Industrial Health 2020, **58**, 170–181

Field Report

Assessment of thermal exposure level among construction workers in UAE using WBGT, HSI and TWL indices

Hafiz Omer AHMED[1]*, Jawahir Abdelaziz BINDEKHAIN[1], Meera Ibrahim ALSHUWEIHI[1], Mohamed Abdikarim YUNIS[1] and Nour Rashid MATAR[1]

[1]Department of Environmental Health, College of Health Sciences, University of Sharjah, United Arab Emirates

Received December 22, 2018 and accepted July 3, 2019
Published online in J-STAGE July 13, 2019

Abstract: The study aimed to assess the heat stress of the construction workers in the United Arab Emirates (UAE), using Wet Bulb Globe temperature (WBGT) index, whereas also computing Heat stress index (HSI), and Thermal Work Limit (TWL) for comparison. Portable Area Heat Stress Monitor (HS-32) was used for measuring WBGToutdoor, Dry Bulb Temperature, Natural Wet Bulb Temperature, Globe Temperature in°C, and Relative humidity. The outcomes demonstrated that the WBGT exceeded the recommended Threshold Limit Value (TLV) and that workers are at risk of heat stress. According to HSI, only fit acclimatized young workers can tolerate work in this site, and workers should be selected by medical examination. As per TWL, the site was labeled as Acclimatization Zone implying that no un-acclimatized worker should work here and working alone should be avoided. The construction workers lie at a high or medium risk of heat stress. The contribution of the radiant heat load was very high compared with metabolic load and convective load. Furthermore, WBGT, HSI, and TWL are suitable to assess thermal stress in construction environments. Scheduling of the work earlier or later (after sunset) along with breaks for rest on cool shaded areas are recommended.

Key words: Construction workers, Heat stress, Wet bulb globe temperature index, Heat stress index, Thermal work limit

Introduction

It is a well-established fact that the increase in global temperature leads to a change in the climate worldwide. This is expected to increase the heat exposure along with its intensity and frequency[1]. This gives rise to new health issues in general living environments along with momentous social and economic impact. It directly increases occupational thermal stress for workers, affecting their health and productivity[2–4].

Thermal stress is the sum of heat generated in the body (metabolic heat) as well as the heat obtained from the environment (environmental heat) minus the heat lost from the body to the environment[5]. The body's natural way of maintaining the basic temperature from ascending to unhealthy levels is by increasing heart rate and sweating. When these are not enough to keep the core body temperature from rising, the result is heat-related illness or death. Higher core body temperatures may cause heat stroke, heat exhaustion, heat cramps, heat syncope, heat rash, and rhabdomyolysis[3]. In addition, Heat-related fatigue, cardio-

*To whom correspondence should be addressed.
E-mail: hafizomer@sharjah.ac.ae

vascular strain and decrease in cognitive performance are reported[6]. However, although thermal risks are common in indoor and outdoor work environments, heat-related and mortality-related diseases can be prevented.

Previous studies have shown that construction workers in the United States are 13 times more likely to die from heat-related illness (HRI) compared to workers in other industries[2]. In Hong Kong from 2007 to 2011, newspapers reported that 43 heat-related accidents, including 11 deaths, occurred at construction sites[7].

It has been observed that the Gulf region is subjected to severe thermal conditions during the summer months. Over the past decade, many oil-rich countries in the region have seen an amazing construction boom. The construction industry in the region has employed large numbers of expatriate workers, mostly from South Asia, and heat-related health problems are a major health and safety problem. In 2007, the United Arab Emirates (UAE) government imposed a mandatory work break for construction workers between 12:30 and 3:00 pm in the hottest months of July and August[8]. Furthermore, the concerned authorities established a heat safety program that refined and validated the Thermal Work Limit (TWL) index for use as well as other control measures to address the problem[9, 10].

The issue of the heat stress among the construction worker is amounting issue particularly considering the increase in the causalities because of changing heat dynamics, integrating various legal and financial issues[11]. It is essential to control the heat stress overcoming various difficulties such as accidents and mortality rate as well as increasing workers' productivity and social sense[12]. Therefore, the objective of this study was to assess the heat stress among construction workers in one of the building construction sites in the UAE using WBGT index, whilst also computing Heat stress index (HSI), and TWL for comparison.

Materials and Methods

Study site

In this investigation, one of the construction building sites in the UAE was selected for this survey.

Procedure

Over the years, many attempts have been made to equate the level of thermal stress with the level of measurement of physiological stress (consequences) along with the development of indicators for signifying different thermal stress. Environmental factors (ambient air temperature, relative humidity, evaporative cooling, radiative heat, conductive temperature, air velocity) and non-environmental factors (a type of work, duration of exposure and clothing) are included in different combinations in many thermal stress indices. The following are the thermal stress indices used worldwide.

ISO 7243, ISO 7933and ISO 9886 Standards for the Human Thermal Environment[13]

For controlling the human thermal environment and overcoming the issues of heat stress, ISO 7243 is used. The commonly used index for industrial environment assessment is WBGT which is empirical in nature. The ISO 7243 for the assessment of hot environments causes heat stress based on the WBGT (wet bulb globe temperature) index, which follows certain steps enlisted below:

- Step 1: Determining the WBGT index.
- Step 2: In case the value of WBGT is greater than the reference value of WBGT, a more comprehensive evaluation takes place (ISO 7933) which is inclusive of the required sweating calculation in a hot environment and also projects the heat strain derived from the heat balance equation.
- Step 3: In case specific group or individual responses are needed (with regard to the hot environment), the measurement of the physiological strain must be taken (ISO 9886).

According to ISO 7243, the WBGT of the workplace should be a weighted average of three readings measured at head, abdomen and ankle levels, and calculated according to the following equation:

$$\frac{WBGT = WBGT\ head + 2WBGT\ abdomen + WBGT\ ankles}{4}$$

Where:

WBGT= 0.7Tnw + 0.3Tg (for Indoor)

WBGT= 0.7Tnw + 0.2Tg + 0.1Ta (for outdoor)

Tnw: Natural wet bulb temperature, Tg: Globe temperature, Ta: Air temperature

In addition, ISO7243 specifies certain requirements for the WBGT monitor such as the globe is of 0.15 m in diameter and natural wet bulb sensor is cylindrical in shape (6 ± 1 mm diameter and 30 ± 5 mm long).

American Conference of Governmental Industrial Hygienists (ACGIH)−WBGT

American Conference of Governmental Industrial Hygienists ACGIH[14] recommends using the WBGT index to evaluate hot environments without specifying any require-

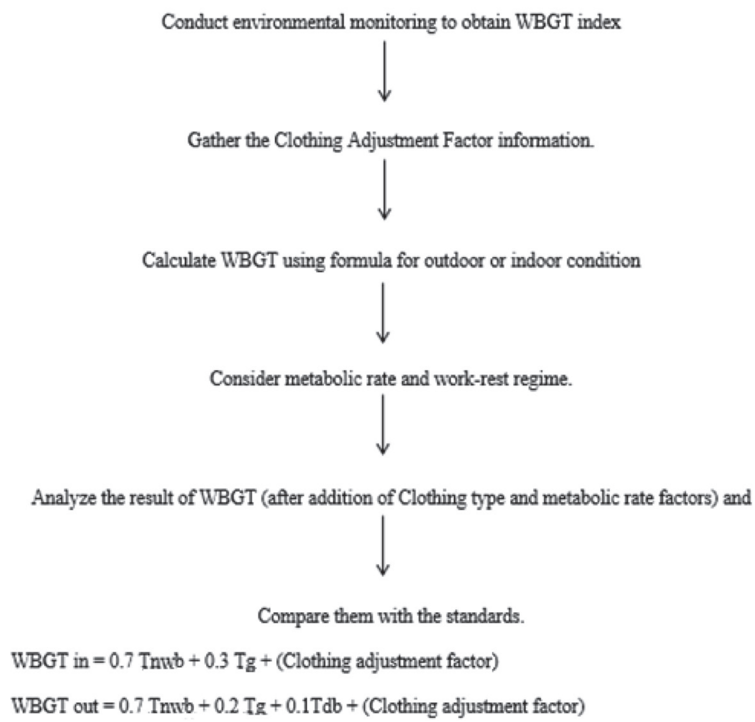

Fig. 1. ACGIH procedures.

ments for the WBGT monitor as in ISO 7243. ACGIH procedures is summarized in (Fig. 1). The figure highlights the monitoring of the environment by using the index in WBGT. The information about the clothing adjustment factor is then collected. The formula is used of WBGT for the analysis of the environment present both indoor and outdoor. It also considers the metabolic rate and the work rest regime. The analysis of WBGT integrates the outcomes of the metabolic rate factors as well as the type of clothes used. Subsequent to this, the standards are then compared.

Risk decision

Risk decision criteria are available, which can be used to determine the level of the risk and the recommendations. At low risk (Adjusted WBGT<Action Leve) work monitoring should be continued, at the medium risk (Action Level<Adjusted WBGT<TLV), implement general controls, continue work and maintain controls monitor. Whereas, at high risk (adjusted WBGT>TLV), in addition to the general control measures, the individual should be further analyzed and monitored with respect to the heat stress signs, symptoms, and disorder.

Heat Stress Index (HSI)[15, 16]

Belding and Hatch (1950) proposed a method of evaluating heat stress, based on the equation that governs the heat exchange between the skin and environment.

$$M \pm C \pm R = E$$

The heat stress index is a single value, which highlights the impact of the fundamental limitations in a particular thermal environment. For instance, the value of HSI will vary based on the strain an individual experience in a thermal environment

The method involves the estimation of metabolic (M), radiant (R) and convective (C) load, and the maximal evaporation cooling (E). These values can be estimated using equations 1 through 5.

Convective heat exchange in Kcal/h (C)=

$$7.0\ V^{0.6}(T_{air}-T_{skin}) \text{ ——— } (1)$$

Radiant heat exchange in Kcal/h (R)=

$$6.6(T_{radiant}-T_{skin}) \text{ ——— } (2)$$

$$T_{radiant} = VGT + (1.8\ V^{0.5})(VGT-T_{air}) \text{ ——— } (3)$$

Evaporative Heat Loss in Kcal/h (E)=

$$14\ V^{0.6}\ (P_{skin}-P_{air}) \text{ ——— } (4)$$

Where:

T_{skin} = 35°C

P_{skin} = Vapor pressure of skin = 42 mmHg

Then The Heat Stress Index (HSI) can be calculated by:

$$HSI = (E_{req}/E_{max}) \times 100 \text{ ——— } (5)$$

Where:

E_{req} = M+C+R and E_{max} = E

Interpretation of Heat Stress Index (HSI) values

HSI values vary from −20 to >100. HSI <zero represents mild cold strain; HSI=0 shows no thermal strain. HSI (10−30) indicates mild to moderate heat strain and little effect on physical work, but the possible effect on skilled work. HSI (40−60) designates severe heat strain involving a threat to health unless workers are physically fit and acclimatization required. HSI (70−90) indicates very severe heat strain. Only a small percentage of the population are expected to qualify for this work, personnel should be selected by medical examination, and ensure adequate water and salt intake. HSI=100 represents maximum strain tolerated by fit acclimatized young workers and HSI >100 exposure time is limited by a rising in deep body temperature[15].

Thermal Work Limit (TWL)

TWL is a newly developed index. It is defined as the maximum sustainable metabolic rate (in W/M^2 of body surface), which acclimatized individuals can maintain in a specific thermal environment, whilst maintaining a safe deep body core temperature (<38.2°C) and sweat rate (<1.2 kg/h)[17]. The index is designed specifically for self-paced workers defined "as those who can do and regulate their own workload and are not subject to excessive peer, managerial pressure or financial incentives"[17]. The TWL uses five environmental parameters (dry bulb, wet bulb, global temperatures, wind speed, and atmospheric pressure)[18]. It is claimed to be "simple to use, less prone to interpretive error, reliable and far superior to currently recommended indices as an indicator of thermal stress"[18]. The Thermal Work Limit, which has been scientifically validated for Gulf conditions, is the heat stress index adopted in UAE by Health Authority Abu Dhabi (HAAD) to enable safe management of heat[10].

Recommended guidelines for TWL values and control action[10, 17, 18]

There were different zones with advised intervention based on TWL level. In TWL <115 (High Risk, Restricted Zone), no person to work alone, no unacclimatized person to work and work limited to essential maintenance or rescue operations.

In TWL between 115–140 (Medium Risk, Buffer or Cautionary Zone), Cautionary indicates situations in which environmental conditions require additional precautions to reduce heat stress, working alone to be avoided if possible and un-acclimatized workers must not work at all.

In TWL 140–220 (Low Risk, Acclimatization Zone), workers with uncertain acclimatization status should not work alone in this zone; TWL >220 (Unrestricted Zone) unrestricted work, and no limits on self-paced work for educated, hydrated workers. The index can also determine the safe work duration, thus providing guidelines for work/rest cycling.

Measurements

WBGT recommended by ACGIH, HSI and TWL methods were used to assess the heat stress in this site. ISO 7243 not used for practicable reasons presented in the discussion.

Heat measurements were taken using a portable Area Heat Stress Monitor (HS-32), which measures WBGT indoor, WBGT outdoor, Dry Bulb Temperature, Natural Wet Bulb Temperature, Globe Temperature in °C, and Relative humidity. Anemometer used to measure airspeed.

TWL in Watts per square meter was calculated using a 'TWL calculator[10]. Metabolic (M), radiant (R) and convective (C) load, and the maximal evaporation cooling (E) were used to calculate the HSI (equations 1–6).

According to ISO 7243, the WBGT of the workplace should be a weighted average of three readings measured at head, abdomen and ankle levels. However, on the construction site, it is not practicable to take measurements at head, abdomen and ankle levels due to the workers and objects movement (nature of the jobs). Thus, in this investigation, the measurements were taken at 1.1 meters above the ground when the workers were standing. On the other hand, when seated, measurements were taken at 0.6 meters above the ground, which is generally equal to abdomen level. Measurements were taken between 12 noon and 15 afternoons, which represents the hottest hours of the day.

Results

General description of the construction site

The area size was 13,000 square meters, and the number of workers in this site was 200 workers working in 3 locations (A, B and C), with one work-shift for 10 h (75% work and 25% rest). This site was in the starting phase of construction, which was the stage of land excavation and pouring. For this stage there was a need for huge amounts of sand and cement.

Heat measurements

American Conference of Governmental Industrial Hygienists (ACGIH- WBGT)

Table 1 shows the results of the measured environmental parameters and WBGT Index following ACGIH method.

It is exhibited that the maximum globe temperature was (53.7°C) in location A, whereas the minimum was (43°C) in location C. Location A had the maximum and minimum percentage of relative humidity i.e. (45%) and (28%) respectively. Air temperature ranged between 32°C in area C and 38°C in area A, while the natural temperature varied between 21.5°C in area C and 24.9°C in area A. The minimum (1.67 m/s) and maximum (5.05 m/s) airspeed were in location B. The maximum WBGT outdoor was (31.1°C) in location A while the minimum was (26.9°C) in location C.

Based on the observation and metabolic rate of employees, the jobs performed by the workers at this location varied between moderate and heavy work. At this construction site, the workers were following 75% work and 25% rest regime. Since the workers were wearing clothes with long sleeve shirt and pants on this site; therefore, the correcting factor for the clothes is zero.

Table 2 shows the comparison of WBGT adjusted for the clothes with Action Limit and the TLV as recommended by ACGIH for 75% heavy and moderate work, which are (24°C, 26°C) and (27.5°C, 29.0°C) respectively. In locations A and B, both the minimum and maximum WBGT exceeded the Action Limit and the TLV as recommended by ACGIH for 75% heavy and moderate work. Considering this and corresponding to ACGIH criteria, the workers are at high risk of getting heat stress-related diseases. For location C, the maximum WBGT exceeded the TLV recommended for the heavy work but lower than that recommended for moderate work. However, the minimum WBGT reported in this location exceeded the action limit, but lower than the TLV that recommended for heavy and moderate work. Thus, workers in location C are at high or medium risk.

Heat Stress Index (HSI)

HSI was calculated using equations 1–6. As per the results, the metabolic heat was estimated to be 400 W for the heavy and moderate work performed by the workers in this site based on observation and metabolic rate of employees by job category recommended by ACGIH. Then the Metabolic Rate in W converted to Kcal/hr as follows:

$$400 \times 0.014665 \times 60 = 351.96 \text{ Kcal/h.} \quad (6)$$

In the equation, 0.014665 is the conversion factor to convert W to Kcal/min. However, the metabolic heat is approximated to 350 Kcal/h. As shown in Table 3, HSI was above 100% in location A, in this location maximum heat strain tolerated only by fit acclimatized young workers. In locations B and C, HSI ranges were (77.70% to 115.83%) and (70.51% to 87.62%) respectively, indicating that workers in these locations are at very severe heat strain. Only a small percentage of the population may be expected to qualify for this work in these locations. Under these conditions, workers should be selected by medical examination and adequate water and salt intake should be ensured. In addition, the contribution of the radiant heat load was very high between 45% and 60%, which is expected because the workers performed their jobs outdoor under the sun.

Thermal Work Limit (TWL)

In this study, TWL in Watts per square meter was calculated using a ‘TWL calculator’. As shown in Table 4, the TWL ranged from 117 W/M^2 in location A to 292 W/M^2 in location B. In location A, the lowest TWL was 117, it can be classified as “High Risk-Buffer Zone/Medium Risk-Cautionary Zone” and it is safe for continuous self-paced light work or continuous paced work (45 min work, 15 min rest) if the work is heavy according to the TWL Guidelines. However, for both options, additional precau-

Table 1. Results of the measured environmental parameters and WBGT index

Parameters	Location		
	A	B	C
	Min.–Max.	Min.–Max.	Min.–Max.
Wet (°C)	23.2–24.9	22.1–24.5	21.5–22.1
Dry (°C)	35.1–38.0	34.1–36.5	32.0–35.8
Globe (°C)	47.7–53.7	49.3–49.6	43–48.5
RH (%)	28–45	29–44	29–40
Air Speed (m/s)	1.92–2.82	1.67–5.05	3.26–3.73
WBGTo (°C)	30.5–31.1	29.3–30.3	26.9–28.4

Measurements were taken between 12 noon and 15 after noon.

RH: relative humidity; WBGTo: Wet Bulb Globe Temperature for outdoor.

Table 2. Comparison of WBGTo adjusted for the clothes* with action limit and the TLV as recommended by ACGIH for 75% heavy/moderate work

Parameters	Location		
	A	B	C
	Min.–Max.	Min.–Max.	Min.–Max.
WBGTo (°C)	30.5–31.1	29.3–30.3	26.9–28.4
Clothing-adjustment factor*	0	0	0
Adjusted WBGTo = WBGT + 0	30.5–31.1	29.3–30.3	26.9–28.4
Action Limit for 75% Heavy/Moderate Work (°C)	24/26	24/26	24/26
TLV for 75% Heavy/Moderate Work (°C)	27.5/29	27.5/29	27.5/29

*Workers wearing clothes with long sleeve shirt and pants. WBGTo: Wet bulb globe temperature for outdoor; TLV: thermal limit value; ACGIH: American Conference of Governmental Industrial Hygienists.

Table 3. Results of the measured environmental parameters and Heat Stress Index (HSI)

Parameters	Location		
	A	B	C
	Min.–Max.	Min.–Max.	Min.–Max.
Vapour Pressure (mmHg)	14–19	12–13	13–14
Air Speed (m/s)	1.92–2.82	1.67–5.05	3.26–3.73
T radiant (°C)	85.79–92.86	80.07–110.78	81.24–89.77
Metabolic Load (M) (kcal/h)	350	350	350
Convective (C) (kcal/h)	1.30–31.06	−16.65–14.28	−46.26–11.38
Radiant Load (R) (kcal/h)	335.19–381.86	297.48–500.17	305.19–361.51
Evaporation (E) (kcal/h)	579.78–599.80	571.32–1072.76	825.01–863.60
Ereq. =M+C+R	686.49–762.92	661.76–833.53	608.92–722.89
Emax= E	579.78–599.80	571.32–1072.76	825.01–863.60
HSI=(Ereq/Emax) ×100 (%)	114.45–131.59	77.70–115.83	70.51–87.62

tions are required to reduce heat stress in this location, such as the provision of shade, improvement of ventilation. Moreover, working alone in this area should be avoided, the un-acclimatized worker should not be allowed to work and adequate fluid intakes by workers should be ensured.

The minimum TWL in Locations B and C were 168 and 176 W/M^2 respectively so both locations can be classified as "Medium Acclimatization Zone" and it is safe for continuous self-paced light work for acclimatized, educated and hydrated worker but not alone (TWL Guidelines).

As shown in Table 5, the workers at locations A and B are posed with high risk, while those at location C face medium/high risk, which recommends further heat strain monitoring (Physiological). HSI and TWL indices agree that site A workers are at high risk while also specifying the control measures necessary to reduce heat stress at this site. Locations B and C are classified as high-risk zones (Very severe heat strain) and workers should be selected by medical examination according to HSI. Since both locations, (B) and (C) are classified by TWL as medium acclimatization zone, which restricts the acclimatized member working alone.

Discussion

The results of the study re-establish that construction workers are prone to thermal stress because they are involved in heavy work in variable outdoor climate. There are various work tasks involved in construction, such as intense shoveling, carrying, and disposal of debris and other tasks. The amount of time workers is exposed to direct hot sun depends on the tasks performed. However, construction activities have multiple impacts on workers' health through exposure to many risks such as dust, noise and thermal hazards during the performance period.

Both ISO 7243 and ACGIH methods recommend using the WBGT index to assess hot environments. WBGT is the most commonly used heat stress index because it is simple. In industry, occupational heat stress is generally assessed based on the WBGT index. However, Oliveira *et al.*[19]

Table 4. Results of the measured environmental parameters and Thermal Work Limit (TWL)

Parameters	Location		
	A	B	C
	Min.–Max.	Min.–Max.	Min.–Max.
Wet (°C)	23.2–24.9	22.1–24.5	21.5–22.1
Dry (°C)	35.1–38.0	34.1–36.5	32.0–35.8
Globe (°C)	47.7–53.7	49.3–49.6	43–48.5
Air Speed (m/s)	1.92–2.82	1.67–5.05	3.26–3.73
Thermal work limit W/M^2	117–163	168–292	176–226

Measurements were taken between 12 noon and 15 afternoons.

Table 5. Comparing Wet Bulb Globe Temperature (WBGT), Heat Stress Index (HSI) and Thermal Work Limit (TWL) indices

Location	Index	Min.–Max.	Risk Level	Action*
A	WBGT (°C)	30.5–31.1	High	Perform Heat Strain Monitoring (Physiological)
	TWL (W/M^2)	117–163	High	Provision of shade. Improvement of ventilation. Working alone in this area should be avoided. The un-acclimatized worker should not be allowed to work. Adequate fluid intakes by workers should be ensured
	HSI (%)	114.45–131.59	High	Exposure time is limited due to high body temperature
B	WBGT (°C)	29.3–30.3	High	Perform Heat Strain Monitoring (Physiological)
	TWL (W/M^2)	168–292	Medium Acclimatization Zone	Acclimatized workers allowed working but not alone.
	HSI (%)	77.70–115.83	High	Very severe heat strain. Personnel should be selected by medical examination. Ensure adequate water and salt intake. Exposure time is limited due to high body temperature
C	WBGT (°C)	26.9–28.4	Medium/High	Implement General Controls Perform Heat Strain Monitoring (Physiological)
	TWL (W/M^2)	176–226	Medium Acclimatization Zone	Acclimatized workers allowed working but not alone.
	HSI (%)	70.51–87.62	High	Very severe heat strain. Personnel should be selected by medical examination. Ensure adequate water and salt intake.

*According to the guidelines of the index.

reported that the index has limitations as it is not possible to determine the maximum time of exposure as a function of dehydration or define the duration of exposure. Thus, for environments where the WBGT index is high, a complementary assessment such as Predicted Heat Strain (PHS) should be used. On the other hand, Parsons concluded that WBGT is the easiest to use and can be easily interpreted by a nonprofessional with a reasonable validity[13] In this investigation, the procedure of ISO7243 was not followed because the specifications of the WBGT monitor available are not complying with that specified by ISO7243 for the WBGT monitor mentioned previously. In this investigation, WBGT index was used to assess the heat stress among construction workers in one of the building construction sites in the UAE, whilst also computing HSI, and TWL for comparison. Measurements took place between 12 noon and 15 afternoons because it represents the hottest hours of the day.

The jobs performed by the workers in this site considered to be ranged between heavy and moderate work. In this construction site, the contribution of the radiant heat load was very high (45% and 60%), followed by metabolic load (42–57%) while the contribution of convective load was very low (−8% −4%). This is expected because the workers performed heavy to moderate work outdoor under the sun. The results of this study that WBGT, HSI, and TWL exceeded the recommended TLV, thus construction site workers are at a risk for heat-related health problems, and WBGT, HSI, and TWL are suitable to assess thermal stress in many environments.

In a survey conducted by Jia et al in 2011, 17 of 37 trades reported cases of heat-induced illness on construction sites, 17% of workers reported experiences of heat-induced illness[20)]. A survey issued from the US Bureau of Labor Statistics (BLS) in 2013, reported that 31 fatalities related to outdoor environmental heat exposure, 45% of the fatalities were associated with the construction industry.

Payel *et al.* reviewed current epidemiological research on occupational heat stress in the construction industry, both in the United States and internationally. The heat-related health effects among construction workers are significant; however, the unprecedented public health issue and adverse health effects associated with heat can be reduced easily through low-cost interventions (e.g., rest periods, shade and drinking water)[2)]. Despite the limitations of WBGT in measuring the effects of metabolic rate and wind speed effect, WBGT remains an important indicator for measuring the effects of heat. Another index of heat stress related to construction workers and outdoor workers is the TWL, a commonly used measure in occupational settings that incorporates environmental parameters into the single index as the equivalent metabolic rate. Although, core body temperature and skin temperature are better measures than other heat stress indices, they have not been used very often because of safety and logistical issues[2)].

Farshad *et al.* also conducted a study to determine the level of thermal stress on construction workers using the TWL and WBGT indices and by measuring the specific gravity of urine (USG) among construction workers in Iran and comparing the suitability of these indices in Iran's climate[21)]. The minimum and maximum WBGT (26.4, 29.6°C), the mean TWL 144 W/M^2, and the maximum WBGT and TWL were in mid-shift work for sun-exposed construction workers as reported by Farshad *et al.*[21)], compared with WBGT (26.9–31.1°C) and TWL (117–292) between 12−15 pm in this study.

In contrast to the present study, Farshad et al concluded that construction workers were exposed to an acceptable level of WBGT (<30°C) and in the acclimatization zone (>140 W/M^2) as defined in the TWL index. However, the authors reported a significant correlation between the WBGT, TWL and USG indices indicating a high level of WBGT and TWL efficiency in thermal stress assessment, but TWL has another advantage over WBGT, including workload measurement, ventilation, and air assessment conditioning systems, and measuring the work and rest cycle[21)].

Miller *et al.*[8)] conducted studies in construction sites and industrial facilities in the UAE over two years to assess the thermal environment and to verify whether self-pacing may be an important preventive behavior for manual workers in extreme thermal conditions. Environmental thermal stress was measured through TWL, and heat strain assessed from heart rate and core body (rectal) temperature. The researchers reported that the TWL ranged between 140 and 200 W/M^2 indicating that individuals who were acclimatized, and well hydrated would be able to perform a moderate level of work without heat storage. However, due to the high daily variation level, TWL may be less than 140, which restricts work[8)]. While in the current study, the minimum TWL was 117 W/M^2 which is less than 140 and at a given time may be less than 115, the recommended "stop" level.

Miller *et al.* concluded that there was no correlation pattern between lower TWL values and higher heart rates or vice versa, and uneducated, well-hydrated, and acclimatized workers who are permitted to self-pace may safely continue working under conditions that would be prohibited by most conventional heat stress indices[8)].

A prospective longitudinal study by Bates and Schneider investigated the physiological responses of a building construction workers in thermally stressful environments in the UAE[22)]. Aural temperature, fluid intake, urine specific gravity and heart rate were monitored to assess fatigue. TWL and WBGT were used to assess the thermal stress. In Bates and Schneider' study, WBGT values varied between 26.9 and 30.8°C and TWL between 122 and 279 W/M^{-2} during 12–16 pm. Similarly, the values of 26.9–31.1°C and 117−292 W/M^{-2} were recorded between 12−15 pm in this study respectively. The authors found no changes in core temperature or average heart rate, despite substantial changes in thermal stress. They concluded that people can work, without adverse physiological effects, in hot conditions if they are provided with the appropriate fluids and are allowed to self-pace[22)]. The use of WBGT as a thermal index is inappropriate for use in Gulf conditions; however, TWL was found to be a valuable tool in assessing thermal stress[22)].

In an outdoor study conducted by Miller and Bates, the workers were monitored for physiological strain signs in thermal environments by measuring the core temperature, heart rate and thermal environment assessed using both conventional WBGT and TWL to evaluate their respective capabilities to accurately reflect thermal stress on workers[18]. The findings highlight that the WBGT values ranged from 27.1 to 34.7°C with steady values >30°C continuously, especially on the construction site. For much of the time, these values exceeded the acceptable limit for acclimatized persons to perform even light work without work/rest cycling which is consistent with this study[18].

However, Miller and Bates reported that the TWL was >140 W/M^{-2} indicating that self-pacing, acclimatized, hydrated individuals may safely perform light to moderate work and for the most time TWL >200 W/M^{-2} corresponding to unrestricted work at any level, while both core temperature and heart rate are normal. The authors conclude that WBGT is not a practical indicator of thermal stress in many situations. TWL was a more appropriate and realistic and valid index of heat stress than WBGT and provides a workable strategy for managing heat stress[18]. Dutta *et al.* also conducted a research and concluded that the mean recorded WBGT in summer was 32.4 ± 1.1°C that is 3.4°C higher than suggested permissible exposure limits for acclimatized men in the tropics and the construction workers have a high burden of heat-related discomfort and illness, particularly during summer months[23].

Farideh *et al.*[24] conducted a study in Iran to analyze outdoor physiological response with respect to the perception of heat-related stress, and the possible differences in response among different occupational groups. The authors assessed the environmental thermal stress through the WBGT index, and physiological parameters including heart rate, systolic and diastolic blood pressure, skin temperature and oral temperature were measured to compare groups. The authors found that WBGT index was maximum between the hours of 13 to 16 pm, and the WBGT index was more than acceptable level in construction workers and other groups[24]. Thus, they are more prone to suffer from heat stress than other groups, which is consistent with the finding of this study that WBGT at the construction site was above the TLV and workers at high risk of heat-related health problems. In contrast to the others, Farideh et al. found a significant relationship between the WBGT index and physiological parameters, and increase in the WBGT index, the deep body temperature, blood pressure, heart rate or thermal strain increases, which indicate the suitability of this index to the assessment of heat stress[24].

A study conducted in a plastic factory located in Malaysia by Ben *et al.*[25] to determine the exposure of heat stress and its biological effects on the workers. WBGT index, body temperature, heart and recovery heart rate were measured. Measurements of WBGT showed a range of 26.5−30.4°C that is slightly above the recommended ACGIH threshold level and workers were exposed to moderate heat stress. This finding is similar to the results of the current study that WBGT range (26.9–31.1°C) was above threshold level and workers were at high risk of getting heat-related health problem. However, Ben *et al.* showed no significant correlation exists between the WBGT measures with the body temperature. Even though the measured WBGT was slightly above the recommended threshold level, the body temperature and heart rate measured did not reach an unacceptable level of physiologic strain[25].

Mahdavi *et al.*[15] carried out a study to assess HSI and WBGT as indicators of heat stress, measure oral temperature as core body temperature (physiological parameter) and compare their values with the threshold limits allowed in steels industry workers. The researchers reported that the WBGT range was 36.7–44.1°C , and the HSI range was 323.00−693 compared with 26.9–31.1°C and 70.51–131.59 reported in this study respectively. The authors reported that the body temperature ranged between 37.19 and 38.5°C. and concluded that the thermal stress assessment using HSI and WBGT was higher than biological monitoring (measuring the core body temperature). Thus, the assessment of thermal stress using biological monitoring in hot environments under high humidity conditions or low air velocity is closer to the reality of heat stress in exposed workers[15].

Pourmahabadian *et al.* applied WBGT, Corrected Effective Temperature (CET), and HSI to assess heat stress among workers in glass manufacturing unit in Iran. The results of Pourmahabadian *et al.* study show that WBGT, (HSI), and (CET) were 33.47°C , 414.67% and 36.5°C respectively, exceeded the standards and; therefore, the heat stress may have a negative impact on workers' health[16]. These findings are in agreement with the findings of the current study that the max WBGT and HSI were 31.1°C and 131.59% respectively above the standard.

A study by Srivastava *et al.*[26] assessed the thermal exposure of workers in the glass manufacturing unit in India. WBGT, CET and Mean Radiant Temperature (MRT) were measured. WBGT, CET, and MRT exceeded the TLV limits and heat exposure has a negative impact on worker efficiency and productivity. Considering this, the authors have concluded that to avoid heat stress problems, the recommendations of ACGIH should be taken as indicative of stress areas and workers should be under the constant medical supervision and ACGIH Standards for work and rest regime[26)].

Oliveira *et al.*[19)] used WBGT for the assessment of heat stress in the ceramic industry. The results showed several types of workplaces with different environmental exposures some of them with harsh conditions where a large number of workers involved are repeatedly under heat stress. The authors concluded that the WBGT index has limitations, namely when the standard values are exceeded, even when rest periods reduce the mean value of the WBGT index below the standard. The deep body temperature may still be rising, or the sweat rate may cause excessive water losses after a few hours of work. Thus, the WBGT index is relevant for the assessment of the thermal environment and to compare different thermal environments. However, to organize the work in the heat, the WBGT is not enough and improved indices are required such as the Predicted Heat Strain index (PHS)[19)].

Comparison of the results of the current study with Li *et al.*[4)], which examined the effect of high temperature conditions on labor productivity. Both studies reported WBGT ranged between 23.77 and 32.11°C . The authors conclude that WBGT has a negative impact on direct working time and a positive effect on idle time. When WBGT increases by 1°C , the percentage of direct labor time decreases by 0.57% and the percentage of downtime (idle time) increases by 0.74%[4)].

Venugopal *et al.*[27)] conducted a study aimed at identifying occupational heat stress and its impact on the health and productivity of workers from organized and unorganized labor sectors in India during hotter and cooler seasons. Exposure to thermal stress and its impact on health and productivity were assessed by WBGT measurements and a questionnaire, respectively.

The WBGT (27.2–31.9°C) recorded by Venugopal *et al.* for-construction sector in the hotter season in agreement with (26.9–31.1°C) reported in the current study. The authors concluded that 82% of the workers were exposed to WBGTs higher than the recommended TLV as per ACGIH guidelines in the hotter season, and heat stress had negative implications on health and productivities of exposed workers[27)].

Another study by Tord *et al.*[28)] concluded that increased exposure to heat due to local climate changes is likely to create risks to occupational health and have a significant impact on the productivity of many workers particularly on outdoor environments unless effective preventive measures are implemented to reduce occupational stress. This may be feasible and economical for indoor environments, but it is much harder for outdoor environments. Furthermore, the authors reported that the working capacity decreases rapidly as WBGT exceeds 26–30°C and this can be used to estimate the impact of increasing heat exposure as a result of climate change in tropical countries. Malakouti *et al.*[29)] carried study with the aim to study the rate of heat stress in bakers using WBGT index. The authors concluded that workers in traditional bakeries at risk of heat stress. The results in contrast to these studies, suggests that the heat stress serves as a health and safety hazard which mitigates workers' productivity, increases the jeopardy of heat-related complaints, and poses safety complications to the workers at construction site.

Conclusion

In this study WBGT, HSI, and TWL were used to assess the heat stress among construction workers. The results revealed that WBGT exceeded the recommended TLV and workers are at risk of heat stress. According to HSI, workers should be selected by medical examination and adequate water and salt intake should be ensured. While TWL classified the site as Buffer or Acclimatization Zone where an un-acclimatized worker should not be allowed to work and working alone should be avoided, in addition to the provision of shade and improvement of ventilation.

In addition, in this study, the contribution of the radiant heat load was very high compared with metabolic load and convective load. Furthermore, WBGT, HSI, and TWL are suitable to assess thermal stress in construction environments, but TWL and HSI have some merit by providing a practical and effective strategy for managing thermal stress. Thus, for environments, where the WBGT index is high, a complementary assessment by HSI or TWL should be used. Since it is not practicable to apply engineering control due to the nature of the tasks that performed in a construction site. Thus, work should be scheduled earlier or later (after sunset) in the day, resting breaks in cool shaded areas should be arranged, continuous paced work i.e. workers must be allowed to adjust their work rate according to environmental conditions.

Conflict of Interest

The authors declare no conflicts of interest.

Acknowledgement

The authors wish to thank all the construction manager and workers who participated in this research. It could not have been done without their cooperation.

References

1) WMO (World Meteorological Organization) (2016) WMO statement on the state of the global climate of WMO No-1189. https://library.wmo.int/opac/doc_num.php?explnum_id=3414 Accessed October 11, 2018.
2) Acharya P, Boggess B, Zhang K (2018) Assessing heat stress and health among construction workers in a changing climate: a review. Int J Environ Res Public Health **15**, 247.
3) OSHA (Occupational safety and Health Administration) (2017) https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html. Accessed October 11, 2018.
4) Li X, Chow KH, Zhu Y, Lin Y (2016) Evaluating the impacts of high-temperature outdoor working environments on construction labor productivity in China: a case study of rebar workers. Build Environ **95**, 42–52.
5) National Institute for Occupational Safety and Health (2013) Criteria for a recommended standard: occupational exposure to hot environments. External review draft released for public comment. Cincinnati, Department of Health and Human Services, Centers for Disease Control and Prevention, NIOSH, OH, USA.
6) Simmons SE, Saxby BK, McGlone FP, Jones DA (2008) The effect of passive heating and head cooling on perception, cardiovascular function and cognitive performance in the heat. Eur J Appl Physiol **104**, 271–80.
7) Rowlinson S, Yunyanjia A, Li B, Chuanjingju C (2014) Management of climatic heat stress risk in construction: a review of practices, methodologies, and future research. Accid Anal Prev **66**, 187–98.
8) Miller V, Bates G, Schneider JD, Thomsen J (2011) Self-pacing as a protective mechanism against the effects of heat stress. Ann Occup Hyg **55**, 548–55.
9) Joubert D, Thomsen J, Harrison O (2011) Safety in the Heat: a comprehensive program for prevention of heat illness among workers in Abu Dhabi, United Arab Emirates. Am J Public Health **101**, 395–8.
10) https://www.haad.ae/Safety-in-Heat/Default.aspx?tabid=65.
11) Yang Y, Chan AP (2017) Heat stress intervention research in construction: gaps and recommendations. Ind Health **55**, 201–9.
12) Ayyappan R, Sankar S, Rajkumar P, Balakrishnan K (2009) Work-related heat stress concerns in automotive industries: a case study from Chennai, India. Glob Health Action **2**, 2060.
13) Parsons K (2013) Occupational health impacts of climate change: current and future ISO standards for the assessment of heat stress. Ind Health **51**, 86–100.
14) American Conference of Governmental Industrial Hygienists (2015) TLVs® and BEIs®: Threshold limit values for chemical substances, physical agents, and biological exposure indices, ACGIH, Cincinnati.
15) Mahdavi S, Esmaelzadeh A, Ebrahemzadeh F, Rashidi R, Naeimi N (2014) Comparing the core body temperature and the heat stress indices of HSI and WBGT in Lorestan steels industry workers. Iran Arch Hyg Sci **3**, 160–6.
16) Pourmahabadian M, Adelkhah M, Azam K (2008) Heat exposure assessment in the working environment of glass manufacturing unit. Iran J Environ Health Sci Eng **5**, 141–7.
17) Brake DJ, Bates GP (2002) Limiting metabolic rate (thermal work limit) as an index of thermal stress. Appl Occup Environ Hyg **17**, 176–86.
18) Miller VS, Bates GP (2007) The thermal work limit is a simple reliable heat index for the protection of workers in thermally stressful environments. Ann Occup Hyg **51**, 553–61.
19) Oliveira AV, Gaspar AR, Raimundo AM, Quintela DA (2015) Assessment of thermal environments: Working conditions in the Portuguese ceramic industry in 1994 and 2012. Work **51**, 457–70.
20) Jia YA, Rowlinson S, Ciccarelli M (2016) Climatic and psychosocial risks of heat illness incidents on construction site. Appl Ergon **53** Pt A, 25–35.
21) Farshad A, Montazer S, Monazzam MR, Eyvazlou M, Mirkazemi R (2014) Heat stress level among construction workers. Iran J Public Health **43**, 492–8.
22) Bates GP, Schneider J (2008) Hydration status and physiological workload of UAE construction workers: a prospective longitudinal observational study. J Occup Med Toxicol **3**, 21.
23) Dutta P, Rajiva A, Andhare D, Azhar GS, Tiwari A, Sheffield P, Ahmedabad Heat and Climate Study Group (2015) Perceived heat stress and health effects on construction workers. Indian J Occup Environ Med **19**, 151–8.
24) Farideh G, Mohammad RM, Mohsen YA, Teimour A, Ebrahim T, Maryam RAS (2016) Investigation of heat stress and heat strain in outdoor workers: a case study in Iran. J Paramed Sci **7**, 4978.
25) Ben GS, Hashim Z, Hamzah R (2004) Occupational heat exposure of workers in a plastic industry Selangor. J Occup Saf Health **1**, 56–63.
26) Srivastava A, Kumar R, Joseph E, Kumar A (2000) Heat exposure study in the workplace in a glass manufacturing unit in India. Ann Occup Hyg **44**, 449–53.
27) Venugopal V, Chinnadurai JS, Lucas RA, Kjellstrom T (2015) Occupational heat stress profiles in selected

workplaces in India. Int J Environ Res Public Health **13**, 89.
28) Tord K, Ingvar H, Bruno L (2009) Workplace heat stress, health, and Productivity—an increasing challenge for low and middle-income countries during climate change. Glob Health Action.
29) Malakouti J, Ahmad RY, Navid S, Gharib M, Shahram N, Soudabeh AM, Shahram AJ, Mohammad SN (2015) Studying the rate of heat stress in bakers. Arch Hyg Sci. **4**, 7–12.