Practical evaluation of hot working areas

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Practical evaluation of hot working areas

Hot working environments must be evaluated in a valid but practical manner. This paper provides practical guidance concerning the variability to be expected in the measurement and the interpretation of heat stress "rules," as well as methods for the design of jobs to permit continued operations in hot work environments.

by Jerry D. Ramsey

Many workplaces throughout the nation have occupational heat as a regular and constant concern, and many others have it as an occasional problem. Heat is found not only at the outside work site or the location where natural ventilation is the major cooling source, but also at many heat-producing workplaces. Even air-conditioned work areas are surrounded by areas which are not air-conditioned, and there is always the opportunity for mechanical failure of such cooling systems. Thus, being knowledgeable about the evaluation and control of hot working areas is a realistic and common concern.

The need for evaluation is primarily prompted by the need for making decisions related to worker protection and to productivity. It is only indirectly driven by laws and regulations, since no heat stress standards (only the General Duty regulations of OSHA) currently exist at the federal or state level.

There have been proposed recommendations: by ACGIH for threshold limit values; by the ISO for international standards on heat stress; by NIOSH which is currently preparing a revised criteria document on heat stress; and by others.[1,2,3] These recommendations do not have the effect of law, but the problems of heat stress do support the use of evaluation procedures for making good functional decisions, as opposed to being driven by specific regulatory numbers.

The evaluation of heat stress is an imprecise activity. This paper discusses the characteristics of this variability, not for the purpose of demonstrating that such an evaluation is fruitless, but rather to develop a better understanding of what the numbers in such an evaluation actually mean.

Variability in environmental measurement

There are four basic components necessary to provide a complete definition of the thermal environment. The first is air temperature, or dry bulb temperature (Ta). The relative humidity of the air is the second important variable, since it relates to human comfort and the ability of the human body to lose heat to its environment. It is determined by means of a psychrometric chart and a measurement of wet bulb or dew point temperature.

Wet bulb temperature (Twb) is obtained by exposing a thermometer, which has a wet wick over the sensing element, to a forced convective air flow (e.g., use of a sling psychrometer). The natural wet bulb temperature (Tnwb) can use the same instruments, but depends on the convective flow of the existing environmental air over a wet wick to determine its value.

The third component, mean radiant temperature, is transferred as electromagnetic energy between a hot (radiating) body and an object. In the occupational environment this is commonly obtained as a globe temperature (Tg), which is measured using a thermometer placed in the center of a black, copper sphere. The fourth component of importance is the air velocity (V) or wind speed; this is normally measured using an anemometer of a vane or hot wire type.

In obtaining a thermal measurement it must first be recognized that there is some natural variability in the measuring process. This variability is a function of many things including the instrument itself, the parallax or other visual and placement differences, the individual differences in perception and interpretation between and within an individual observer, the fluctuations of the environment due to changes in air movement, cloud cover, and thermostat changes in the heating/cooling cycles.

A group of observers, when asked to independently read a temperature and record it from the same instrument, will typically produce a distribution of temperature values, not a single value. So, the estimates of temperature are typically represented by a population of values with some central tendency and some dispersion, or variance, as shown in Figure 1.

The Ta on this figure displays a distribution of measurements taken using a sling psychrometer compared with those obtained with an electronic instrument in the same area. One would expect the same central tendency for both instruments, unless there is calibration error, which would be represented by the distribution shown in dotted lines of Figure 1. The electronic instrument, however, would likely generate a distribution with a smaller variance since decimal numbers are directly available without the human round-off that occurs in reading most thermometers.

The measurement of Twb using a sling psychrometer, if compared to that obtained from the electronic instrument, would typically have more variance and a higher mean. The mean difference observed, however, repre-

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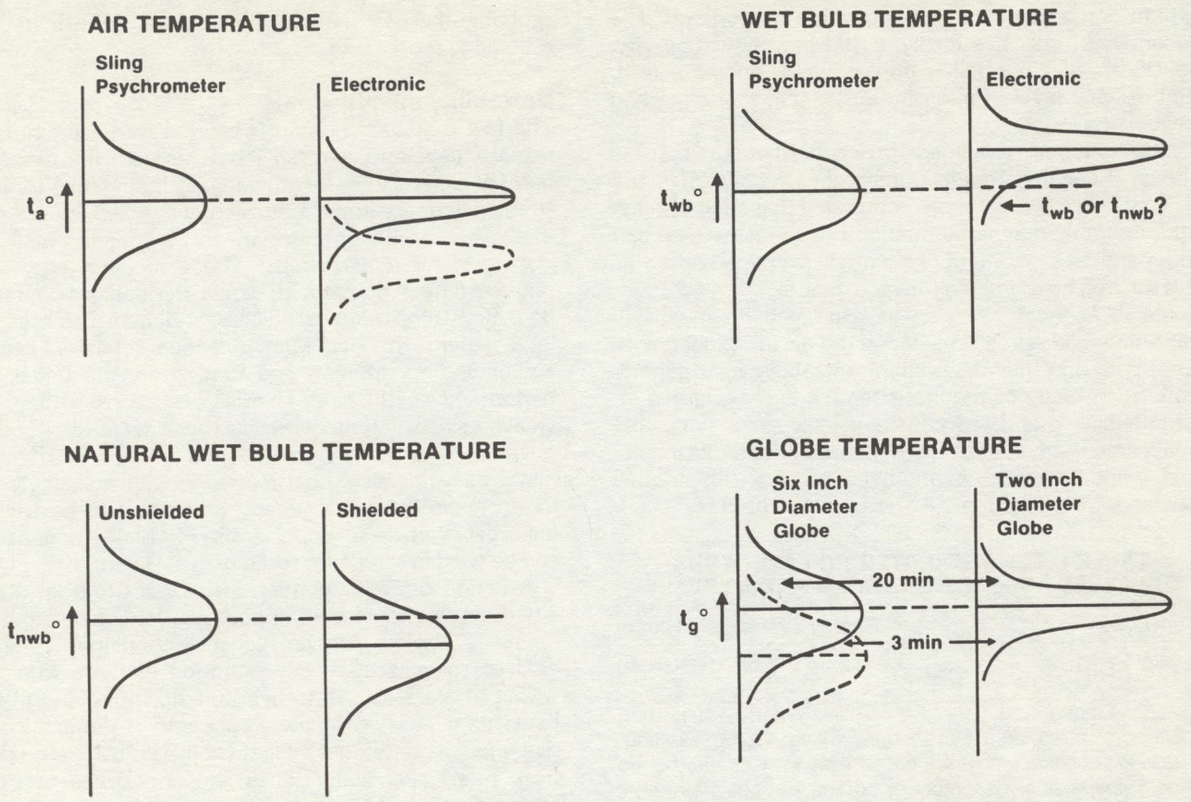

Figure 1: Typical Distribution of Thermal Measurements. (i.e. Differences in Central Tendency and Dispersion)

sents a difference between Twb and Tnwb even though the electronic instrument is probably labeled as a Twb value.

In comparing Tnwb which is shielded or unshielded, it is possible to see the differences noted in Figure 1. A substantially higher value can result where an instrument is unshielded for long periods of time in a radiant field. However, it is important when shielding the Tnwb from a radiant source that the flow of air not be blocked.

Also on Figure 1 is a look at Tg variability. The standard six-inch diameter globe has a stabilization time of 15-20 minutes. If readings are obtained after a brief period, say three minutes, errors are possible since the estimate of radiant heat will be made prior to equalization of the thermal system. The smaller diameter globe, which is found on most electronic instruments, stabilizes much more quickly to the environmental conditions.

Variability in estimating metabolic heat

Work in the heat will tend to elevate several physiological responses. The deep body temperature, which is the integrated result of all heat gain and heat loss into the human body, remains the parameter most useful in determining the risk that an individual assumes in the heat. The storage of heat in the body, as indicated by the deep body temperature, is a function of the summation of metabolic gains, evaporation losses, and the radiation and convection gains or losses.

The ability to estimate metabolic heat is at least of equal importance with measurement of the other environmental components. Numerous lists and tables are available as an aid in this particular endeavor. For example, the list in Table 1 shows the workload level ranging between resting and very heavy, and identifies an array of typical work tasks (including manual materials handling) and a range of energy expenditure for these tasks.[4] Such tables are useful, but are certainly not precise.

Based on available metabolic workload information (i.e., an analysis of tables, charts and methods from the literature) a coding method called Systematic Workload Estimation (SWE) has recently been developed.[5] The SWE provides a more specific basis for training an individual in workload estimation, and for conducting the estimation itself. This code as shown in Figure 2 is divided into two parts.

The first part indicates the body position or movement with "S" for stationary (sitting, standing or stooping); "W" for walking; and "E" for extra effort (walking on soft

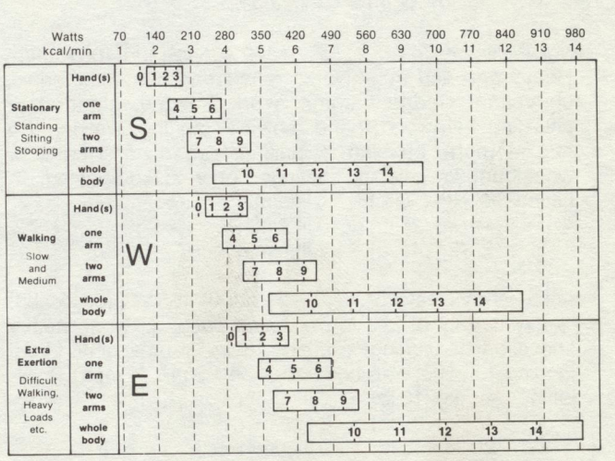

Figure 2. Systematic Workload Estimation (SWE) Schema

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ground, on a grade, or working with a heavy load). The second part indicates the type and intensity of activity; specifically whether hands, arms or whole body are used, and at what level of intensity (e.g., light, moderate and heavy).

The metabolic workload in Kcal/h (standard man) is shown above the numeric portion of each code on Figure 2. To use this figure it is recommended that a log of activity (preferably minute by minute) be maintained, and an independent assessment of metabolic workload based on this schema be estimated for each minute.

Metabolic heat can also be estimated by means of capturing expired air, evaluating the air for oxygen consumption, and thus determining metabolic heat generation. Such methods require extensive and expensive instrumentations and procedures, yet still suffer somewhat in accuracy with their ability to extrapolate results to general work behavior on another day and with another similar set of conditions. An error range of ±10-20% is probably the best that can be expected from metabolic estimating procedures.

TABLE 1: SOME SELECTED TYPES OF WORK CLASSED ACCORDING TO WORK-LOAD LEVEL

Work Load	Energy Expenditure Range
Level 1—Resting	Less than 117 W (100 Kcal/h)
Level 2—Light	117-232 W (100-199 Kcal/h)

Sitting at ease: light hand work (writing, typing, drafting, sewing, bookkeeping); hand and arm work (small bench tools, inspecting, assembly or sorting of light materials); arm and leg work (driving car under average conditions, operating foot switch or pedal).
Standing: drill press (small parts); milling machine (small parts); coil taping; small armature winding; machining with light power tools; casual walking (up to 0.9 m/s, i.e., 2 mph).
Lifting—4.5 kg (10 lb) < 8 lifts/min.;
11 kg (25 lb) < 4 lifts/min.;
20 kg (45 lb) < 2 lifts/min.

Level 3—Moderate	233-348 W (200-299 Kcal/h)

Hand and arm work (nailing, filing); arm and leg work (off road operation of trucks, tractors or construction equipment); arm and trunk work (air hammer operation, tractor assembly, plastering, intermittent handling of moderately heavy materials, weeding, hoeing, picking fruits or vegetables); pushing or pulling lightweight carts or wheelbarrows; walking 0.9-1.3 m/s (2-3 mph).
Lifting—4.5 kg (10 lb) – 10 lifts/min.;
11 kg (25 lb) – 6 lifts/min.;
20 kg (45 lb) – 4 lifts/min.

Level 4—Heavy	349-465 W (300-400 Kcal/h)

Heavy arm and trunk work; transferring heavy materials, shoveling; sledge hammer work; sawing, planting or chiseling hardwood; hand mowing, digging, walking 1.8 m/s (4 mph), pushing or pulling loaded hand carts or wheelbarrows; chipping castings; concrete block laying.
Lifting—4.5 kg (10 lb) – 14 lifts/min.;
11 kg (25 lb) – 10 lifts/min.;
20 kg (45 lb) – 7 lifts/min.

Level 5—Very Heavy	above 465 W (400 Kcal/h)

Heavy activity at fast to maximum pace; ax work; heavy shoveling or digging; climbing stairs, ramps or ladders; jogging, running, walking faster than 1.8 m/s (4 mph).
Lifting—4.5 kg (10 lb) > 18 lifts/min.;
11 kg (25 lb) > 13 lifts/min.;
20 kg (45 lb) > 9 lifts/min.

Smith and Ramsey[4]

Variability in individuals

The fact that each human is blessed with a set of individual characteristics often interferes with the development of general rules for anything, including rules for heat stress. There are some factors, however, which are well established as being important in determining heat exposure-effect relationships. These include: age, sex, physical fitness, body build, health, acclimatization, nutrition, motivation, physical abilities, and mental abilities.

In general the better an individual's fitness, health, acclimatization, training and motivation, the better the performance in the heat. There is, however, a general decrease in heat tolerance abilities with increasing age or obesity. Although the trained and acclimatized female might have identical heat tolerance with a similarly selected male, there are general differences in heat tolerance between these populations. Medical examinations can be used to screen for some of these factors.

A period of acclimatization for workers to a task-heat environment provides an opportunity for evaluating heat tolerance abilities prior to high risk conditions. A great deal of self-selection occurs among workers who are willing to work in a hot environment. In looking at the heat stroke fatality data, there appear to be dominant corollary factors to the heat. Heat fatalities most often occur from heat, plus either illness, alcohol/drugs or poor acclimatization. Poor acclimatization can occur after return from vacation, at the initial heat wave of the season, or at the beginning of a new hot job.

Variability in limits and indices

The Wet Bulb Globe Temperature (WBGT) is the most widely used and understood of the heat stress indices. The Threshold Limit Values (TLV) as published by the ACGIH depict time-weighted-average WBGT which are not to be exceeded for a given level of metabolic workload.[1] When the curves are transferred into a table, two constraints are encountered. First, the most conservative point on the curve is identified for each of the workload levels, and second, work rest schedules showing reduced work time imply that the rest must occur in the same temperature.

This basic relationship between metabolic cost and continuous exposure in a time-weighted WBGT is repeated in most of the recommendations concerning heat exposure. The Occupational Safety and Health Administration Standards Advisory Committee felt that the TLV values were too low in that they inadequately compensated for high levels of velocity.[6] Thus their recommendations supported the TLV numbers at low velocity, but allowed 2°C higher numbers where air movements greater than 300 fpm were available.

The ISO has similarly supported the fact that WBGT does not adequately compensate for velocity.[2] They chose, however, to specify lower temperature limits in those cases where low velocity was found.

These and other published recommendations are slightly different from one another, and in total present a confusing and sometimes conflicting set of information. The underlying similarity, though, is readily demonstrated if one looks at the summary information in Table 2.

This table shows different recommendations according to ranges of metabolic cost, rather than according to a

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TABLE 2: A COMPARISON OF PROPOSED WBGT THRESHOLD VALUES

SOURCE:	ACGIH[1]	AIHA[7]	OSHA[6]	ISO[2]	ABBREVIATED GUIDELINES[8]
WORKLOAD:					
Resting		32.2°C* 100 Kcal/h (117 W)		33°C ≤ 100 Kcal/h (117 W)	
			Low Velocity / High Velocity		
Light	30°C 100-200 Kcal/h (117-233 W)	30°C** 200 Kcal/h (233 W)	30.0°C 32.2°C < 200 Kcal/h (233 W)	30°C 100-201 Kcal/h (117-234 W)	30°C# < 200 Kcal/h (233 W)
Moderate	26.7°C 201-350 Kcal/h (234-407 W)	26.7°C*** 300 Kcal/h (349 W)	27.8°C 30.6°C 201-300 Kcal/h (234-349 W)	28°C 201-310 Kcal/h (234-360 W)	28°C# 201-300 Kcal/h (234-349 W)
				Low Velocity / High Velocity	
Heavy			26.1°C 28.9°C > 301 Kcal/h (350 W)	25°C 26°C 310-403 Kcal/h (360-468 W)	26°C# 301-400 Kcal/h (350-465 W)
Very Heavy	25°C*** 350-500 Kcal/h (407-581 W)			23°C 25°C > 403 Kcal/h (468 W)	25°C# > 401 Kcal/h (466 W)

LEGEND:
RESPECTIVE SOURCE: *LIGHT, **MODERATE, ***HEAVY
#MODIFY FOR: AIR VELOCITY > 1.67 m/s and Ta < 35°C by (+2°C);
STANDARD CLOTHING PLUS JACKET by (−2°C);
SEMI-NUDE OR SHORTS by (+2°C).

Ramsey and Chai[9]

word description of light, moderate, heavy, etc. In this format the similarities, differences and velocity recommendations become more apparent; especially the definitions of work level which are named differently by a respective source and thus have generated much of the underlying confusion.

Although WBGT is the most widely used index it is also important to recognize that it has some basic deficiencies. Several studies have shown the differences in physiological response obtained at "equal" WBGT levels that consist of different combinations of radiant heat, humidity and velocity. The main combinations for which WBGT provide the poorest indicator are those where relative humidity is high and air velocity is low. This particular combination in an environment is much more stressful to the human than is indicated by the WBGT index.

The Wet Globe Temperature (WGT) index as measured by the Botsball, has a very high correlation with the WBGT index. The Botsball instrument has some major advantages in ruggedness and simplicity, and has increasingly been validated in the field as a high correlate with WBGT. Figure 3 summarizes several individual studies where these two variables were correlated. Any of these equations are basically equivalent, but the last two (WBGT=WGT+3.0°C or WBGT=1.1 WGT °C) are much simpler to remember and use, and could be argued to be as valid as any of the individual studies.

A word of caution is in order, however, since this correlation implies a moderate level of both humidity and radiant temperature; at both high and low levels for either of these two variables the well behaved relationship shown in Figure 3 may not be valid. For example, environments with moderate heat, high humidity and no

Study No.	No. of Obs.	Regression Equation °C	WBGT Range (°C)	r
10 ○	13489	WBGT = 1.01 WGT + 2.60	0 - 37	0.956
11 □	210	WBGT = 1.07 WGT + 0.80	16 - 48	0.948
12 △	1023	WBGT = 1.05 WGT + 1.14	11 - 42	0.913
13 ◇	34	WGT = 0.958 WBGT - 2.52	21 - 41	0.967
14 ⬡	379	WBGT = 0.0212 (WGT)^2 + 0.192 (WGT) + 9.5	18 - 56	0.976
15 ——		WBGT = WGT + 3.00		
---		WBGT = 1.1 WGT		

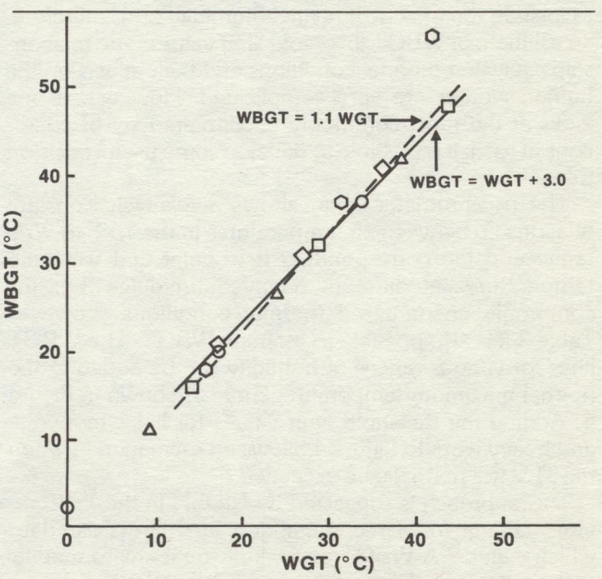

Figure 3. WBGT/WGT Correlations

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TABLE 3: ESTIMATING WBGT INDOORS

If, Air temperature warm - hot (Ta ≅ 75-95°F)
Natural ventilation with perceptible air flow (Twb ≅ Tnwb)
Minimal or no radiation (Tg ≅ Ta)

Then, at a given RH, Tnwb ≅ Ta - (Ta - Twb)

And, WBGT = 0.7 Tnwb + 0.3 Tg ≅ 0.7 [Ta-(Ta-Twb)] + 0.3 Ta

Or, WBGT ≅ Ta - 0.7 (Ta - Twb)

RH (%)	Ta (°F)	Twb (°F)	Ta-Twb (°F)	WBGT (approx. °F)
90%	75	73	2	Ta-1.5
	95	92.5	2.5	
70%	75	68.5	6.5	Ta-5
	95	87	8	
50%	75	63.5	11.5	Ta-9
	95	79	16	
30%	75	57	18	Ta-15
	95	71.5	23.5	

radiant heat have WBGT and WGT values which are almost equal.

Variability in climatic conditions

It is often useful for a plant or work site to establish its own thermal profile as an aid in knowing when more detailed measurements should be made, or when job/work practices should be initiated.

Data available from the nearest National Weather Service, plus measures at typical work areas can be used for such a purpose. The normal maximum air temperature is perhaps the most valid and available measure for use in predicting plant temperatures. Figure 4 shows, for example, the Lubbock, Texas normal maximum temperatures (30-year average) plotted against a calendar scale. This is a very stable temperature number, since it represents the average high Ta for a given day and locale, and it refers to the afternoon period of the day where the climatic heat is at its peak.

It is also possible to carry this estimate one step further to include the effects of relative humidity and, therefore, an estimate of WBGT threshold limit values. The relationships between thermal conditions and their effects on the human worker are very complicated. However, if one looks at the most commonly encountered set of conditions at work it is possible to develop some useful decision rules.

The psychrometric chart shows a relatively constant relationship between air temperatures in the 75°F to 95°F range and the corresponding dew point and wet bulb temperatures at different relative humidities. For the commonly encountered thermal conditions shown in Table 3 it is also possible to estimate WBGT. The WBGT lines for various ranges of humidity can be added to the normal maximum temperature curve as shown in Figure 4. Adding the threshold limit values for light, moderate and heavy work to Figure 4 allows an estimation of when the TLV will normally be exceeded.

This approach is suggested by NIOSH in the 1986 revised criteria for a recommended heat stress standard which states: "A WBGT or an individual environmental factors profile shall be established for each hot work area for both winter and summer seasons . . ."[16] A climatic profile does not replace the use of specific measurements in the working environment, but it does provide some general guides for initiating work practices or other controls, and for determining when individual measurements may be warranted.

Guidelines for evaluation

Since there are so many factors contributing to the variability in measuring or otherwise determining the criticality of a hot working area, does this imply that meaningful evaluation is impossible? The answer most certainly is that work areas should and can be evaluated to provide protection to the worker's health and protection from poor productivity.

The variability of the process suggests that there is a limit to the value of precision in any measurement; a fact that will adversely affect rigid standard compliance, but one that will not affect the ability to make useful decisions. An understanding of the factors contributing to variability should help in the evaluation and decision making process.

One approach to the synthesis of these numerous considerations and factors is to use a set of abbreviated guidelines.[8] This set of rules suggests that a threshold value WBGT be determined based on the estimate of the metabolic workload. This threshold number then would be modified based on several variables which are specific to the work in question.

For example, the unacclimatized and/or not physically conditioned worker would subtract 2°C (4°F) from these threshold values to acknowledge the higher heat storage and physiological cost associated with these conditions.

Conversely, if the work is being conducted in an area where natural wind movement or fans increase the air velocity to a strongly perceptible level (i.e., above 1.5 mps [300 fpm]), then 2°C (4°F) could be added to the threshold value. This adjustment is in response to the observation that WBGT index is not as responsive to the cooling power of increased air flow as is the human body.

Adjustments can also be made to the threshold numbers based on the level of clothing, since these numbers assume normal factory type clothing of shoes, trousers and shirt. The worker who is in shorts or semi-nude could add 2°C (4°F) to these limits; whereas, for impermeable clothing which interferes with evaporation these adjustments should be made:

a. Body armor, impermeable jacket—subtract 2°C (4°F)
b. Rain coat, fireman coat, full-length coat—subtract 4°C (7°F)
c. Completely enclosed suit—subtract 5°C (9°F)

The rules for impermeable clothing are those with the largest margin for error. The individual required to work in these types of clothing must be fully aware of heat illness symptoms, and should be allowed to control the heat exposure as appropriate.

Another modification to the threshold values would be as it relates to the obese or elderly, where 1 or 2°C (2-4°F) would be subtracted to acknowledge the basic interference with the cardiovascular and pulmonary function, and thus the higher risk associated with these populations of workers.

Additionally, an adjustment subtracting 1°C if the worker is female may be justified if the female has had minimal experience with work in the heat. Sex differences in heat tolerance have appeared frequently in laboratory

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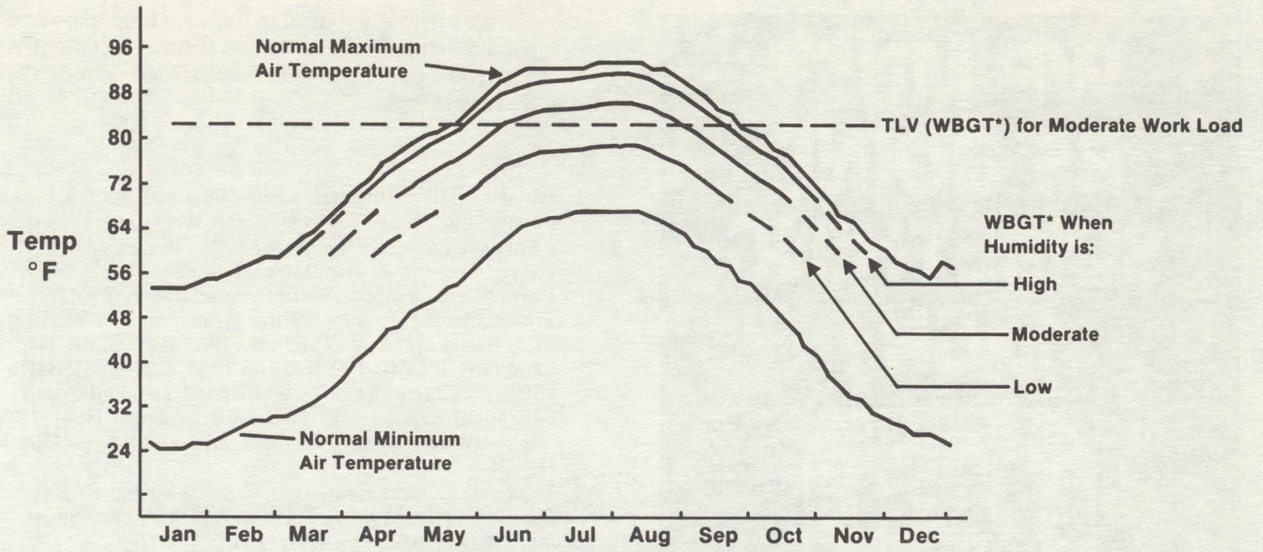

Figure 4: Use of Climate Profile to Estimate Workplace WBGT*. (Lubbock, TX, 1950-1980)

*Assumes: Indoors, Perceptible Air Movement and No Radiant Heat

and other data, but where populations of males/females are matched as to size, fitness and acclimatization, these differences tend to disappear.

Table 2 summarizes these suggested modifications of threshold WBGT. The multiplications for increased air velocity are not appropriate where the air temperature is above that of skin temperature (35°C/95°F), or where impermeable clothing is used.

Job design factors for work in hot areas

After an area has been evaluated and it is determined that the combination of work and heat exceeds the limits prescribed by either WBGT or WGT indices, the implication is that some action must be taken. It should be remembered that the limits currently recommended and summarized above all refer to the threshold or entry level of heat exposure, above which the risk for heat illness will dramatically increase. These limits do not represent upper tolerance limits where work must be curtailed. Maximum exposure limits have been suggested as an important and missing component in the definition of working environments.

The actions available for protecting the heat-exposed workers consist of an array of activities relating to the design of the job, the work and the environment. Some of the more important actions are summarized below.[8]

1. Potable water: An adequate supply should be available near the work site and workers informed of the necessity for frequent water intake.
2. Acclimatization: Newly assigned employees and those recently returning from serious illness or long vacations, and who are normally assigned to other than light work load tasks, should not be required to perform at full-normal pace until they have an opportunity to become acclimatized.
3. First aid training: Each workplace where heat stress may occur should have persons trained in the recognition and first-aid treatment of heat-related disorders.
4. General ventilation: Increased general ventilation or spot cooling can be used to reduce temperature at the workplace.
5. Exhaust ventilation: Local exhaust ventilation at points of high heat production will help remove latent heat from the work area.
6. Local cooling: Local or spot cooling of the worker may be an effective and energy efficient means of providing relief from heat exposure.
7. General cooling or refrigeration: Evaporative cooling or mechanical refrigeration can be used to reduce the temperature of supply air and general work site temperatures.
8. Fans: Personal cooling fans increase air velocity and evaporative heat loss as long as air temperatures are below 35°C (95°F).
9. Radiant shielding: Shielding by means of reflective screens, barriers, aprons or clothing will interrupt line-of-sight radiant thermal exchange.
10. Isolation or change: Isolation, relocation, redesign or substitution of equipment and/or processes can be used to reduce the thermal stress at the work site.
11. Metabolic heat: Internally generated heat can be reduced by adjustments in the duration of the work period, the frequency and length of rest pauses, the pace and tempo of work, and the increased use of work-saving devices or mechanization.
12. Personal clothing and cooling devices: Personal cooling devices and/or protective clothing may help reduce heat stress in applications where other controls are limited.
13. Climate peaks: When feasible, heavy work should be scheduled during the cooler parts of the work shift or on cooler days.
14. Rest areas: The use of air conditioned or cooler areas for rest and recovery will reduce heat storage in the worker.
15. Self-limited exposure: Based on signs and symptoms of heat strain, the worker can be allowed to limit his exposure and interrupt work if necessary.
16. Buddy rule: The risk of excessive heat exposure will be reduced if the worker is under observation by a trained supervisor or fellow worker who can detect early signs of heat strain.

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17. Medical: Those exposed to extreme heat exposure should be medically evaluated before placement in this type work and medically examined periodically thereafter.

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