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ABBREVIATED GUIDELINES FOR HEAT STRESS EXPOSURE

(NADC PROGRAM ELEMENT 62757N/F55-525/
WF55-525-000/ZH302)

By
J. D. RAMSEY, Ph.D.
Texas Tech University

(Contract N61756-76-M-5962)

May 1978

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A wide array of recommendations, rules, and research results were aggregated into a simplified set of decision criteria for estimating threshold levels of heat stress for people working in hot environments. The wet bulb globe temperature (WBGT) was used as a basis, with appropriate modification for metabolic heat generated during work, velocity of air movement, state of acclimatization, amount of clothing (e.g., shorts, jackets, coats, enclosed suits), age, obesity, and sex. When WBGT levels for the person-task-environment combination are exceeded, initiation of appropriate engineering and work practices is indicated.

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The WBGT levels and modification factors presented in this report can serve as very useful criteria for determining when heat stress reduction methods and practices are indicated.

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PACIFIC MISSILE TEST CENTER
Point Mugu, California 93042

ABBREVIATED GUIDELINES FOR HEAT STRESS EXPOSURE

(Contract N61756-76-M-5962)

By

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SUMMARY

A wide array of recommendations, rules, and research results were aggregated into a simplified set of decision criteria for estimating threshold levels of heat stress for people working in hot environments. The wet bulb globe temperature (WBGT) was used as a basis, with appropriate modification for metabolic heat generated during work, velocity of air movement, state of acclimatization, amount of clothing (e.g., shorts, jackets, coats, enclosed suits), age, obesity, and sex. When WBGT levels for the person-task-environment combination are exceeded, initiation of appropriate engineering and work practices is indicated.

The WBGT levels and modification factors presented in this report can serve as very useful criteria for determining when heat stress reduction methods and practices are indicated.

The research for this work at Texas Tech University was performed under Naval Air Development Center Program Element 62757N/F55-525-000/ZH302.

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INTRODUCTION

Many persons are exposed at work to hot conditions either from the climate, from a work process, or from internally generated metabolic heat. A very complicated interrelationship exists between heat exposure limits and variables such as temperature, humidity and velocity of the air; radiant heat; metabolic heat; clothing; acclimatization; age, sex; general health, physical fitness, and state of nutrition.

Although general analytical models have been developed which incorporate many of these variables and allow assessment of an individual hot work situation, these tend to be complicated and require a large number of detailed environmental measurements (references 1 through 4). In addition to detailed analytical models, a multitude of guidelines and rules for specific situations can be found in the literature, as indicated by the following examples:

> "When the WBGT reaches 82°F (27.8°C), discretion should be used in planning heavy exercise for unseasoned personnel." (reference 5)
>
> "Generally the physical strain due to . . . . heat stress increases with age." (reference 6)
>
> "WBGT 88 to 90°F (31.1 to 32.2°C) strenuous exercise curtailed for all personnel with less than 12 weeks training in hot weather.' (reference 7)
>
> "The obese individual is at a disadvantage in the heat and is more likely to incur illness." (reference 1)

[1] American Industrial Hygiene Association. "Heating and Cooling for Man in Industry." *AIHA Journal,* Second Edition (1975).

[2] Belding, H.S. "The Search for a Universal Heat Stress Index," Chapter 13 in *Physiological and Behavioral Temperature Regulation,* Hardy, J.E., et al., (Eds.), Charles C. Thomas Publishing Co., p. 193 (1970).

[3] Dayal, D. and J.D. Ramsey. "A Heart Rate Index for Assessing Heat Stress," in *Proceedings, Sixth Congress International Ergonomics Association.* Maryland, p. 537, (July, 1976).

[4] Givoni, B. and R.F. Goldman.""Predicting Rectal Temperature Response to Work, Environment, and Clothing," in *Journal of Applied Physiology.* 32:812 (1972).

[5] Department of the Army, Navy, and Air Force. *The Etiology, Prevention, Diagnosis, and Treatment of Adverse Effects of Heat.* TB MED 175, NAVMED P-502-5, AFP 160-1 (1969).

[6] "Health Factors Involved in Working under Conditions of Heat Stress," in *World Health Organization Technical Report Series No. 412.* Geneva (1969).

[7] Department of the Navy. *Ventilation and Thermal Stress Ashore and Afloat.* Department of the Navy, Bureau of Medicine and Surgery, NAVMED P 5010-3 (1974).

Presented in this report is a composite set of guidelines that can be used as a general estimator of "threshold" to increasing risk of heat strain for an individual worker. Above these threshold values, there is an increasing probability of heat stroke and other effects of excessive heat exposure. These guidelines represent an aggregation of information and rules concerning work in the heat. The use of estimates for all major components rather than precise measurements for some factors in the work and environment can yield a useful set of decision criteria for determining the combination of conditions which indicate the use of engineering and work practices. These are not upper limit or tolerance levels, but rather are levels that indicate the need for instigation of work practices to reduce adverse thermal effects.

The Occupational Safety and Health Act (OSHA) Standard Advisory Committee on Heat Stress developed a set of recommendations as a basis for the projected "threshold wet bulb globe temperature levels" (WBGT) (table 1) (reference 8).

Table 1 incorporates the thermal conditions of the environment, as well as the level of metabolic costs associated with a particular work task. The energy expenditure of metabolic cost of a work task can be estimated by using summary data of the type shown in table 2 (reference 9).

Both the metabolic cost and WBGT values displayed in table 1 represent time-weighted averages over a 2-hour period. In cases where work load or temperature are not constant, both of these factors should be prorated over the peak 2-hour heat period. As a sample calculation, assume that during the hottest 2 hours (120 minutes of the day) a worker is performing light work (150 kilocalories per hour (kcal/hr)) in a 35°C temperature for 20 minutes; and performing heavy work (350 kcal/hr) in 26°C for 100 minutes. The time-weighted average (TWAvg) for the metabolic (m) heat would be:

$$\text{TWAvg (m)} = \frac{20(150\ \text{kcal/hr}) + 100\,(350\ \text{kcal/hr})}{120} = 317\ \text{kcal/hr}$$

Table 1. Threshold Wet Bulb Globe Temperature (WBGT) Levels*
(Two-Hour Time-Weighted Average Values)

Metabolic Costs	Threshold WBGT °C	Threshold WBGT °F
Light work (less than 200 kcal/hr)**	30	86
Moderate work (201 to 300 kcal/hr)	28	82
Heavy work (301 to 400 kcal/hr)	26	79
Very heavy work (over 401 kcal/hr)	25	77

*Assumption: Adult male, normally clothed, acclimatized, physically fit, and good health and nutrition.

***kilocalories per hour.*

[8] Ramsey, J.D. Heat Stress Standard. OSHA's Advisory Committee Recommendations. *National Safety News*, p. 89 (1975a).

[9] American Industrial Hygiene Association. "Ergonomic Guides," in *AIHA Journal, 32*, p. 560 (1971).

Similarly, the time-weighted average temperature would be:

$$\text{TWAvg (temperature)} = \frac{20\,(35^{o}C) + 100(26^{o}C)}{120} = 27.5^{o}C$$

A more detailed explanation of this time-weighted procedure is explained in the Heat Stress Standard of OSHA's Advisory Committee Recommendations (reference 8).

Table 2. Selected Types of Work Classed According to Workload Level*

Workload	Energy Expenditure Range
Level 1 - Resting	100 kcal/hr** or less
Level 2 - Light	101 to 200 kcal/hr
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); peeling potatoes.	
Standing: drill press (small parts); milling machine (small parts); coil taping; small armature winding; machining with light power tools; casual walking up to 3 kilometers per hour (kph) at 2 miles per hour (mi/h); assembling weapons.	
Level 3 - Moderate	201 to 300 kcal/hr
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 light-weight carts or wheelbarrows; walking (3 to 5 kph, 2 to 3 mi/h); vehicle repairs.	
Level 4 - Heavy	301 to 400 kcal/hr
Heavy arm and trunk work; transferring heavy materials; shoveling; sledge hammer work; sawing, planing or chiseling hardwood; hand mowing, digging, level walking (6 kph 4 mi/h), pushing or pulling loaded hand carts or wheelbarrows; chipping castings; concrete block laying; walking, 60 lb load (5 kph 3 mi/h); walking up slope; creeping, crawling.	
Level 5 - Very Heavy	Above 401 kcal/hr
Heavy activity at fast to maximum pace; ax work; heavy shoveling or digging; climbing, stairs, ramps or ladders; jogging, running, walking faster than (6 kph 4 mi/h), lifting more than 44 lbs at 10 lifts per minute; walking in snow; swimming; walking up a 36 percent grade with a 43-pound load.	

*For accurate determination of a worker's energy expenditure on the job by measuring oxygen uptake of *the man, refer to AIHA, 1971 (reference 9).*

**kilocalories per hour.

[8] Ramsy, J.D. Heat Stree Standard, OSHA's Advisory Committee Recommendations, *National Safety News*, p.89 (1975a).

[9] American Industrial Hygiene Association. "Ergonomic Guides, in *AIHA Journal*, 32, p. 560 (1971).

MODIFICATIONS OF THE THRESHOLD WET BULB GLOBE TEMPERATURE

The threshold WBGT levels of table 1 apply to the worker who is normally clothed, acclimatized to the heat, physically fit for the job, and in a good state of nutrition and health. In order to improve the validity and expand the applicability of the values in table 1, the effects of those factors listed in table 3 can be incorporated. Specifically, for decision rule purposes, the threshold WBGT values of table 1 can be modified by sequential adjustment of the following variables:

1. Unacclimatized and/or not physically conditioned
2. Increased air velocity
3. Clothing
4. Obese or elderly
5. Female

Unacclimatized and/or Not Physically Conditioned (Subtract 2°C (4°F) From the WBGT Threshold Limits

This is to acknowledge the higher heat storage and physiological costs associated with the unacclimatized state. (reference 10 and 11) Complete acclimatization can almost always be obtained over a period of 6 to 10 days with daily exposures of about 2 hours to the desired temperature and work conditions. Similarly, the person who is not physically conditioned to a physical work task requires a period of conditioning in order to minimize thermal stress effects (reference 12).

Increased Air Velocity (Add 2°C (4°F) to WBGT Threshold Limits)

Fans or natural wind movement which increase air velocity above 1.5 miles per second (mps) (300 feet per minute (fpm)) will raise the threshold limits. This compensates for the fact that the WBGT index is not as responsive to the cooling power of increased air flow as is the human body (reference 13). This is also consistent with the +2°C adjustment for low air velocity (<0.5 mps) recommended by the Swedish WBGT (reference 14). As the air temperature reaches the 32 to 35°C (90 to 95°F) level, this difference and thus the 2°C (4°F) adjustment disappears. Also, if a person is wearing impervious clothing (item 2 following) no adjustment for increased air velocity should be made.

Clothing

1. For shorts or seminude, add 2°C (4°F).

[10] Minard, D. "Physiology of Heat Stress," in *The Industrial Environment -- Its Evaluation and Control.* National Institute for Occupational Safety and Health, p. 399 (1973).

[11] Webb, P. (Ed.): *Bioastronautics Data Book.* National Aeronautics and Space Administration, NASA, SD-3006 (1964).

[12] Wyndham, C.H. "The Physiology of Exercise Under Heat Stress," in *Ann. Rev. Physiol.*, 35:193 (1973).

[13] Ramsey J.D. "Threshold Limits for Workers in Hot Environments," in *Proceedings, International Mine Ventilation Congress.* Johannesburg, South Africa (September, 1975b).

[14] Astrand, I., O. Axelson, U. Erkson, and Lars Olander: "Heat Stress in Occupational Work," *AMBIO,* 4:37 (1975).

Table 3. Modification of Threshold Wet Bulb Globe Temperature

Factors		Modification of Threshold	
		WBGT°C	WBGT°F
1	Unacclimatized, not physically fit	-2	-4
2	Air Velocity:		
	Velocity above 1.5 meters per second (300 feet per minute) and air temperature below 35°C (95°F)	+2	+4
3	Clothing:		
	Shorts, semi-nude	+2	+4
	Impermeable jacket or body armor*	-2	-4
	Raincoats, firemans' coat*	-4	-7
	Completely enclosed suits*	-5	-9
4	Obese, elderly	-1 to -2	-2 to -4
5	Female	-1	-2

*Modification for increased air velocity not appropriate *with impervious clothing.*

2. For impervious clothing which interferes with evaporation:

Body armor, impermeable jackets	- subtract 2°C (4°F)
Raincoats fireman coats, full-length coats	- subtract 4°C (7°F)
Completely enclosed suits	- subtract 5°C (9°F)

Any clothing covering the human skin interferes to some degree with individual evaporative capability (reference 1, 15, 16). Goldman, for example, reports "wearing current body armor can be roughly equated with a rise of 10° . . . (°F WBGT) (reference 15). Threshold WBGT limits for normal work clothing shown in table 1 should be modified to account for these effects, raising limits on an increasing scale when clothing becomes increasingly impermeable. If impervious clothing is worn, this precludes any adjustments or modification of the WBGT threshold limits due to increased air velocity (item 2).

Obese or Elderly (Subtract 1 to 2°C (2 to 4°F))

Lowering threshold limits will acknowledge the higher risk associated with these populations in general. The adverse effects of obesity to cardiovascular and pulmonary function and efficiency are well

[1] American Industrial Hygiene Association. "Heating and Cooling for Man in Industry," in *AIHA Journal,* Second Edition (1975).

[15] Goldman, R.F. "Physiological Costs of Body Armor," in *Military Medicine,* 134:812 (1972)

[16] Horvath, S.M. and C. Jensen, (Eds.). *Standards for Occupational Exposures to Hot Environments, Proceedings of a Symposium.* National Institute for Occupational Safety and Health, HEW Publication #(NIOSH) - 76 - 100, Pittsburgh (1976).

documented (reference 10). Similarly, the aging process which results in a general degradation of these same physiological systems places these populations at a slightly higher risk when exposed to hot working conditions (reference 17).

Female (Subtract 1°C (2°F))

This adjustment of the threshold limit is to recognize the generally lower sweat rates of females reported in literature. Differences in physiological response by males and females are well established, although it is sometimes unclear if these represent true sex differences or simply differences between prior heat experiences. In any event, however, some adjustment in the threshold WBGT limits is supportable. Dukes-Dobos suggested lowering these WBGT threshold limits in women by 0.5°C (1°F) to compensate for lower heat tolerance and 1°C (2°F) for lower aerobic capacity (reference 18).

By adjusting the WBGTs indicated in table 1 by those factors indicated in table 3, a new estimated threshold WBGT level can be obtained. This number represents the WBGT level for initiation of enginering and work practices, such as those listed below. If the resulting number is below the thermal comfort level (20°C to 70°F WBGT) then the stress is primarily a work stress from internally generated heat rather than an environmental heat stress. Corrective actions and work practices in this case should be directed toward reducing the work load or increasing the evaporative heat loss capacity of the worker.

ENGINEERING AND WORK PRACTICES

In any event, a WBGT threshold level is indicated which estimates and incorporates the characteristics of the particular person-task-environment for which protective work practices should be initiated. Table 4 lists some of the engineering and work practices which are useful in reducing or eliminating conditions of heat stress.

Although a detailed explanation of these practices can be found in the literature, a summary of these methods for controlling heat exposure follows (reference 1 and 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, or those recently returning from serious ilness 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 work place 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 work place.
5. Exhaust ventilation. Local exhaust ventilation at points of high heat production will help remove latent heat from the work area.

[1] American Industrial Hygiene Association. "Heating and Cooling for Man in Industry." *AIHA Journal*, Second Edition (1975).

[8] Ramsey, J.D. Heat Stress Standard: OSHA's Advisory Committee Recommendations, in *National Safety News*, p. 89 (1975a).

[10] Minard, D. "Physiology of Heat Stress," in *The Industrial Environment – Its Evaluation and Control*, National Institute for Occupational Safety and Health, p. 399 (1973).

[17] Henschel, A. "Effects of Age and Sex on Heat Tolerance," in *Standards for Occupational Exposure to Hot Environments.* HEW Publication #(NIOSH) - 76 - 100 (1976).

[18] Dukes-Dobos, F.N. Rationale and Provisions of the Work Practices Standard for Work in Hot Environments as Recommended by NIOSH. *Standards for Occupational Exposures to Hot Environments.* HEW Publication #(NIOSH) - 76 - 100 (1976).

Table 4. Engineering and Work Practices for Reducing Heat Stress

	Engineering and Work Practices
1	Provide potable water
2	Acclimatize
3	Train in first aid and recognition of heat strain symptoms
4	Provide general ventilation
5	Provide exhaust ventilation
6	Use local cooling
7	Provide evaporative cooling-refrigeration
8	Provide fans to move air
9	Use radiant shielding
10	Isolate, relocate, redesign, or substitute
11	Reduce metabolic heat through work reduction or increased rest periods
12	Use personal cooling devices and/or protective clothing
13	Schedule work to cooler period of the shift
14	Use air-conditioned rest areas
15	Allow self-limited exposure
16	Provide preplacement medical examinations
17	Use "buddy" rule

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. Cooling or refrigeration. Evaporative cooling or mechanical refrigeration can be used to reduce the temperature of air and work site.
8. Fans. Person-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, reflective 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, the increased use of work-saving devices, or mechanization.
12. Clothing and cooling devices. Personal cooling devices and/or protective clothing will help reduce heat stress in applications where engineering controls are limited.
13. Climate peaks. When feasible, heavy work should be scheduled during the cooler parts of the work shift.
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. Medical. Those exposed to extreme heat should be medically evaluated before placement in work of this type and medically examined periodically thereafter.

17. "Buddy" rule. Workers should be under the observation of a trained supervisor or fellow worker who can detect any early signs of heat strain.

CONCLUSIONS

The guidelines presented in this paper represent a set of simplified and approximate procedures for determining those person-task-environment combinations where protective work practices and engineering controls should be initiated. Effects of factors which tend to either raise or lower threshold levels can be jointly evaluated using this procedure. The fact that all heat stress components are estimated requires that the final WBGT level obtained be used as a general indicator of onset heat stress. This indicator, however, is just as useful and accurate as is the model, guideline, or rule which requires measurement of some factors very precisely, but then estimates or ignores the other factors.

Although considerable experience with the job and/or knowledge of heat stress problems will still be required to evaluate and implement appropriate engineering and work practices, the WBGT levels and modification factors presented in this report can serve as very useful criteria for determining when heat stress reduction methods and practices are indicated.

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