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Correlation between Heat Strain Score Index and WBGT Index with Physiological Parameters in a Glass Manufacturing Plant

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ABSTRACT
The objectives of this research were to study the correlations of heat strain score index (HSSI) and values of wet-bulb globe temperature (WBGT) index with physiological parameters such as core body temperature, heart rate, and blood pressure of workers exposed to heat stress in a glass manufacturing plant in order to determine the reliability of HSSI. This cross sectional study was carried out on 72 production, packing, and quality control male workers of a glass manufacturing plant. The WBGT values were recorded according to standard No. International Standard Organization (ISO) 7243 heat stress standard during the summer season in July–August 2013. Metabolic rate for each task was estimated according to standard No. ISO 8996. Body core temperature and heart rate were monitored according to standard No. ISO 9886. HSSI questionnaire was used to evaluate heat strain. The data were analyzed using Pearson and Spearman correlation coefficients and linear regression test. The maximum WBGT value (30.20±1.06ºC) was recorded in production unit of plant. The scores of HSSI index in production, packing, and quality control operators were 23.16±1.9, 21.56±1.69, and 21.43±2.04, respectively. The highest correlation coefficient was found between the measured WBGT values and core body temperature (r=0.462). Positive correlations between the values of WBGT index and studied physiological parameters indicated that the WBGT as the most widely accepted index is better than HSSI for the assessment of thermal stress in glass manufacturing industry.

KEYWORDS: *Heat stress, Wet-bulb globe temperature, Heat strain score index, Physiological parameters*

INTRODUCTION
Workers at some industries including metallurgical plants, glass-manufacturing, ceramic production, foundry plant, petrochemical plant, power plants and etc. are expected to experience high levels of heat exposure, especially the radiation type [1-3].

Working in a hot workplace for a long time may impact on the workers' health and welfare. This may reduce the level of employee's performance, and increase the risk of heat illnesses, discomfort, and rate of accidents among the

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workers [4-5]. The metabolic heat production plus external heat transfer can impose heat stress. Environmental factors including air temperature, humidity, radiant heat, air movement and clothing insulation may also influence heat loads imposed on human body [5].

Heat strain as a physiological consequence of heat stress might introduce a raise in core body temperature [6]. Core body temperature, skin temperature, heart rate, and weight loss have been introduced as the physiological parameters for heat stress and indicators of heat strain. The core temperature of 38 ºC was recommended as the upper limit of body temperature by the World Health Organization (WHO). The heart rate (HR) of 110 beats per minute (bpm) was set as the upper limit of heart rate. The weight loss of 1-3% through sweating was identified as the maximum limit of heat tolerance [7]. More than 20 heat strain indexes have been proposed during the past years but none of them has been set as a universally accepted index for evaluating of heat stress [8]. In recent years, physiological strain index (PSI) was used to measure heat stress based on calculating HR and rectal temperature (Tre) [9].

However, some previously mentioned methods suffer from some serious drawbacks. Wet-bulb globe temperature (WBGT) is the most widely used index for evaluating heat stress in workplaces. The WBGT index was proposed based on a combination of three environmental parameters including wet bulb air temperature, dry bulb air temperature, and radiant temperature. Perhaps the most serious disadvantage of this method is that it is a time consuming and expensive method. Approximately at least 30 min is necessary to perform each measurement [9-11]. The Required Sweat Rate (SWreq) index as an index of heat strain is calculated using computer supported tools and instruments [9].

Various observational-perceptional methods have been developed to evaluate the effects of heat stress on human beings. These approaches are shown to have some advantages such as ease-of-use, low cost, user-friendly, fast response, and non-interference properties [5]. A significant correlation was demonstrated between Subjective Judgment Scale for evaluating the thermal stress and WBGT index in a study and a good subjective perception of heat by participants was reported [12]. The perceptual hyperthermia index (PHI) revealed a significant correlation with physiological strain index in studied firefighters who wore protective garments at different temperatures in the laboratory and a good perception of heat by the studied firefighters was reported [13]. Chenb et al. reported the measured WBGT values in the range of 25.4 to 28.7°C and 30.0 to 33.2°C for continuous casting and electric arc melting working area, respectively. They showed that the increase in the WBGT index will increase the heart rate, systolic blood pressure, and subjective fatigue in workers exposed to a hot environment [14].

Heat strain score index (HSSI) as an observational-perceptional index was designed in a form of questionnaire. A good subjective perception of the heat stress was reported by 122 workers exposed to heat. A significant correlation was found between HSSI and physiological strain index (r = 0.57, P <0.001), heart rate (r = 0.428, P <0.001), oral temperature (r = 0.556, P <0.001), and WBGT index [15]. Habibi et al. found a direct significant relationship between HSSI index and WBGT index (R^2 = 0.974, and P <0.001) in Iranian veiled women under laboratory thermal conditions with light activity within 2 hours [16].

More investigations are required for validation of HSSI in other hot environments such as glass manufacturing. The objectives of this research were to study the correlations of HSSI and WBGT index with physiological parameters such as core body temperature, heart rate, and blood pressure of workers who were exposed to heat stress in a glass manufacturing plant and investigate the more appropriate index for the assessment of thermal stress in glass manufacturing industry.

MATERIALS AND METHODS

Study participants: This cross sectional study was carried out on production, packing, and quality control men workers of a glass manufacturing plant located in Tehran, Iran exposed to a hot environment in their workplaces. Among all heat exposed workers, 72 of them who met the study entrance criteria were enrolled. The entrance criteria excluded those with cardiovascular diseases, hypertension, kidney diseases, diabetes, other metabolic diseases, infectious disease, antidiuretic drug users (according to their medical records), and workers with symptoms such as fever and diarrhea. The participants completed the informed consent. Demographic features of workers such as age, education, height, weight, body mass index (BMI), and occupational category were collected with appropriate questionnaire.

Environmental parameters: Indoor environmental parameters were measured during the summer season in July–August 2013. Relative humidity (RH) was measured with an Assman hygrometer (Casella, UK) in each workstation. The air velocity was estimated with a silvered kata-thermometer (Casella Nr 240, UK) with a cooling range of 52.9 ºC. Due to the homogeneous environment of the study in terms of the temperature variation, the WBGT values were recorded using Questemp 10, Oconomowoc, USA

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according to standard No. International Standard Organization (ISO) 7243 heat stress standard at abdomen height during the rest and work time [17]. This device was designed to measure the WBGT in the range of 0 to 60 ºC with the accuracy of ±5 ºC.

Time-weighted average WBGT was calculated according to the Equation 1 [18]:

Equation 1

$$WBGT_{average} = \frac{\sum_{i=1}^{n} t_i \times WBGT_i}{\sum_{i=1}^{n} t_i},$$

Where $WBGT_i$ is the value of WBGT while performing each task and t_i is the time spent in each task. All variables were measured 6 times in the working shift.

Metabolic rate: Metabolic rate for each task was estimated according to standard No. ISO 8996 [19]. The average metabolic rate of the participants was determined according to the Equation 2 [18]:

Equation 2

$$M_{average} = \frac{\sum_{i=1}^{n} t_i \times M_i}{\sum_{i=1}^{n} t_i},$$

Where M_i is the metabolic rate and ti is the time spent doing each task [18]. The quality control workers (n=17) performed light tasks (75% work–25% rest each hour) with one arm in a sitting position. Production (n=34) and packing (n=21) workers performed moderate working practices with all body parts.

Physiological parameters: Specific objectives of the study were explained to the participants on the day before the experiment. Coffee should not be used by workers at the night before the experiment. Body core temperature and heart rate were monitored according to ISO 9886 [20]. Tympanic temperature was measured as a core temperature using a FT 70 tympanic thermometer (Beurer, Germany). The accuracy of the measuring device was ±0.2 ºC and the measurements were carried out at a temperature range of 34 to 43 ºC [18].

The heart rate and blood pressure were measured with Beurer BM85 blood pressure monitor (Beurer, Germany). At the start of experiment and before exposure to heat, workers rested in a cool room (WBGT = 23.6 ± 1.4°C) for 30 min. Body core temperature and heart rate were monitored at 20, 25, and 30 min after entering the room and the average of each variable was recorded as baseline values [18]. In the second stage, according to previously published study, body core temperature and heart rate were monitored during the work time at 20, 40, and 60 min after starting work practices. Physiological strain index was calculated according to Equation 3 [18]:

Equation 3

$$PSI = \left[\frac{5 \times (t_w - t_r)}{39.5 - t_r}\right] + (5(HR_w - HR_r) \times (180 - HR_r))$$

Where t_w is core body temperature (ºC) during work time (exposure to heat), tr is core body temperature (ºC) during rest time, HR_w is heart rate (bpm) during exposure to heat, and HR_r is heart rate (bpm) during rest time. PSI was rated in the range of 0 to10 where 0 indicates no/little strain and 10 represents very high strain. Physiological strain index based on heart rate (PSI_{HR}) was estimated according to Equation 4 [18]:

Equation 4

$$PSI_{HR} = \left[\frac{5 \times (HR_w - HR_r)}{(180 - HR_r)}\right]$$

The PSI_{HR} was scaled from 0 to 5, where 5 represents high level of strain.

HSSI questionnaire: HSSI questionnaire included 17 subjective items about the heat stress, such as those related to sensations of temperature and humidity, the intensity of sweating, the fatigue level, perception of thirst intensity, and other factors related to the onset of heat strain [16]. The first 12 questions were asked from respondents while the last 5 questions were completed after observation of the workers. Scores for each item were multiplied by the effect coefficient of each question. Finally, the scores of the items were summed to yield total score. Three separate heat strain boundary zones were defined for HSSI scale including green, yellow, and red [5].

The total score of less than 13.5 (green zone or safe level) represents the absence of heat strain.

The total score between 13.6 and 18 (yellow zone or alarm level) represents a potential health risk to workers and the need for further evaluation [5].

The total score of greater than 18 (red zone or danger level) indicates onset of heat-induced illnesses in which immediate implementations of appropriate control measures may be necessary.

Dehghan et al. developed and validated the HSSI questionnaire in Iran [5].

Ethical considerations: The proposal of the study was approved by ethical committee of Shahid Beheshti University of Medical Sciences prior to its final approval for execution. Ethical considerations including the conduct and reporting the results of research as well as the declaration of Helsinki on ethical principles for medical research involving human subjects were considered.

Statistical analysis: All statistical tests were conducted with version 16 of SPSS for Windows (SPSS Inc., IL, USA). The data were analyzed using paired t test, one-way analysis of variance (ANOVA), Pearson (for normal distribution) and Spearman correlation (for non-normal distributions) coefficients and linear regression test.

RESULTS

The average age of the studied subjects was 34.96 ± 8.45 yr. Their mean weights, heights and BMI were 77.19 ± 10.86 kg, 175.42 ± 9.28 cm, and 25.13 ± 3.30 kg/m^2, respectively. Approximately half of them (49%) had a high school diploma. Many of these workers (47%) were employed in production part of the factory.

The mean values of measured air temperature, globe temperature, and natural wet-bulb temperature in the studied plant were 47.3 ± 5.06 °C, 50.15 ± 6.15 °C, and 24.48 ± 1.1 °C, respectively. The calculated metabolic rate for production, packing, and quality control operators were 165 w/m^2, 165 w/m^2, and 100 w/m^2, respectively. The mean relative humidity at production, packing, and quality control units were 32.64%, 37.36%, and 43.35%, respectively. The results of assessing the WBGT values at studied workstations are shown in Figure 1. The maximum measured WBGT value (30.20 ± 1.06ºC) was recorded in production unit of the plant which is exceeded the Iranian occupational exposure limits (OELs) and American conference of governmental industrial hygienists Threshold Limit Value (ACGIH TLV) (28ºC). The measured WBGT values in the other studied units were lower than OELs [21-22].

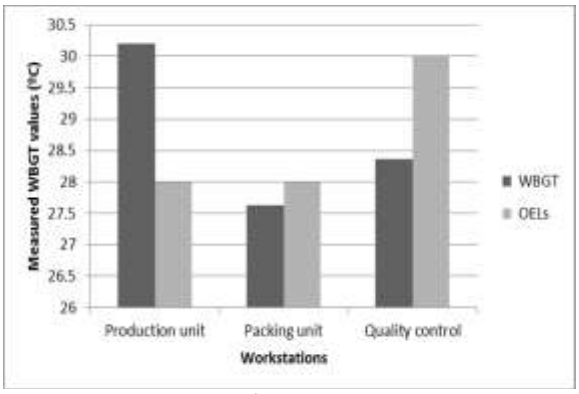

Fig.1. The comparison of measured WBGT values with OELs at studied work units

The mean value of HSSI scores for production, packing, and quality control operators were 23.16 ± 1.9, 21.56 ± 1.69, and 21.43 ± 2.04, respectively.

The mean values of PSI for workers at production, packing, and quality control units were 2.94, 1.55, and 1.58, respectively lower than recommended value (3.76). The mean values of PSIHR for workers at production, packing, and quality control units were 1.03, 0.68, and 0.55, respectively.

The maximum heart rate (98.4 bpm), tympanic temperature (37.7ºC), systolic blood pressure (13.6 mm Hg), and diastolic blood pressure (8.5 mm Hg) were recorded for production workers during performing their tasks. The measuring results are summarized in Table 1.

Table 1. The mean values of workers' physiological parameters during rest and working time in the different job categories

Physiological parameters	**Work/rest**	**Production (n=34)**	**Packing (n=21)**	**Quality control (n=17)**	***P*-value$^\beta$**
Heart rate (bpm)	Rest	76.800	72.900	76.100	-
	Work	98.400	87.700	88.300	-
	(Work-rest)	8.500	5.200	6.8400	<0.001
	P-value$^\alpha$	<0.001	<0.001	<0.001	-
Systolic blood pressure (mm Hg)	Rest	12	11.900	11.900	-
	Work	13.600	12.700	12.600	-
	(Work–rest)	0.812	0.615	0.903	<0.001
	P-value$^\alpha$	<0.001	<0.001	<0.001	-
Diastolic blood pressure (mm Hg)	Rest	7.900	7.800	7.700	-
	Work	8.500	8.100	8.200	-
	(Work–rest)	0.660	0.770	0.480	0.372
	P-value$^\alpha$	<0.001	<0.001	<0.001	-
Tympanic temperature (ºC)	Rest	36.600	36.600	36.400	-
	Work	37.700	37.100	37.000	-
	(Work–rest)	0.690	0.370	0.320	<0.001
	P-value$^\alpha$	<0.001	<0.001	<0.001	-

P-value$^\alpha$: Within groups; *P*-value$^\beta$: Between groups

Table 1 shows significant changes in the values of physiological parameters of studied workers before and after a work shift in the different job categories (P-value$^{\alpha}$<0.001). In addition, changes in workers' physiological parameters (except diastolic blood pressure) between the three job categories were significant (P-value$^{\beta}$<0.001). Besides, the results of Tukey test indicated significant differences in the studied physiological parameters between production workers and workers in the two other job categories (P<0.001).

The correlation coefficients between the values of WBGT index and HSSI scores with physiological parameters are presented in Table 2. The highest correlation coefficient was between the WBGT index and core body temperature.

The relationships between the HSSI scores and the values of WBGT index with PSI are also shown in the Figures 2 and 3.

Table 2. The correlation coefficients between the measured WBGT values and HSSI scores with physiological parameters

Physiological parameters	WBGT			HSSI		
	R^2	r	*P*-value	R^2	r	*P*-value
Core body temperature	0.214	0.462	0.001	0.018	0.134	0.256
Heart rate	0.208	0.456	0.001	0.016	0.126	0.282
Systolic blood pressure	00184	0.428	0.002	0.004	0.063	0.554
Diastolic blood pressure	0.023	0.151	0.202	0.026	0.161	0.173

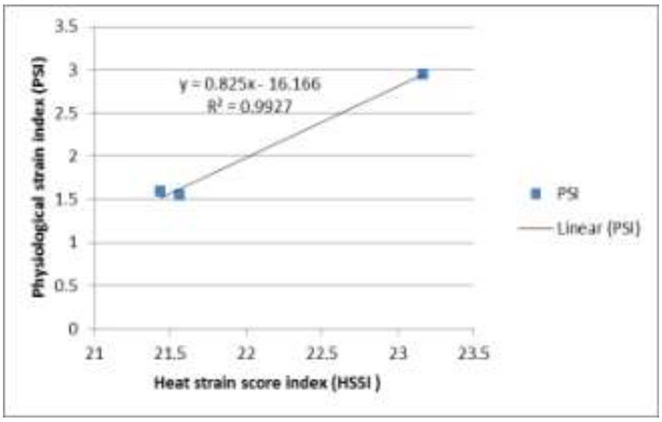

Fig.2. The relationship between the scores of HSSI and PSI

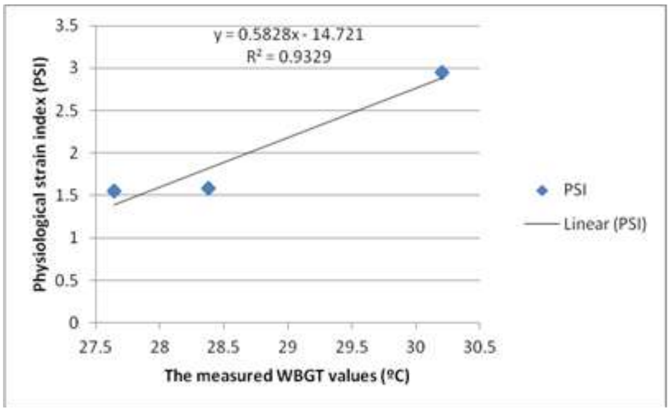

Fig.3. The relationship between the measured WBGT values and PSI

DISCUSSION

This research was designed to study the correlations of HSSI scores and values of WBGT index with physiological parameters such as core body temperature, heart rate, and blood pressure of workers exposed to heat stress in a glass manufacturing plant. The results showed that 44.44% of study subjects did their tasks under heat stress. The heat stress value was higher for production workers. The results of heat exposure assessment in glass manufacturing units showed

that the mean WBGT values in the press forming machine (40.18 ºC) and individual section forming machine (39.04 ºC) units were seen to exceed the standard values [4].

The values of HSSI in many studied workers were in the red zone or danger level. HSSI values were higher in production workers than in other studied workers. The results indicated that 98.62% of the workers certainly had experienced strain at work (red zone or danger level) and 1.38% of them had the strain (yellow zone or alarm level). According to the results of Dehghan et al., 66.2% of participants working under the warm condition in 2011 had not experienced any strain (green zone). Among 145 workers, 2.1% of them had heat strain (yellow zone) and 11.7% of the participants certainly had strain (red zone) [23].

The mean values of PSI and PSI_{HR} in all studied workers were lower than recommended levels. The results of the estimation of the heat strain in 71 workers from Assaluyeh petrochemical company and 51 workers from Isfahan steel company in 2010 revealed that the values of WBGT index in studied sites were 33.3 ± 2 ºC and 30.8 ± 4.4 ºC, respectively. The values of PSI were 2.7 ± 1.4 and 3.8 ± 1.8, respectively. The PSI_{HR} values were 1.5 ± 0.8 and 1.7±1.0, respectively [24]. The values of PSI_{HR} obtained here were lower than that estimated in Assaluyeh petrochemical company and Isfahan steel company. This occurred because the values of WBGT heat stress index were lower in the study than that reported in the other study.

The results of physiological data from the subjects indicated that the highest heart rate, the highest blood pressure (systolic and diastolic) levels during working and rest time, and the maximum core body temperature (tympanic temperature) were recorded for production workers who worked under higher heat stress condition. This finding is in agreement with Miller and Bates's findings which showed the higher heart rate (104.2 ± 11.7 bpm) and tympanic temperature (37.2 ± 0.3 ºC) at higher values of WBGT index [25].

Comparisons were made between the correlations of measured WBGT values and the HSSI scores with physiological parameters. The findings revealed that higher positive correlations were found between the values of WBGT index and studied physiological parameters than those obtained between the HSSI scores and physiological parameters. The findings of the current study are consistent with those of Dehghan et al. who found higher correlation between the WBGT index and heart rate (r=0.439) than that obtained between the HSSI scores and heart rate (r=0.428) [23].

Investigating the relationships between the scores of HSSI and measured WBGT values with PSI indicated a strong positive relationship between the scores of HSSI and PSI (R^2=0.992) than that obtained between the measured WBGT values and PSI (R^2=0.932). Results of the previous study pointed out a higher correlation between the scores of HSSI with PSI (r=0.57, *P*< 0.001) than was found between the values of WBGT index and PSI (r = 0.397, *P*< 0.001) [23].

Finally, a number of important limitations need to be considered. The numbers of studied subjects were relatively small. It is suggested that the associations of these parameters are investigated in future studies.

CONCLUSION

WBGT has a stronger correlation with physiological parameters than HSSI. HSSI is recommended for screening as it is designed for. Measured physiological parameters show a higher correlation than PSI with WBGT.

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