



Estimation of Heat Stress and Maximum Acceptable Work Time Based on Physiological and Environmental Response in Hot-Dry Climate: A Case Study in Traditional Bakers

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Abstract

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Background: Heat stress is common among workers in hot-dry areas. To take preventive strategies for the protection of workers against heat stress, it is important to choose a suitable index that can accurately explain environmental parameters relative to physiological responses.

Objective: To evaluate heat stress and maximum acceptable work time (MAWT) based on physiological and environmental response in hot-dry climate among traditional bakers.

Methods: The current study was carried out on 30 traditional bakers of 3 different bread baking systems in Ahvaz, Iran. Environmental and physiological parameters were measured simultaneously for a work shift. The work-rest time was also determined based on the relative heart rate (RHR) and the wet-bulb globe temperature (WBGT) index.

Results: The average WBGT index was estimated to be higher than the standard limit for all baking stations. Despite the higher-than-the-recommended-limit WBGT index, there was no significant relationship between the WBGT index and physiological parameters. The results indicated a significant ($p < 0.05$) difference between the percentages of work-rest time estimated using the WBGT and RHR index.

Conclusion: Based on the results of environmental and physiological monitoring of this study as well as the limitations of the use of the WBGT index, it seems that using WBGT as a standard index would not suit heat stress management in hot-dry climates. A revision of this standard to adapt to hot climatic conditions should be in order.

Keywords: Heart rate; Temperature; Workplace; Occupational stress; Work; Rest; Heat stress disorders

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Introduction

Working in hot-dry environments can result in a strain on workers and, thereby, may lead to reduction of their performance, heat-related illnesses, and even death.¹ Heat stress refers to the total thermal burden to which the body is subjected by both external sources (environmental heat) and internal factors (metabolic heat load) minus the heat loss from the body to the environment.² The adverse effects of heat stress are likely to increase because of climatic changes, particularly in countries with arid and tropical environmental conditions.^{3,4} Ahvaz is located in an arid area in Southwest of Iran. The city is consistently one of the hottest cities on the planet during the summer where the temperature is regularly at least 45 °C, sometimes exceeding 50 °C in summer. Sandstorms and dust storms are common during the summer; the minimum temperature may fall to 5 °C in winter.⁵ In the summer of 2016, the average temperature was reported to be approximately 41 °C during daily working hours (8:00 to 17:00)—the weather condition appears to be extremely hot for these working hours in summer in Ahvaz.

In working environments with hot climates, heat stress is mainly produced from the sensible heat emitting from the hot process existing in the workplace via convection and radiation.^{6,7} Workers employed in some heavy industries, such as glass manufacturing, steel-casting, and brick-making industries, as well as bakeries, undergo heat stress that arises from the hot climate; this heat stress may be amplified for those working close to the heating sources, especially ovens. It has been reported that diseases caused by heat stress in some industries may be due to the hot climate in the workplace during workday.^{7,8}

Traditional bread baking is one of the

most tedious professions that require long hours of static work. Workers in the bakeries are exposed to numerous health and safety hazards that lead to illnesses and injuries every year. In Iran, there are nearly 72 000 traditional bakeries with about 1.5 million full-time and part-time bakers.⁹ Bakers in baking stations are known to be potentially susceptible to heat strain. Heat stress arising from hot climates is more serious for those bakers working close to ovens. The results of previous studies have shown that the exposure to heat stress in traditional bakers is 3.3% higher than that in industrial bakers, and that the WBGT index in the vicinity of the oven is more than 5 °C higher than that recorded in other areas of the bakery.^{10,11}

The comprehensive evaluation of heat stress in baking stations is necessary to protect workers from exposure to hazardous levels of heat. There are several heat strain and stress indices for the assessment of heat exposure under various climates. The wet-bulb globe temperature (WBGT) has been validated and used as a popular index worldwide.^{12,13} The Iranian Ministry of Health and Medical Education (MHME) has considered this index as a national standard for health judgment and control tools for the prevention of heat-related illnesses.¹⁴ In spite of the wide usage and applicability of WBGT, it suffers from some limitations that make it only a screening tool for thermal conditions.¹² For example, the effectiveness of WBGT is limited in very hot and humid conditions where a more detailed analysis by accurate heat-related physiological responses is strongly recommended.

Increased heart rate is a physiological index associated with heat stress. There are recommended limits for physiological parameters such as heart rate, core temperature, blood pressure, suggested by World Health Organization (WHO) and others.¹⁵ To take every preventive strategy



Figure 1: Bakers putting bread dough in the oven in three unites of *Tanoori*, *Sangak*, and *Taftoon* baking systems

for protecting workers against heat stress, it is important to choose a suitable index that accurately relates environmental parameters to physiological responses. The objective of this study was therefore to evaluate heat stress and maximum acceptable work time (MAWT) based on physiological and environmental responses in hot-dry climate among traditional bakers in Ahvaz, southwestern Iran.

Materials and Methods

Description of Bread Baking Systems

This study was carried out in Ahvaz, southwestern Iran. Three types of bread baking systems are commonly used in Iran—*Sangak* baking system, *Tanoori* baking system, and *Taftoon* baking system (Fig 1). In all three types of baking systems, bakers have to place the prepared dough inside an oven with special tools and remove it from the oven. Workers' physical activity in each of the three systems is roughly the same with a difference that bakers in the *Sangak* baking system use a wooden tool 3–3.5-me-

ter long and weighing about 3.5 kg with the dough of bread. In the case of *Taftoon* and *Tanoori* baking systems, a cushion weighing 1.5 kg with the dough is used. The difference between the two bread baking systems pertains to the type of oven used. The oven in *Tanoori* baking system has been made of tile; it has two forms—ground and air ovens. The oven opening is 50–60 cm in diameter; the oven inside diameter and depth are 1 m and 1.2 m, respectively. In *Taftoon* baking, the oven is roughly industrialized and consists of a bread baking plate that is rotated by a conventional rotary machine.

Participants

The sample units of this study consisted of the list of bakers in Ahvaz city that was obtained from Ahvaz bakers' union. From the three types of bread baking systems, 10 were randomly selected from the list. The inclusion criteria included age between 20 and 35 years, weight <80 kg, height <180 cm, over two years of work experience, and no drug abuse. The exclusion criteria included history of hypertension or car-

diac surgery, presence of respiratory or cardiovascular diseases. A data sheet was prepared to record the demographic characteristics of bakers and determine the inclusion and exclusion criteria. The bakers were asked about their sick-leave due to the complaints to identify those who acclimatized with the environmental heat during the past month; they were then asked if they thought their complaints were work-related (ie, caused by or associated with work).

Data Collection

Heart Rate Monitoring

The heart rate (HR) was recorded using a Polar Team Pro® heart rate monitor (Polar Electro, Kempe, Finland). This device consists of transmitter with an internal memory, an elastic strap, and a transmitter belt in such a way that workers can wear the heart rate monitor as a wristwatch.

Before the transmitters were placed, the skin was cleaned with alcohol and the hair was removed with a shaver. To start recording the HR, back surface of the transmitter was initially rubbed with gel; then, it was positioned over the sternum using strapping. The bakers' resting HR (HR_{rest}) was measured for three minutes in a sitting position.

The bakers' HR during work was measured continuously at three intervals—7:00–10:00, 11:00–13:00, and 14:00–17:00. The collected data were analyzed with Polar Team Pro software.

Deep Temperature

To measure the deep body temperature (ears), a digital thermometer (FT55 model) was used. The accuracy of the device was ± 0.2 °C; its measurement ranged from 34 to 43 °C. Before making measurements, individuals' ears were cleaned by ear swabs to prevent any error in measuring the temperature. The tympanic ther-

момeter sensor was completely enclosed with insulating foam to minimize the effect of ambient temperature on the measured temperature. After getting started, the temperature was measured at 20-min intervals for each activity period. The average deep body temperature during the work time was then reported.

Heat Stress Monitoring

The thermal environment of the work was assessed using the standard ISO 7243,¹⁶ which measures the combination of two environmental parameters—natural wet temperature (T_{nw}) and globe temperature (T_g). A calibrated WBGT meter (MK427 JY model, Casella Company) was used to measure the T_{nw} and T_g . WBGT was then calculated using the following equation:

$$WBGT = 0.7T_{nw} + 0.3T_g \quad (\text{Eq 1})$$

In the case of temperature heterogeneity, the WBGT must be evaluated at the levels of head, abdomen, and ankles. The mean WBGT was then calculated using the following equation:

$$\text{mean WBGT} = (WBGT_{Head} + 2WBGT_{Abdomen} + WBGT_{Feet})/4 \quad (\text{Eq 2})$$

To determine the time-weighted average (TWA) of WBGT, the following equation was used:

$$WBGT_{TWA} = \frac{\sum_{i=1}^n WBGT_i \times T_i}{\sum_{i=1}^n T_i} \quad (\text{Eq 3})$$

where T_i represents exposure time (8 hours).

The mean metabolic rate was estimated from the measured HR based on the revised approach of level 3, as described in ISO 8996.^{17,18} After derivation of $WBGT_{TWA}$ for different baking systems, the values were compared with the American Conference of Governmental Hygienists (ACGIH) threshold limit values (TLVs).¹⁴ The values belong to the physically fit workers wear-

Table 1: Mean (SD) of demographic characteristics of the participants working in three baking systems

Variable	Tanoori (n=10)	Sangak (n=10)	Taftoon (n=10)	Total (n=30)
Age (yrs)	37 (9.1)	29 (8.1)	33 (5.5)	33 (9.5)
Height (cm)	175 (5.3)	175 (5.9)	176 (4.1)	174 (4.8)
Weight (kg)	68 (14)	74 (3.1)	67 (1.9)	71 (10.1)
Work experience (yrs)	18 (5)	8 (5.1)	12 (8.1)	13 (7.7)

ing light summer clothes (0.6 clo).¹⁹ In this study, all workers were wearing light summer clothes during work.

Estimation of the Relative Heart Rate

The relative heart rate (RHR) has been shown to be a reliable indicator of physical workload.²⁰ RHR was calculated using the following equation:

$$RHR = \frac{HR_{work} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \quad (\text{Eq 4})$$

where HR_{work} represents HR during work; HR_{rest} , HR during rest; and HR_{max} , the maximum HR ($205.8 - 0.685 \times \text{age}$). If RHR exceeds 33%, it indicates an increase in physical workload and fatigue.²¹

Estimation of the Maximum Acceptable Work Time

To prevent excessive fatigue, the maximum acceptable work time (MAWT) was estimated based on RHR, using the following equation:¹⁵

$$MAWT = 26.12 e^{-4.81RHR} \quad (\text{Eq 5})$$

Statistical Analysis

All statistical analyses of this study were performed using SPSS® for Windows® ver 18.0 (SPSS Inc, Chicago IL, USA). Wilcoxon signed rank test was used to compare values of the work-rest regime based on two indices of RHR and WBGT. Correlations between the indices and physiologi-

cal parameters were assessed with Spearman's ρ . A p value <0.05 was considered statistically significant.

Results

Thirty bakers participated in this study. Their demographic characteristics are presented in Table 1. None of the bakers had been on sick leave for heat-related sicknesses during the past six months. This reflected the bakers' acclimatization to heat exposure in the workplace.

The metabolic rate for *Sangak* and *Taftoon* bakery workers ranged between 348 and 354 W; it was about 434 W for *Tanoori* bakers (Table 2). According to ACGIH-TLV, the WBGT-TLV is 26.7 °C for a metabolic heat production of 234 to 407 W; it is 25 °C for 407–581 W. Physiological and environmental parameters measured in the studied bread baking systems are presented in Table 2.

The highest WBGT value was recorded in *Tanoori* baking system; the mean value was 35.8 °C—higher than the standard limit for all baking systems (Table 2). Based on the measured WBGT values and metabolic rates (Table 2), bakers working in all studied baking systems required 25% work and 75% rest per hour.

The highest percentage (34.7%) of RHR belonged to *Tanoori* baking system (Table 2). The MAWT value in this baking system should also be the lowest one (5 hours). For *Sangak* and *Taftoon* baking systems, the MAWT was estimated at about 8 hours. A significant ($p < 0.05$) difference was observed between the percentages of work-rest time estimates. There was no significant correlation between the WBGT and physiological parameters measured (Table 3).

Discussion

In this study, continuous monitoring of

Table 2: Mean (SD) of measured physiological parameters and environmental indicators in three studied baking systems

Variables	Tanoori	Sangak	Taftoon
Environmental factors			
Globe temperature (°C)	46 (4.2)	39 (6.6)	33 (5.3)
Natural wet temperature (°C)	30.4 (3.8)	29 (5.2)	31 (4.2)
Relative humidity (%)	42 (5)	45 (6.7)	48 (6.2)
Wet-bulb globe temperature (WBGT) (°C)	35.8 (0.7)*	32.9 (0.4)*	34.1 (1.6)*
WBGT-TLV (°C)	25	26.7	26.7
Work/Rest time-regimens based on the WBGT (%)			
%Work	25 [†]	25 [†]	25 [†]
%Rest	75	75	75
Physiological parameters			
Tympanic temperature (°C)	37.1 (0.2)	36.5 (0.3)	36.9 (0.3)
Heart rate (beat/min)	120.2 (14.5)	102.8 (9.2)	108.7 (5.2)
Severity of work	High	Moderate	Moderate
Metabolic rate (W)	434 (29)	348 (25)	354 (27)
Relative heart rate index (RHR%)	34.7 (11.7) [‡]	24.3 (8.3)	26.5 (6.4)
Maximum acceptable work time (h)	5.6 (3.3) [†]	8.2 (3.1)	8.5 (2.6)
Work/Rest time based on the RHR (%)			
%Work	70	100	100
%Rest	30	0	0

*Difference in maximum acceptable work time (MAWT) among the three types of bread baking systems

[†]Difference between work-rest time (%) based on the two indices in each unit of bakery

[‡]Difference in relative heart rate (RHR) index among bakers among the three types of bread baking systems

environmental and physiological conditions was carried out from June to September 2016 to evaluate the reliability and applicability of WBGT as an index for the risk management of heat stress in hot-dry

climates among bakery workers in Ahvaz, southwestern Iran. WBGT values exceeded the TLV for moderate and heavy workloads during work; the studied bakers were at risk of heat stress. According to the

Table 3: Spearman's correlation coefficient between heat stress indices and physiological parameters

Variables	HR* (beat/min)	TT (°C)	Metabolic rate (W)	RHR (%)
Wet-bulb globe temperature (°C), ρ (p value)	0.11 (0.54)	0.36 (0.05)	0.28 (0.15)	0.09 (0.65)
Relative heart rate (%), ρ (p value)	0.79 (<0.001)	0.15 (0.4)	0.68 (<0.001)	1.00 (<0.001)

*HR: Heart rate, TT: Tympanic temperature, RHR: Relative heart rate

reference values set in the ACGIH guidelines,¹⁴ Working under such circumstances increases the risk of heat strain that can lead to acute health effects such as dehydration, heat cramps, heat exhaustion, and heatstroke.²² At the global level, the current findings are consistent with the level of summer heat exposure in different industrial sectors, such as bakeries, and steel, glass, and construction industries reported in other studies conducted in tropical and subtropical countries.^{7,23-25} Compared to similar studies performed in Iran, we found that bakery workers in Ahvaz had a higher exposure to heat stress than those studied in other Iranian cities.^{10,11,26} A combination of heat gained from the surrounding work environment and heating sources, especially ovens, may be one of the main reasons for higher-than-TLV WBGT values recorded during work.

Recent studies have indicated that equivalent WBGT values underestimate or overestimate the thermal load in certain conditions. In fact, the WBGT-based TLV has a high sensitivity for detecting unsustainable heat exposure, however, its specificity is relatively low.²⁷ Therefore, use of WBGT might result in overestimation of heat stress in our study. Rastogi, *et al*, report that workers in glass bangle and brassware industries in India experience low physiological strain despite severe en-

vironmental heat stress levels. They suggest that this might be due to a high degree of acclimatization to the work environment or that the index is not appropriate in environments with high radiant heat load due to the low weighting factor for the radiant heat.^{28,29}

WBGT is an empirical index that only measures environmental factors, regardless of personal factors that might require higher protection (*eg*, age, physiological parameters) and affect workers' ability to tolerate heat strain. Despite the excessive values of WBGT in comparison with the TLV at baking systems, physiological responses, such as RHR and metabolic rate in *Sangak* and *Taftoon* baking stations were estimated at a moderate level; these parameters were at a high level in *Tanoori* baking. In *Tanoori* baking station, for its different structure and characteristics, *ie*, the availability of two ovens and the closeness of worker to the ovens, physiological responses are expected to be at a higher level. Physiological conditions suggest that the bakery workers in *Tanoori* baking system should be exposed to higher physical workload and risk of heat stress. A number of studies have so far evaluated the stress and heat strain in hot-dry climates in southern Iran. They show that although heat exposure among all workers is higher than the threshold level, only a small percentage of workers are under high heat strain, based on their core temperature and HR.^{6,30,31}

In the present study, there was a significant difference between the percentage of estimated work-rest, using environmental and physiological monitoring in such a way that work percentage in a work-rest cycle was determined to be 25% work and 75% rest per hour working in all baking systems (Table 2). Based on RHR, however, the work-rest cycle was estimated to be 70% and 100% work for *Tanoori* and *Taftoon* baking systems, respectively.

TAKE-HOME MESSAGE

- Despite the widespread use of WBGT, this index has some limitations, especially in hot-dry climate.
- There was no significant relationship between the WBGT and physiological parameters of the bakers in hot-dry climate.
- Estimation of the work/rest time based on WBGT as a standard, would not suit for heat stress management in hot-dry climate.

The practice of self-pacing by workers through the reduction of their metabolic rate to a safety margin has been identified as a protective response to heat exposure in workplace. Not accounting for self-pacing might result in overestimation of the risk.^{6,25,32,33} It seems that the self-pacing phenomenon has made WBGT to be a weak index for physiological responses in the hot climate of Ahvaz so that the correlation between WBGT and physiological factors was low. Bate, et al, believe that workers can work in summer without serious physiological consequences provided that they receive enough body fluids and consider self-pacing in tropical climates. They conclude that use of WBGT in tropical conditions is not precise and reliable; the thermal work limit index has been suggested for evaluating the heat stress.³⁴

From summer to mid-fall, the relative humidity in Ahvaz is between 70% and 90%; then, the amount of sweat evaporation is restricted by high humidity. The most serious limitation of the WBGT is that the environment at a given level of WBGT becomes more stressful when sweat evaporation is restricted (*eg*, by high humidity or low air movement). Moreover, the accuracy of WBGT measurement is eroded by measurement errors pertaining to the omission of the globe temperature with non-standard instrumentation and with poor calibration procedures. Due to the above-mentioned limitations, WBGT can only provide a general guide for the probability of adverse effects of heat exposure.¹²

Based on the results of the environmental and physiological monitoring made in our study, and taking into account the limitations of using WBGT, especially in hot climates, it is recommended to use more appropriate models considering climatic conditions of the area to predict heat stress and strain. Combined application of the environmental and physiological measurements seems to be better for the evalu-

ation of heat stress and strain in hot-dry climates.^{6,31,35}

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Conflicts of Interest: None declared.

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