IH for the CSP 6: Wet Bulb Globe Temperature Index

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Abstract

In the year 2000 alone, OSHA recorded 21 workplace fatalities due to heat stress. There were an additional 2,554 heat stress injuries sufficiently serious to require days away from work. OSHA noted that heat stress-related injuries are likely under-reported as many employers fail to recognize the symptoms of heat-related illness. It should further be recognized that heat stress will impair the metal and physical abilities of employees. There is no way to estimate the number of fatalities and injuries in which heat stress may have plated a significant role.

There are many methods for evaluating the hazard due to conditions of heat stress. The American Conference of Governmental Industrial Hygienists, ACGIH, publishes a method known as the Wet Bulb Globe Temperature Index (WBGT). Currently OSHA has no heat stress standard and is enforcing the WBGT recommendations of the ACGIH under section 5(a)(1) of the OSH Act, the General Duty Clause.

Heat Stress and Heat Strain

"Heat stress" refers to adverse conditions to which employees are exposed. Stressors include air temperature, humidity, radiant energy (e.g. infra-red radiation), clothing worn, air movement, and others. "Heat strain" refers to the response of the body to heat stress, i.e. heat related illness.

The human body cannot tolerate even small changes ($\pm$ 1 ^{O}C or $\pm$ 2 ^{O}F) in body core temperature without adverse effect. Fortunately we are equipped with remarkable systems to regulate body temperature. These systems are largely controlled by the hypothalamus area of the brain. In hot environments the body removes heat through two main systems, evaporation of perspiration and dilation (opening) of peripheral blood vessels.

The most serious form of heat strain is heat stroke. In heat stroke, the hypothalamus simply stops functioning. The body ceases to produce perspiration and core temperatures can increase rapidly. Heat stroke is characterized by **hot, dry skin**. It can cause mental confusion, convulsions, or unconsciousness. Heat stroke will be fatal if not treated promptly. Treatment should include cooling the body as rapidly as possible. Treat for shock by opening restrictive clothing and raising the feet. Emergency medical services should be summoned immediately.

Much more common than heat stroke is heat exhaustion. Heat exhaustion is usually caused by water deficiency. It can also be caused by a lack of salt. However this is rare, especially in acclimatized workers. When heat exhaustion is related to salt depletion it is usually accompanied by heat cramps due to a build up of lactic acid. Heat exhaustion is characterized by moist, clammy skin. Symptoms may include giddiness, headache, nausea, or fatigue. Treat by moving the employee to a cooler area. Give water orally. Never give anything orally to an unconscious individual. Water should include at most 0.9% salt. In the past, salt tablets were given to individuals suffering heat exhaustion, especially when related to outdoor sports activities. Today, this practice is no longer advised. If not taken for medical treatment, sufferers of heat exhaustion should be carefully watched. Heat exhaustion is often a precursor to heat stroke discussed above.

Miliaria (a.k.a. prickly heat or heat rash) can result if the shin surface is occluded (i.e. covered by impermeable materials). This includes not only clothing, but also other surfaces (e.g. seating) if contact is continuous. Miliaria will quickly resolve without medical treatment once the occlusion is removed (i.e. once the skin is allowed to "breathe").

The final heat stress concern is chronic heat fatigue. It is characterized by reduced performance, especially in vigilance tasks. Physical and mental errors are simply more likely in hot environments. Employees suffering chronic heat fatigue may exhibit a lowering of self-imposed behavioral standards, such as removing all clothing or drinking excessively during working hours.

WBGT

The WBGT method uses two indices, one for conditions indoors or outdoors with no solar load (no sun shining on the employees), and one for conditions outdoors with a solar load. The indoor index, $WBGT_{in}$, is,

$$WBGT_{in} = 0.7\ NWB + 0.3\ GT \quad . \qquad 1$$

The index outdoors with a solar load, $WBGT_{out}$, is,

$$WBGT_{out} = 0.7\ NWB + 0.2\ GT + 0.1\ DB \quad , \qquad 2$$

where NWB is the natural wet-bulb temperature (the temperature of a wet thermometer with no forced air flow), GT is the globe temperature (the temperature within a 6-in hollow copper globe with a flat black finish), and DB is the dry bulb temperature (the temperature measured by a conventional thermometer).

A WBGT index of greater than 26 ^{O}C (79 ^{O}F) is considered a "hot environment." If the WBGT measures less than 26 ^{O}C everywhere and at all times, then the workplace is relatively safe for most workers and no further analysis need be done.

All three of these temperatures can be measured simultaneously with a device called the WiBGeT. In addition, the WiBGeT will calculate both the indoor and outdoor indices. Most WiBGeT's can be set to read in either ^{O}C or ^{O}F. It should be noted that for the sake of convenience, the globe temperature is measured using a globe approximately 3-cm in diameter.

Measurement Protocol

Like all instruments used in industrial hygiene measurements, the heat stress monitor must be calibrated according to manufacturer's instructions. Usually the instrument will be factory calibrated, often every two years, and field calibrated before and after each day's use.

Field calibration is performed by the industrial hygienist using a calibration key. The temperature sensor array, or a single temperature sensing element, is detached from the monitor. The key is then inserted in place of the array or the element and the output of the monitor is recorded. The manufacturer will specify the temperature or temperatures that should be displayed, and the tolerance allowed. Often the desired readings are printed on the key itself. For example, the key may be inserted in place of the globe temperature sensor. If the manufacturer specifies the globe temperature should read 25.0 ^{O}C $\pm$ 0.2 ^{O}C, and it indicates above 25.2 ^{O}C or below 24.8 ^{O}C with the key inserted, the instrument fails the calibration test, and must be returned to the manufacturer for servicing before use. If the key is to be inserted in place of the entire sensor array, the required readings for all three temperatures (globe, dry bulb, and natural wet bulb) are usually specified. If any one of the temperatures is observed to fall outside the specified range, the monitor must be returned to the manufacturer for servicing and factory calibration before it may be used.

A significant period of time, often 15 minutes, is required for the device to equilibrate, i.e. come to equilibrium with the surroundings. The main reason for this delay is the globe temperature sensor. It simply takes some time to heat up (or cool down) the air inside the hollow sphere. If employees move from area to area in times less than 15 minutes, additional monitors may be required.

Clothing

The primary mechanism for removing heat from the body in hot conditions is evaporation of perspiration. Obviously, the effect of heat stress will depend on the clothing worn by the employee. For example, the air within a totally encapsulating, vapor-protective suit (Level A worn by emergency spill responder) will quickly become saturated with moisture. This will prevent any evaporation of perspiration. Emergency responders may face life-threatening heat stress conditions even on a cool day.

The ACGIH recommends correcting the WBGT based on the clothing worn. For a normal work uniform (long sleeve shirt and pants) or cotton coveralls (with only undergarments, not another set of outerwear) no correction is needed. For double-layered woven clothing (such as coveralls over a work uniform) 3 ^{O}C Celsius is added to the WBGT. The correction factors for SMS polypropylene, and polyolefin coveralls are 0.5 and 1.0 ^{O}C, respectively. For limited-use vapor-barrier coveralls, a correction factor of 11 is recommended. Your author interprets "vapor-barrier coveralls" to mean garments such as chemical splash protective suits (Level B).

Time-Weighted Average

In industry, employees usually move from area to area. Since heat stress conditions may differ greatly even in relatively close locations, a method of averaging the WBGT indices is required. The ACGIH recommends a **one-hour** time-weighted average WBGT. The time-weighted average is calculated for hottest **continuous** 60-minute period. A two-hour time-weighted average may be used if the employee moves frequently in and out of heat stress areas. The one-hour average is used in stead of an eight-hour average (as for air contaminants) because one hour is all it takes for the heat to affect you. It won't matter that you plan to spend the rest of the afternoon in a cool place if you are already dead by noon. The time-weighted average WBGT is given by,

$$WBGT_{TWA} = \frac{WBGT_1\ (t_1) + WBGT_2\ (t_2) + \ldots + WBGT_n\ (t_n)}{t_1 + t_2 + \ldots + t_n} , \quad 3$$

where $WBGT_i$ is either the indoor or outdoor (as required) wet bulb globe temperature index during the i^{th} time period, and t_i is the time the employee is exposed to $WBGT_i$.

If employees wear the same clothes throughout the day, the time-weighted average may be calculated based on the direct WiBGeT readings and then corrected for the clothing worn. If different clothes are worn in different areas, each WiBGeT reading must be corrected individually and the time-weighted average calculated using the corrected values. This is often the case if coveralls are donned in areas exposed to chemical contamination and removed before exiting the area to prevent the spread of contamination.

Metabolic Rate

According to the WBGT method of heat stress assessment, the maximum time-weighted average WBGT to which employees should be exposed will depend on their average metabolic rate, or the rate at which the body generates heat due to the work being performed. There are many ways to estimate metabolic rate, monitoring heart rate, measuring oxygen consumption, etc. The ACGIH method for estimating metabolic heat rate (M) as published in the 2008 TLV and BEI booklet is quite simple.

The work done during the hottest 60-minute period is estimated using professional judgment and the benchmark four (4) categories shown in the table below.

Category	M (Watts, W)	Examples
Rest	115	Sitting, relatively inactive
Light	180	Sitting with light hand and arm work, occasionally walking
Moderate	300	Moderate work with hand arm and body, pushing or pulling, normal walking
Heavy	415	Intense work with hands arms and body; carrying, shoveling, sawing, pushing or pulling heavy loads, walking at a fast pace
Very Heavy	520	Very intense activity at fast to maximum pace.

Table 1: ACGIH guidelines for estimating the metabolic rate

The above values are representative of an employee weighing 70 kg (154 lb). Obviously, a larger employee will expend more energy doing the same tasks. The WBGT method assumes the metabolic rate will be proportional to weight or mass. The metabolic rate corrected for weight, M_{COR}, is given by,

$$M_{COR} = M \frac{\text{weight}}{154 \text{ lb}} = M \frac{\text{mass}}{70 \text{ kg}} .$$

TLV

The maximum recommended WBGT for a given metabolic rate is called the "Threshold Limit Value" or "TLV." It is given as a function of corrected metabolic rate in the figure below. For example, the TLV for a metabolic rate of 200 W, is a WBGT = 30^{O}C.

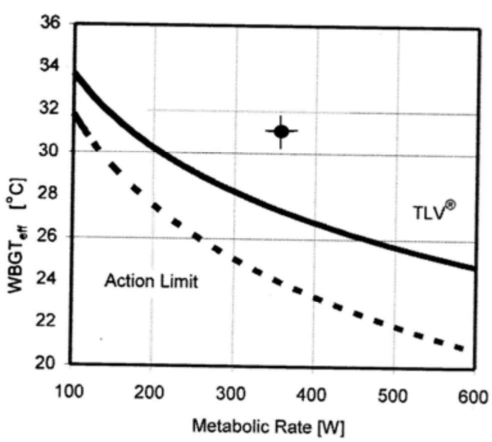

Figure 1: ACGIH Threshold Limit Values for Heat Stress

If the data point falls below the dotted line, nearly all fit employees should not suffer heat-related illnesses under these conditions, and no action is recommended.

If the data point falls anywhere above the dotted line, we are above the action level. It is likely that some employees may experience heat-related illness; and a heat stress management program is recommended.

If the data point falls above the solid line, we have exceeded the TLV, or maximum recommended WBGT. Engineering controls (e.g. increased ventilation or insulation), administrative controls (e.g. a work/rest or employee rotation regiment), or personal protective equipment (PPE) such as reflective clothing or ice-pack vests should be considered in addition to the implementation of a heat stress management program.

Care must be taken when implementing abatement methods. Proper abatement requires an understanding of the nature of the heat load. For example, if the air is very humid (wet bulb temperature close to dry bulb temperature) and the dry bulb temperature exceeds that of the surface of the skin (35^{O}C or 95^{O}F) increasing air velocity will actually worsen heat stress conditions. A certified industrial hygienist (CIH) knowledgeable about heat stress should be consulted. For very high heat stress loads, the Heat Stress Index (HSI) method of evaluation is preferred over the WBGT method. The HSI method requires much more complicated calculations, but gives a better understanding of the nature of the heat load. The HSI method also allows calculation of the maximum allowable exposure time (AET) for very high heat stress levels.

Acclimatization

In previous editions of the Threshold Limit Values and Biological Exposure Indices handbook, the ACGIH referred to the dotted line as "the TLV for unacclimatized workers." Workers who have not been acclimatized are likely to suffer heat strain under heat stress conditions above the action limit, even if they are still below the TLV. Acclimatization is defined by the ACGIH as "a gradual physiological adaptation that improves an individual's ability to tolerate heat stress." Employees are considered "acclimatized" if they have spent two consecutive hours during five (5) out of seven (7) consecutive days in the hot environment. In order to become acclimatized, employees must be doing the work expected under the heat stress condition they will encounter. Some employees may require ten (10) out of 14 consecutive days to become fully acclimatized.

Noticeable loss of acclimatization can occur in as little as four (4) days without working in the hot environment. Acclimatization can be lost completely in three (3) to four (4) weeks. Employees returning from vacation or from shift rotations with more than four (4) days off, should be given the opportunity to again become acclimatized before returning to full work expectations in hot environments.

Example

In practice, the employee is followed throughout the day. The time spent in each location is recorded along with the WBGT in that location. The WBGT is then averaged for the hottest **continuous** 60 minute period. Suppose the following were observed,

Location	Time (min)	WBGT	
		^{O}C	^{O}F
1. Bench Grinder	20	29.4	84.9
2. Office	15	27.7	81.9
3. Heat Treat	20	32.2	90.0
4. Bench Grinder	30	28.9	84.0
5. Heat Treat	20	33.3	91.9
6. Bench Grinder	20	30.6	87.1

On inspection, it is seen that the hottest continuous 60 minutes were spent in locations 3, 4, and 5. Locations 3, 5, and 6 were the hottest observed, however, exposure at these temperatures was not continuous. The time spent at 84 ^{O}F can not simply be ignored. The total time spent in locations 3, 4, and 5 was 70 minutes. A 60-minute average is required. Therefore ten minutes of this total time must be excluded from the calculation. Since the period averaged must be continuous, the ten minutes must be "shaved off" either the beginning or the end of the time period, not from the middle. Since location 3 is observed to be cooler than location 5, the time excluded from the average must be the first ten minutes spent in period 3. Suppose the employee entered location 1 at 10:20 am. The hottest one-hour period of the day was 11:05 am to 12:05 pm. The time-weighted average Wet Bulb Globe Temperature, $WBGT_{TWA}$, is therefore,

$$WBGT_{TWA} = \frac{WBGT_3\ (t_3) + WBGT_4\ (t_4) + WBGT_5\ (t_5)}{t_3 + t_4 + t_5}$$

$$= \frac{32.2\ ^{O}C\ (10\ min) + 28.9\ ^{O}F\ (30\ min) + 33.3\ ^{O}F\ (20\ min)}{10\ min + 30\ min + 20\ min}$$

$$= 30.9\ ^{O}C\ .$$

Notice the denominator in the above expression adds to 60 minutes. This must always be the case when using the WBGT method of heat stress assessment.

Our employee moved between the grinding bench and heat treat. After observing the work done in these areas, we characterize the work as moderate, 300 W. If our employee weighs approximately 180 lb, the corrected metabolic rate is given by

$$M_{COR} = M \ \frac{weight}{154\ lb} = 300\ W\ \frac{180\ lb}{154\ lb} = 351\ W \quad .$$

The data for our example (WBGT = 30.9 ^{O}C and M = 351 W) are plotted on Figure 1 above. The point for our example is well above the TLV, engineering controls and program implementation are recommended.

Heat Stress Management Programs

Unfortunately, there are no standards detailing the elements of an effective heat stress program. OSHA has however, prepared a Safety and Health Guide for Heat Stress. It can be found at http://www.osha.gov/SLTC/emergencypreparedness/guides/heat.html.

A program should include, at a minimum, employee training on heat stress and its effect on the body, a buddy system, a mandatory rehydration schedule, and regular monitoring of the WBGT. Emergency responses for employees suffering heat stress should be included in the employer's Emergency Response Program.

The importance of the buddy system and a rehydration schedule cannot be over stressed. The buddy system means that someone trained in the effects of heat stress is watching every employee for signs of heat strain. This can be pairing of employees to watch each other, or assignment of one individual to watch over a number of employees. Remember, however, the watchers also need watching. Loss of mental faculty is among the earliest symptoms of heat stress. Employees suffering even severe heat strain are likely not to be aware of their condition. A rehydration schedule usually includes a requirement to drink at least one cup of water ever 20 minutes. Thirst is **not** a good indicator of dehydration. Adherence to the mandatory rehydration schedule should be confirmed by the buddy.