According to Table 2, a significant relationship was found between UTCI and WBGT with deep body temperature (oral temperature, tympanic temperature), skin temperature and heart rate. Results of Vatani *et al.* study showed no significant correlations between all physiological responses with both WBGT and UTCI at outdoor environment[19]. They reported the negative correlations between oral, tympanic and skin temperatures with WBGT. The highest correlation was seen between applied indices and physiological responses for the oral and the tympanic membrane temperature[19]. Wan (2006) was measured rectal temperature, tympanic membrane temperature, the sublingual temperature, heart rate, recovery heart rate and physiological strain index for two different work clothes and she showed that both tympanic membrane and oral temperature are the best indicators for evaluating the heat strain in workplaces[29]. The results of Aliabadi (2014) research indicated that there is a significant correlation between the WBGT and oral temperature in bakeries[30]. Hajizadeh *et al.* (2016) concluded that a significant relationship between the indices including WBGT, HSI, predicted heat strain (PHS) and discomfort index (DI) with deep body temperature (oral temperature, ear carotid artery temperature) and skin temperature[8].

Conclusion

The results showed that there are relationships between the UTCI and WBGT index, as well as with environmental and physiological parameters. Due to the low relative humidity and air velocity which are measured in this study and also a high correlation which is found between UTCI and WBGT, it seems that UTCI may be applicable to assess occupational heat stresses in the outdoor environments such as open-pit mines.

Acknowledgement

This research has been financially supported by Institute for Environmental Research, Tehran University Medical Sciences (Grant No. 94-01-46-28540). The authors declare that there is no conflict of interests.

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