

HEAT STRESS AND HEAT STRAIN

The goal of this TLV® is to maintain body core temperature within $+ 1^{\circ}\text{C}$ of normal (37°C). This core body temperature range can be exceeded under certain circumstances with selected populations, environmental and physiologic monitoring, and other controls.

More than any other physical agent, the potential health hazards from work in hot environments depends strongly on physiological factors that lead to a range of susceptibilities depending on the level of acclimatization. Therefore, professional judgment is of particular importance in assessing the level of heat stress and physiological heat strain to adequately provide guidance for protecting nearly all healthy workers with due consideration of individual factors and the type of work. Assessment of both heat stress and heat strain can be used for evaluating the risk to worker safety and health. A decision making process is suggested in Figure 1. The exposure guidance provided in Figures 1 and 2 and in the associated *Documentation* of the TLV® represents conditions under which it is believed that nearly all heat acclimatized, adequately hydrated, unmedicated, healthy workers may be repeatedly exposed without adverse health effects. The Action Limit (AL) is similarly protective of unacclimatized workers and represents conditions for which a heat stress management program should be considered. While not part of the TLV®, elements of a heat stress management program are offered. The exposure guidance is not a fine line between safe and dangerous levels.

Heat Stress is the net heat load to which a worker may be exposed from the combined contributions of metabolic heat, environmental factors, (i.e., air temperature, humidity, air movement, and radiant heat), and clothing requirements. A mild or moderate heat stress may cause discomfort and may adversely affect performance and safety, but it is not harmful to health. As the heat stress approaches human tolerance limits, the risk of heat-related disorders increases.

Heat Strain is the overall physiological response resulting from heat stress. The physiological responses are dedicated to dissipating excess heat from the body.

Acclimatization is a gradual physiological adaptation that improves an individual's ability to tolerate heat stress. Acclimatization requires physical activity under heat-stress conditions similar to those anticipated for the work. With a recent history of heat-stress exposures of at least two continuous hours (e.g., 5 of the last 7 days to 10 of 14 days), a worker can be considered acclimatized for the purposes of the TLV®. Its loss begins when the activity under those heat stress conditions is discontinued, and a noticeable loss occurs after four days and may be completely lost in three to four weeks. Because acclimatization is to the level of the heat stress exposure, a person will not be fully acclimatized to a sudden higher level; such as during a heat wave.

The decision process illustrated in Figure 1, should be started if (1) a qualitative exposure assessment indicates the possibility of heat stress, (2) there are reports of discomfort due to heat stress, or (3) professional judgment indicates heat stress conditions.

Section 1: Clothing. Ideally, free movement of cool, dry air over the skin's surface maximizes heat removal by both evaporation and convection.

TLV®-PA

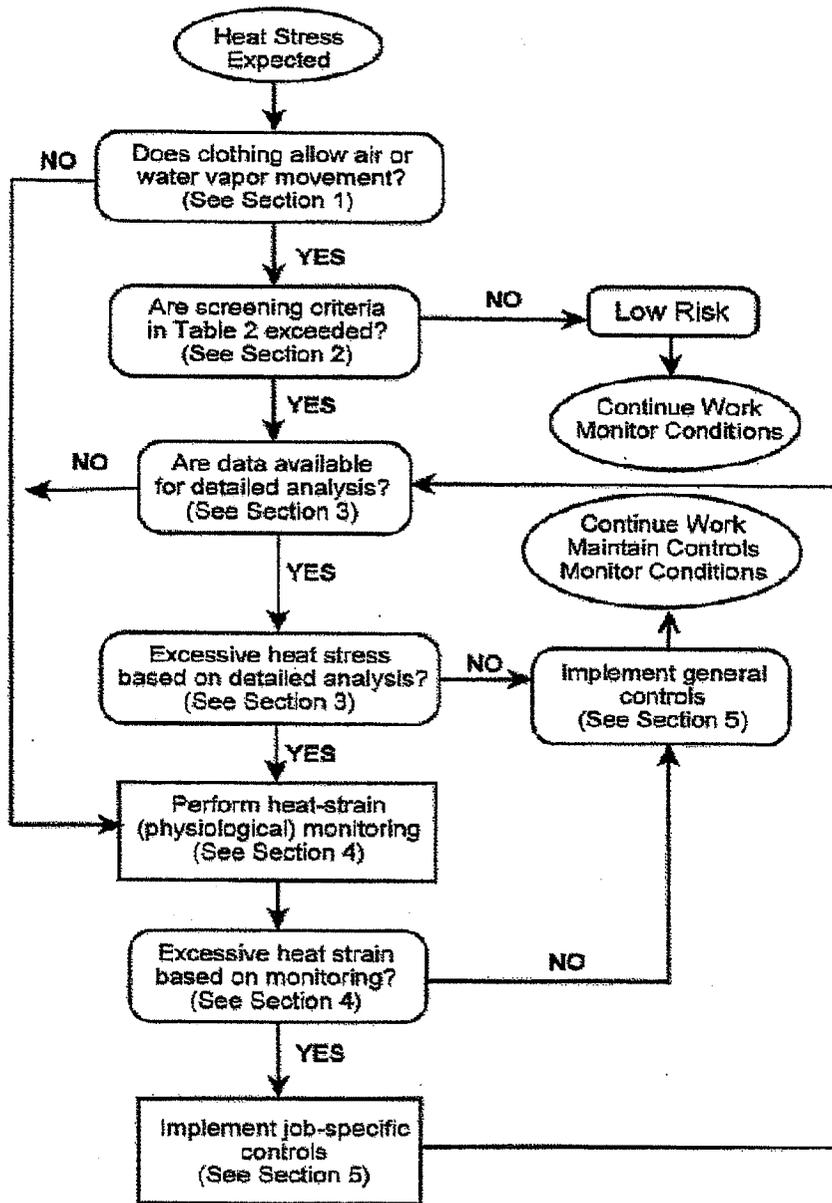


FIGURE 1. Evaluating heat stress and strain.

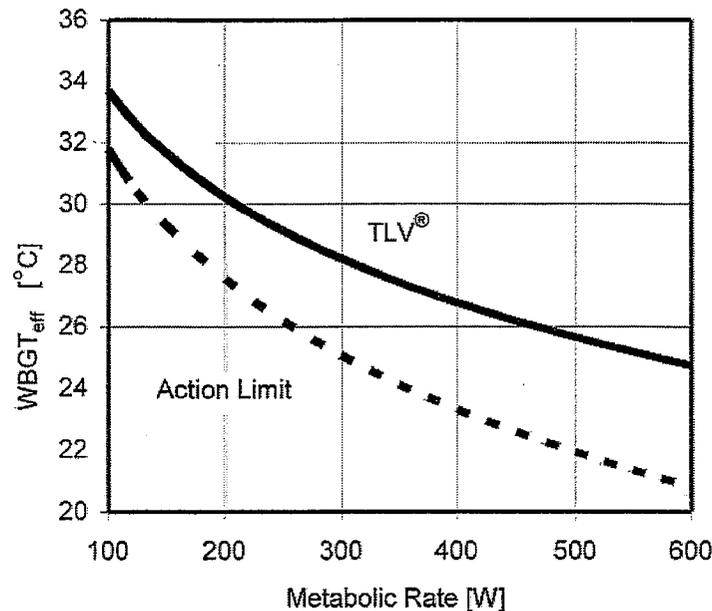


FIGURE 2. TLV® (solid line) and Action Limit (broken line) for heat stress. $WBGT_{eff}$ is the measured WBGT plus the Clothing-Adjustment Factor.

Evaporation of sweat from the skin is the predominant heat removal mechanism. Water-vapor-impermeable, air-impermeable, and thermally insulating clothing, as well as encapsulating suits and multiple layers of clothing, severely restrict heat removal. With heat removal hampered by clothing, metabolic heat may produce excessive heat strain even when ambient conditions are considered cool.

Figure 1 requires a decision about clothing and how it might affect heat loss. The WBGT-based heat exposure assessment was developed for a traditional work uniform of a long-sleeve shirt and pants. If the required clothing is adequately described by one of the ensembles in Table 1 or by other available data, then the "YES" branch is selected.

If workers are required to wear clothing not represented by an ensemble in Table 1, then the "NO" branch should be taken. This decision is especially applicable for clothing ensembles that are 1) totally encapsulating suits or 2) multiple layers where no data are available for adjustments. For these kinds of ensembles, Table 2 is not a useful screening method to determine a threshold for heat-stress management actions and some risk must be assumed. Unless a detailed analysis method appropriate to the clothing requirements is available, physiological and signs/symptoms monitoring described in Section 4 and Table 4 should be followed to assess the exposure.

Section 2: Screening Threshold Based on Wet-Bulb Globe Temperature (WBGT). The WBGT offers a useful first order index of the environmental contribution to heat stress. It is influenced by air temperature, radiant heat, air movement, and humidity. As an approximation, it does not fully account for all the interactions between a person and the environment and cannot account for special conditions such as heating from a radiofrequency/microwave source.

TABLE 1. Clothing-Adjustment Factors for Some Clothing Ensembles*

Clothing Type	Addition to WBGT [°C]
Work clothes (long sleeve shirt and pants)	0
Cloth (woven material) coveralls	0
Double-layer woven clothing	3
SMS polypropylene coveralls	0.5
Polyolefin coveralls	1
Limited-use vapor-barrier coveralls	11

*These values must not be used for completely encapsulating suits, often called Level A. Clothing Adjustment Factors cannot be added for multiple layers. The coveralls assume that only modesty clothing is worn underneath, not a second layer of clothing.

WBGT values are calculated using one of the following equations:

With direct exposure to sunlight:

$$WBGT_{out} = 0.7 T_{nwb} + 0.2 T_g + 0.1 T_{db}$$

Without direct exposure to the sun:

$$WBGT_{in} = 0.7 T_{nwb} + 0.3 T_g$$

where:

T_{nwb} = natural wet-bulb temperature (sometimes called NWB)

T_g = globe temperature (sometimes called GT)

T_{db} = dry-bulb (air) temperature (sometimes called DB)

Because WBGT is only an index of the environment, the screening criteria are adjusted for the contributions of work demands and clothing. Table 2 provides WBGT criteria suitable for screening purposes. For clothing ensembles listed in Table 1, Table 2 can be used when the clothing adjustment factors are added to the environmental WBGT.

To determine the degree of heat stress exposure, the work pattern and demands must be considered. If the work (and rest) is distributed over more than one location, then a time-weighted average WBGT should be used for comparison to Table 2 limits.

As metabolic rate increases (i.e., work demands increase), the criteria values in the table decrease to ensure that most workers will not have a core body temperature above 38°C. Correct assessment of work rate is of equal importance to environmental assessment in evaluating heat stress. Table 3 provides broad guidance for selecting the work rate category to be used in Table 2. Often there are natural or prescribed rest breaks within an hour of work, and Table 2 provides the screening criteria for three allocations of work and rest.

Based on metabolic rate category for the work and the approximate proportion of work within an hour, a WBGT criterion can be found in Table 2 for

TABLE 2. Screening Criteria for TLV[®] and Action Limit for Heat Stress Exposure

Allocation of Work in a Cycle of Work and Recovery	TLV [®] (WBGT values in °C)				Action Limit (WBGT values in °C)			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
75 to 100%	31.0	28.0	—	—	28.0	25.0	—	—
50 to 75%	31.0	29.0	27.5	—	28.5	26.0	24.0	—
25 to 50%	32.0	30.0	29.0	28.0	29.5	27.0	25.5	24.5
0 to 25%	32.5	31.5	30.5	30.0	30.0	29.0	28.0	27.0

Notes:

- See Table 3 and the *Documentation* for work demand categories.
- WBGT values are expressed to the nearest 0.5°C.
- The thresholds are computed as a TWA-Metabolic Rate where the metabolic rate for rest is taken as 115 W and work is the representative (mid-range) value of Table 3. The time base is taken as the proportion of work at the upper limit of the percent work range (e.g., 50% for the range of 25 to 50%).
- If work and rest environments are different, hourly time-weighted averages (TWA) WBGT should be calculated and used. TWAs for work rates should also be used when the work demands vary within the hour, but note that the metabolic rate for rest is already factored into the screening limit.
- Values in the table are applied by reference to the “Work-Rest Regimen” section of the *Documentation* and assume 8-hour workdays in a 5-day workweek with conventional breaks as discussed in the *Documentation*. When workdays are extended, consult the “Application of the TLV[®]” section of the *Documentation*.
- Because of the physiological strain associated with Heavy and Very Heavy work among less fit workers regardless of WBGT, criteria values are not provided for continuous work and for up to 25% rest in an hour for Very Heavy. The screening criteria are not recommended, and a detailed analysis and/or physiological monitoring should be used.
- Table 2 is intended as an initial screening tool to evaluate whether a heat stress situation may exist (according to Figure 1) and thus, the table is more protective than the TLV[®] or Action Limit (Figure 2). Because the values are more protective, they are not intended to prescribe work and recovery periods.

TABLE 3. Metabolic Rate Categories and the Representative Metabolic Rate with Example Activities

Category	Metabolic Rate [W] *	Examples
Rest	115	Sitting
Light	180	Sitting with light manual work with hands or hands and arms, and driving. Standing with some light arm work and occasional walking.
Moderate	300	Sustained moderate hand and arm work, moderate arm and leg work, moderate arm and trunk work, or light pushing and pulling. Normal walking.
Heavy	415	Intense arm and trunk work, carrying, shoveling, manual sawing; pushing and pulling heavy loads; and walking at a fast pace.
Very Heavy	520	Very intense activity at fast to maximum pace.

* The effect of body weight on the estimated metabolic rate can be accounted for by multiplying the estimated rate by the ratio of actual body weight divided by 70 kg (154 lb).

TLV®-PA

the TLV® and for the Action Limit. If the measured time-weighted average WBGT adjusted for clothing is less than the table value for the Action Limit, the NO branch in Figure 1 is taken, and there is little risk of excessive exposures to heat stress. If the conditions are above the Action Limit, but below the TLV®, then consider general controls described in Table 5. If there are reports of the symptoms of heat-related disorders such as fatigue, nausea, dizziness, and lightheadedness, then the analysis should be reconsidered.

If the work conditions are above the TLV® screening criteria in Table 2, then a further analysis is required following the YES branch.

Section 3: Detailed Analysis. Table 2 is intended to be used as a screening step. It is possible that a condition may be above the TLV® or Action Limit criteria provided in Table 2 and still not represent an exposure above the TLV® or the Action Limit. To make this determination, a detailed analysis is required. Methods are fully described in the *Documentation*, in industrial hygiene and safety books, and in other sources.

Provided that there is adequate information on the heat stress effects of the required clothing, the first level of detailed analysis is a task analysis that includes a time-weighted average of the Effective WBGT (environmental WBGT plus clothing adjustment factor) and the metabolic rate. Some clothing adjustment factors have been suggested in Table 1. Factors for other clothing ensembles appearing in the literature can be used in similar fashion following

good professional judgment. The TLV[®] and Action Limit are shown in Figure 2.

The second level of detailed analysis would follow a rational model of heat stress, such as the International Standards Organization (ISO) Predicted Heat Strain (ISO 7933 2004; Malchaire et al., 2001). While a rational method (versus the empirically derived WBGT thresholds) is computationally more difficult, it permits a better understanding of the sources of the heat stress and is a means to appreciate the benefits of proposed modifications in the exposure. Guidance to the ISO method and other rational methods is described in the literature.

The screening criteria require the minimal set of data to make a determination. Detailed analyses require more data about the exposures. Following Figure 1, the next question asks about the availability of data for a detailed analysis. If these data are not available, the NO branch takes the evaluation to physiological monitoring to assess the degree of heat strain.

If the data for a detailed analysis are available, the next step in Figure 1 is the detailed analysis. If the exposure does not exceed the criteria for the Action Limit (or unacclimatized workers) for the appropriate detailed analysis (e.g., WBGT analysis, another empirical method, or a rational method), then the NO branch can be taken. If the Action Limit criteria are exceeded but the criteria for the TLV[®] (or acclimatized workers) in the detailed analysis are not exceeded, then implement general controls and continue to monitor the conditions. General controls include training for workers and supervisors, heat stress hygiene practices, and medical surveillance. If the exposure exceeds the limits for acclimatized workers in the detailed analysis, the YES branch leads to physiological monitoring as the only alternative to demonstrate that adequate protection is provided.

Section 4: Heat Strain. The risk and severity of excessive heat strain will vary widely among people, even under identical heat stress conditions. The normal physiological responses to heat stress provide an opportunity to monitor heat strain among workers and to use this information to assess the level of heat strain present in the workforce, to control exposures, and to assess the effectiveness of implemented controls. Table 4 provides guidance for acceptable limits of heat strain.

Following good industrial hygiene sampling practice, which considers likely extremes and the less tolerant workers, the absence of any of these limiting observations indicates acceptable management of the heat stress exposures. With acceptable levels of heat strain, the NO branch in Figure 1 is taken. Nevertheless, if the heat strain among workers is considered acceptable at the time, consideration of the general controls is recommended. In addition, periodic physiological monitoring should be continued to ensure acceptable levels of heat strain.

If limiting heat strain is found during the physiological assessments, then the YES branch is taken. This means that suitable job-specific controls should be implemented to a sufficient extent to control heat strain. The job-specific controls include engineering controls, administrative controls, and personal protection.

After implementation of the job-specific controls, it is necessary to assess their effectiveness and to adjust them as needed.

TABLE 4. Guidelines for Limiting Heat Strain

Monitoring heat strain and signs and symptoms of heat-related disorders is sound industrial hygiene practice, especially when clothing may significantly reduce heat loss. For surveillance purposes, a pattern of workers exceeding the heat strain limits is indicative of a need to control the exposures. On an individual basis, the limits represent a time to cease an exposure and allow for recovery.

One or more of the following measures may mark excessive heat strain, and an individual's exposure to heat stress should be discontinued when any of the following occur:

- Sustained (several minutes) heart rate is in excess of 180 bpm (beats per minute) minus the individual's age in years (e.g., 180 – age), for individuals with assessed normal cardiac performance; or
- Body core temperature is greater than 38.5°C (101.3°F) for medically selected and acclimatized personnel; or greater than 38°C (100.4°F) in unselected, unacclimatized workers; or
- Recovery heart rate at one minute after a peak work effort is greater than 120 bpm; or
- There are symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.

An individual may be at greater risk of heat-related disorders if:

- Profuse sweating is sustained over hours; or
- Weight loss over a shift is greater than 1.5% of body weight; or
- 24-hour urinary sodium excretion is less than 50 mmoles

EMERGENCY RESPONSE: If a worker appears to be disoriented or confused, suffers inexplicable irritability, malaise, or chills, the worker should be removed for rest in a cool location with rapidly circulating air and kept under skilled observation. Absent medical advice to the contrary, treat this as an emergency with immediate transport to a hospital. An emergency response plan is necessary.

— **NEVER ignore anyone's signs or symptoms of heat-related disorders** —

Section 5: Heat Stress Management and Controls. The elements of a heat stress management program including general and job-specific controls should be considered in the light of local conditions and the judgment of the industrial hygienist. The recommendation to initiate a heat stress management program is marked by 1) heat stress levels that exceed the Action Limit or 2) work in clothing ensembles that limit heat loss. In either case, general controls should be considered (Table 5).

Heat stress hygiene practices are particularly important because they reduce the risk that an individual may suffer a heat-related disorder. The key elements are fluid replacement, self-determination of exposures, health status monitoring, maintenance of a healthy lifestyle, and adjustment of expectations based on acclimatization state. The hygiene practices require the full cooperation of supervision and workers.

TABLE 5. Elements to Consider in Establishing a Heat Stress Management Program

Monitor heat stress (e.g., WBGT Screening Criteria in Table 2) and heat strain (Table 4) to confirm adequate control

General Controls

- Provide accurate verbal and written instructions, annual training programs, and other information about heat stress and strain
- Encourage drinking small volumes (approximately 1 cup) of cool, palatable water (or other acceptable fluid replacement drink) about every 20 minutes
- Encourage employees to report symptoms of heat-related disorders to a supervisor
- Encourage self-limitation of exposures when a supervisor is not present
- Encourage co-worker observation to detect signs and symptoms of heat strain in others
- Counsel and monitor those who take medications that may compromise normal cardiovascular, blood pressure, body temperature regulation, renal, or sweat gland functions; and those who abuse or are recovering from the abuse of alcohol or other intoxicants
- Encourage healthy lifestyles, ideal body weight and electrolyte balance
- Adjust expectations of those returning to work after absence from hot exposure situations and encourage consumption of salty foods (with approval of physician if on a salt-restricted diet)
- Consider pre-placement medical screening to identify those susceptible to systemic heat injury
- Monitor the heat stress conditions and reports of heat-related disorders

Job-Specific Controls

- Consider engineering controls that reduce the metabolic rate, provide general air movement, reduce process heat and water vapor release, and shield radiant heat sources, among others
- Consider administrative controls that set acceptable exposure times, allow sufficient recovery, and limit physiological strain
- Consider personal protection that is demonstrated effective for the specific work practices and conditions at the location

— NEVER ignore anyone's signs or symptoms of heat-related disorders —

In addition to general controls, appropriate job-specific controls are often required to provide adequate protection. During the consideration of job-specific controls, Table 2 and Figure 2, along with Tables 1 and 3, provide a framework to appreciate the interactions among acclimatization state, metabolic rate, work-rest cycles, and clothing. Among administrative controls, Table 4 provides acceptable physiological and signs/symptoms limits. The mix of job-specific controls can be selected and implemented only after a review of the demands and constraints of any particular situation. Once implemented, their effectiveness must be confirmed and the controls maintained.

The prime objective of heat stress management is the prevention of heat stroke, which is life-threatening and the most serious of the heat-related disorders. The heat stroke victim is often manic, disoriented, confused, delirious, or unconscious. The victim's body core temperature is greater than 40°C (104°F). If signs of heat stroke appear, aggressive cooling should be started immediately, and emergency care and hospitalization are essential. The prompt treatment of other heat-related disorders generally results in full recovery, but medical advice should be sought for treatment and return-to-work protocols. It is worth noting that the possibility of accidents and injury increases with the level of heat stress.

Prolonged increases in deep body temperatures and chronic exposures to high levels of heat stress are associated with other disorders such as temporary infertility (male and female), elevated heart rate, sleep disturbance, fatigue, and irritability. During the first trimester of pregnancy, a sustained core temperature greater than 39°C may endanger the fetus.

TLV®-PA

References

1. International Organization for Standardization (ISO): Ergonomics of the thermal environment – Analytical determination and interpretation of heat stress using calculation of the predicted heat strain. ISO 7933:2004. ISO, Geneva (2004).
2. Malchaire J; Piette A; Kampmann B; et al.: Development and validation of the predicted heat strain model. *Ann Occup Hyg.* 45(2):123–135 (2001).