

Applicability of Universal Thermal Climate Index (UTCI) in occupational heat stress assessment: a case study in brick industries

Javad VATANI¹, Farideh GOLBABAEI^{2*}, Somayeh Farhang DEHGHAN² and Azam YOUSEFI³

¹Department of Occupational Health, School of Public Health, International Campus, Tehran University of Medical Sciences, Iran

²Department of Occupational Health, School of Public Health, Tehran University of Medical Sciences, Iran

³Department of Medicinal Plants, School of Agriculture, University of Applied Science and Technology, Iran

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Abstract: The present study aimed to investigate the applicability of Universal Thermal Climate Index (UTCI) as an innovative and science-based index in public health researches, in occupational heat stress assessment. All indoor and outdoor workers (200 people) of Brick industries of Shahrood, Iran participated in the research. First, the environmental variables such as air temperature, wet-bulb temperature, globe temperature, air velocity and relative humidity were measured; then UTCI and WBGT (wet-bulb globe temperature) indices were calculated. Simultaneously, physiological parameters including systolic and diastolic blood pressure, oral temperature, skin temperature, tympanic temperature and heart rate of workers were measured. UTCI and WBGT indices were $34.2 \pm 2^\circ\text{C}$, $21.8 \pm 1.8^\circ\text{C}$ in the outdoor environments and $38.1 \pm 4.4^\circ\text{C}$, $24.7 \pm 3.3^\circ\text{C}$ at the indoor environments, respectively. There were the weak inverse relationships between UTCI and WBGT indices at the outdoor environments and physiological responses such as systolic blood pressure, and diastolic blood pressure. However, there were no similar results for indoor environments. The significant relationships were found between UTCI and WBGT at both indoor and outdoor environments. Both UTCI and WBGT indices are suitable for assessing the occupational heat stress. Although, UTCI index seems more appropriate for heat stress assessment in the environments with low humidity and air velocity.

Key words: Heat stress, Physiological response, UTCI index, WBGT index

Introduction

The growth and development of technology in workplaces leads to improve productivity and health and welfare of employees. Nevertheless, most of the countries including Iran, still face the occupational health and safety

hazards and work-related diseases and injuries. Brick production industries are one of the most important industrial sectors in Iran, which allocate a high volume of structural productions itself and have employed a large number of workers, who are working in hot indoor and outdoor environments.

Heat stress is represented as a physical harmful agent in the workplaces like mining, agriculture, smelting industries and etc^{1, 2}. Heat Exposure endangers the health and safety of the workers and increases the risk of many

*To whom correspondence should be addressed.

E-mail: fgolbabaei@sina.tums.ac.ir

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health problems like heat exhaustion and heat stroke^{3, 4}. Tawatsupa *et al.* found that heat stress increases risk of kidney diseases⁵. Exposure to heat stress can reduce work efficiency and productivity^{4, 6}. Whereas, heat stress has been recognized as a main harmful factor, it is sometimes neglected⁷.

Heat stress indices as valid tools to conduct a heat stress assessment, are a single number that considers the effects of the basic environmental parameters on human response⁴. In occupational hygiene, there are different indices to assess heat stress, which some of them is approved by International Standard Organization (ISO) like Wet Bulb Globe Temperature (WBGT) and Predicted Heat Strain (PHS)^{4, 8}. WBGT is the most widely used estimator for assessing heat stress in industry and some studies showed good correlation between WBGT and environmental factors¹. Moreover, physiological parameters such as heart rate, sweat rate, rectal temperature and metabolic rate have been used to evaluate heat stress⁹.

Monazzam *et al.* have been found a linear relationship between the heat stress indices including WBGT and DI (Discomfort Index) and physiological parameters in their subjects⁴.

Universal Thermal Climate Index (UTCI) is a non-occupational hygiene index to assess heat stress in the outdoor thermal environment for public health purposes^{10, 11}. It is recently presented by COST (a European Union program promoting Cooperation in Science and Technology) Action 730¹². UTCI is derived from the most recent scientific progress in human thermo-physiology, in biophysics and heat exchange theory¹². UTCI has been used in the numerous community-oriented studies, but its application has not been yet investigated in occupational health issues^{10, 12}.

The aim of the present study was to assess the possibility of application of UTCI in occupational heat stress assessment and determine the relationship between UTCI, as an innovative and science-based index in public health researches, and WBGT, as the most applied index for evaluating heat stress in workplaces. Workers of Brick production industries in Shahroud were exposed to both indoor and outdoor heat stress, so it could be possible to investigate the applicability of UTCI for assessing occupational heat stress in both work environments. In addition, Shahroud is a city with a cold desert climate in Semnan Province, Iran. It experiences hot summers, cool winters and low precipitation¹³.

In order to achieve the mentioned goal, first the WBGT and UTCI indices in workplaces and some physiological

parameters of workers were measured, then the correlations between WBGT and UTCI indices were determined and also it was investigated how the intended indices can be correlated with the physiological parameters.

Subjects and Methods

This descriptive-analytical cross-sectional study was conducted on all workers (totally, 200 men including 104 subjects in outdoors and 96 ones at indoors) of Brick industries of Shahroud, Iran at the end of the summer season.

Environmental parameters, including dry temperature, wet-bulb temperature, globe temperature, relative humidity and air velocity were alternatively measured at workstations from 8.00 am to 14.00 pm by Microtherm Heat Stress system (Casella CEL Inc.) and Air flow meter (PCE-007, PCE Co). WBGT index for indoor and outdoor environment was calculated as follow equations, according to ISO 7243 standard¹¹:

$$\text{WBGT}_{(\text{indoor})} = 0.7 T_{\text{nw}} \times 0.3 T_{\text{g}} \quad (\text{Eq. 1})$$

$$\text{WBGT}_{(\text{outdoor})} = 0.7 T_{\text{nw}} \times 0.2 T_{\text{g}} \times 0.1 T_{\text{a}} \quad (\text{Eq. 2})$$

Where, T_{nw} is natural wet-bulb temperature, T_{g} is the black-globe temperature and T_{a} is the natural dry-bulb temperature. UTCI index was calculated by UTCI software (ver. A002) regarding air temperature, mean radiant temperature, wind speed and humidity¹⁴. The UTCI is defined as the air temperature of the reference condition causing the same model response as actual conditions. This can be shown in general function as follow¹⁴.

$$\text{UTCI} = f(T_{\text{a}}; T_{\text{mrt}}; V_{\text{a}}; \text{RH}) \quad (\text{Eq. 3})$$

Where T_{a} : air temperature, T_{mrt} : mean radiant temperature, V_{a} : wind speed and RH: relative humidity. T_{mrt} was considered equal to air temperature¹⁴.

Simultaneously, physiological parameters including systolic and diastolic blood pressure, heart rate, oral temperature, ear's external skin and tympanic temperature of workers were measured from 8 am to 16pm by Sphygmomanometer (ALP K2 Co.), Stethoscope (ALP K2 Co.), and Thermometer (DT-01A, Frolic Co.), respectively. Ethical approval was granted by the Research Ethics Committee of Tehran University of Medical Sciences. All statistical analyses were performed using SPSS statistical software (ver. 16). Significance level was set at 0.05 for all statistical analyses.

Results

The mean \pm SD age of participants was 33.64 ± 5.73 yr

Table 1. Measurement results of environmental and physiological parameters

	Variable	Workplace location	N	Minimum	Maximum	Mean	Std. Deviation
Environmental factors	Dry-bulb temperature (Ta) (°C)	Indoor	96	25.4	35.5	30.36	3.33
		Outdoor	104	24.5	31.2	28.28	1.71
	Globe temperature (Tg) (°C)	Indoor	96	26.0	39.5	32.32	4.87
		Outdoor	104	25.3	35.0	31.69	2.51
	Wet bulb temperature (Tnw) (°C)	Indoor	96	18.4	26.6	20.99	2.52
		Outdoor	104	15.6	19.8	17.69	0.87
	Relative humidity (RH) (%)	Indoor	96	32.0	53.3	42.04	6.82
		Outdoor	104	22.7	40.4	30.96	4.04
	Air velocity (m/s)	Indoor	96	0.2	0.5	0.36	0.15
		Outdoor	104	2.0	3.0	2.38	0.49
Heat Stress index	UTCI (°C)	Indoor	96	32.4	45.5	38.17	4.45
		Outdoor	104	29.4	37.6	34.29	2.04
	WBGT (°C)	Indoor	96	20.7	32.0	24.71	3.39
		Outdoor	104	18.5	29.0	21.88	1.89
Physiological parameters	Heart rate (beat/min)	Indoor	96	60.0	120.0	79.41	19.04
		Outdoor	104	60.0	120.0	80.07	15.68
	Systolic blood pressure (mmHg)	Indoor	96	90.0	150.0	114.58	13.05
		Outdoor	104	90.0	145.0	116.42	10.439
	Diastolic blood pressure (mmHg)	Indoor	96	60.0	110.0	78.96	11.33
		Outdoor	104	7.0	95.0	79.69	16.55
	Oral temperature (°C)	Indoor	96	36.5	37.5	37.04	0.26
		Outdoor	104	36.2	37.5	36.82	0.29
	Tympanic temperature (°C)	Indoor	96	36.2	37.2	36.73	0.25
		Outdoor	104	35.7	37.1	36.55	0.32
	Skin temperature (°C)	Indoor	96	36.0	37.0	36.50	0.28
		Outdoor	104	35.9	36.9	36.39	0.27

(ranged in age from 16 to 60 yr), body mass index $23 \pm 3.86 \text{ kg/m}^2$ and work experience 7.44 ± 6.93 yr. Results of environmental and physiological parameters measurement are presented in Table 1. Environmental parameters including dry, globe and wet temperatures and relative humidity were higher in indoor environment than outdoor; therefore, the higher values of WBGT and UTCI were obtained at indoor. Mean WBGT at both workplace locations was smaller compared to UTCI. However, physiological responses like heart rate and systolic and diastolic blood pressure in outdoor were higher.

Table 2 indicates the relationships which exist between heat stress indices (UTCI and WBGT) and environmental and physiological parameters (Pearson Correlation Coefficient test).

As seen in Table 2, at indoor environment, UTCI is significantly correlated with all environmental parameters. Also, there were the negative correlations between both WBGT and UTCI and air velocity. The highest correlation coefficient has been found between the UTCI and globe temperature and also between WBGT and wet-bulb tem-

perature.

In terms of physiological responses, the no significant and weak positive correlations exist between heart rate and oral, tympanic and skin temperatures and the two heat stress indices ($p\text{-value} > 0.05$). Systolic and diastolic blood pressures were significantly negatively related to UTCI and WBGT ($p\text{-value} < 0.05$).

In outdoor workplaces, UTCI was significantly correlated with environmental parameters. No statistically significant relationship existed between WBGT and air velocity. UTCI has stronger correlation with environmental parameters than WBGT and the strongest relationship was found for UTCI and air temperature which is consistent with Kampmann *et al*¹⁵. No significant correlations were found between all physiological responses and both WBGT and UTCI and (except for a significant relationship between skin temperature and WBGT). The negative correlations existed between oral, tympanic and skin temperatures with WBGT.

Correlation between WBGT and UTCI in indoor and outdoor places is shown in Fig. 1. Scatterplot shows posi-

Table 2. Correlations between UTCI & WBGT and Environmental and Physiological parameters

		UTCI (°C)		WBGT (°C)	
		R	p-value	R	p-value
Indoor	Environmental variables				
	Ta (°C)	0.815	<0.001	0.777	<0.001
	Tg (°C)	0.983	<0.001	0.947	<0.001
	Tnw (°C)	0.906	<0.001	0.958	<0.001
	Air velocity (m/s)	-0.818	<0.001	-0.80	<0.001
	Physiological responses				
	Heart rate (beat/min)	0.102	0.325	0.089	0.391
	Systolic blood pressure (mmHg)	-0.371	<0.001	-0.374	<0.001
	Diastolic blood pressure (mmHg)	-0.414	<0.001	-0.419	<0.001
	Oral temperature (°C)	0.02	0.848	0.058	0.573
Tympanic temperature (°C)	0.126	0.223	0.092	0.372	
Skin temperature (°C)	0.134	0.193	0.172	0.094	
Outdoor	Environmental variables				
	Ta (°C)	0.939	<0.001	0.459	<0.001
	Tg (°C)	0.891	<0.001	0.561	<0.001
	Tnw (°C)	0.886	<0.001	0.555	<0.001
	Air velocity (m/s)	0.253	0.01	0.058	0.556
	Physiological responses				
	Heart rate (beat/min)	0.008	0.939	0.113	0.255
	Systolic blood pressure (mmHg)	0.125	0.207	0.116	0.242
	Diastolic blood pressure (mmHg)	0.176	0.075	0.056	0.574
	Oral temperature (°C)	0.167	0.091	-0.082	0.407
Tympanic temperature (°C)	0.163	0.098	-0.092	0.355	
Skin temperature (°C)	-0.039	0.692	-0.284	0.004	

tive and direct relationships between variables. Analysis of the Pearson r coefficients indicated that there was statistically significant relationships between UTCI and WBGT at indoor environments ($r=0.971$, $p\text{-value}<0.001$) and in outdoor environment ($r=0.544$, $p\text{-value}<0.001$). This correlation for outdoor environment is not the same strong as indoor.

Discussion

Heat stress is one of the most hazardous agents in the workplaces. This is very important issue in a tropical and subtropical region like Shahroud, Iran. As mentioned before, exposure to heat stress has a range of health effects including heat stroke, heat exhaustion, heat cramp, increased risk of kidney diseases, reduced attention and concentration and decreased work efficiency and productivity^{1, 5, 16}. Periodic assessment of occupational exposure to heat stress is health necessity, so a large number of indices including rational, empirical and direct indices were developed by involved scientists and organization.

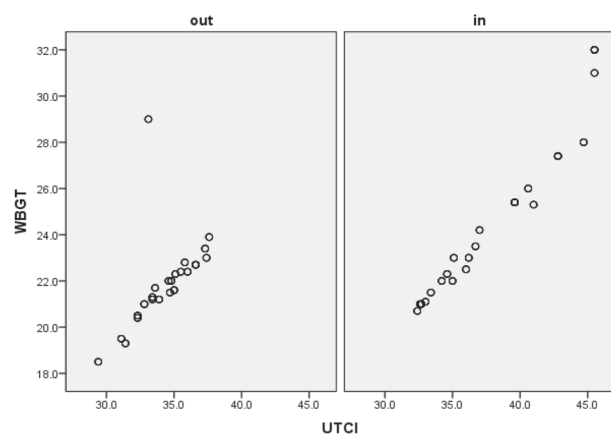


Fig. 1. Scatter plot of Association between UTCI & WBGT in indoor and outdoor places.

ACGIH (American Conference of Governmental Industrial Hygienists) was determined threshold limit values for occupational exposure to heat stress; regarding WBGT index⁴. European COS T Action 730 had put together

certified experts in the field of human thermophysiology, physiological modelling, meteorology and climatology to develop the UTCI. It is a valid assessment procedure of the outdoor thermal environment considering public weather services, public health systems, urban planning, and climate impact research^{12, 14}. Workers of outdoor environments are exposed to heat as the general population as in warm seasons. But in comparison with the general population, they are at a much higher risk due to doing vigorous physical activities which boost their heat production, and working in hot processes. Therefore we aimed to investigate the applicability of this valid tool for thermal environment assessment, UTCI, in occupational heat stress assessment. In Brick production industries in Shahroud, Workers were exposed to both indoor and outdoor heat stress, so it could be possible to investigate the applicability of UTCI in both work environments.

The results of present study indicated that understudy workplaces were hot and dry environment as the mean temperature and relative humidity in outdoor and indoor were 28.29 °C, 30.36 °C and 42.04%, 30.96%, respectively. The higher temperature at indoor can result from the presence of the many different heat sources and lack of sufficient ventilation. The higher relative humidity at indoor can be resulted from drying and cooking processes of raw bricks.

There was a noticeable and significant correlation between UTCI and WBGT indices ($r=0.971$) at indoor environment; however, a moderate correlation existed between them in outdoors ($r=0.544$), but these results have been inconsistent with Blazejczyk *et al.*¹⁰. Kampmann *et al.* found that there are good agreement between UTCI and WBGT for humid conditions and considerably different for low humidity¹⁵.

The significant relationships have been found between UTCI and all environmental factors such as air temperature, globe temperature and wet-bulb temperature at both indoor and outdoor environments. Relationship between air velocity and both UTCI and WBGT is negative at indoor and is positive in outdoor. In another word, UTCI which has significant correlation with air velocity for both environments is appropriate for assessing the environments with low air velocity. In line with Brode *et al.* and Blazejczyk *et al.* findings, UTCI is less applicable for assessing the environment with high air velocity^{10, 12}.

The correlations existed between UTCI and some physiological responses in environments with low air velocity (like understudy indoor environments) confirmed these results, which is in accordance with the work of Blaze-

czyk *et al.*¹⁷. The stronger relationships have been seen between WBGT and indoor environmental parameters including air, glob and wet temperatures, in comparison with outdoors. This finding is consistent with the study of Blazejczyk *et al.*¹⁰, however that is in disagreement with observation of Jay and Kenny⁶. WBGT seems not to be a suitable index for heat stress assessment in areas with higher air velocity and lower relative humidity (like understudy outdoor environments), since in outdoor conditions with less humidity than indoors, there was weaker correlation between WBGT and air velocity. In another words, WBGT index can be strongly not suggested to use for the evaluation of heat stress in areas with low humidity and high air velocity, which is in contrast to the results of Srivastava *et al.*⁷.

Conclusion

In conclusion, the present study illustrates that UTCI, as a heat stress index in public health research showed the high positive correlation with WBGT, as the most applicable index for evaluating heat stress in workplaces. UTCI can be applicable to evaluate heat stresses in the workplaces, especially at indoor environment. In general, UTCI index is appropriate to assess the occupational heat stress in area with low humidity and air movement. Despite all of WBGT' capabilities, there are some limitations for using it for heat stress assessment, and it is claimed that it can provide only a general guide to the likelihood of adverse effects of heat⁸, so more accurate and comprehensive indices of heat stress are required. Here, authors recommend doing further research for assessing the applicability of UTCI, as an innovative and science-based index, in occupational heat stress issues.

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