## The Case of the
# HEAT-STRESSED TREE FELLER

**By Mitch Ricketts**

**Math Toolbox is designed to help readers apply STEM principles to everyday safety issues. Many readers may feel apprehensive about math and science. This series employs various communication strategies to make the learning process easier and more accessible.**

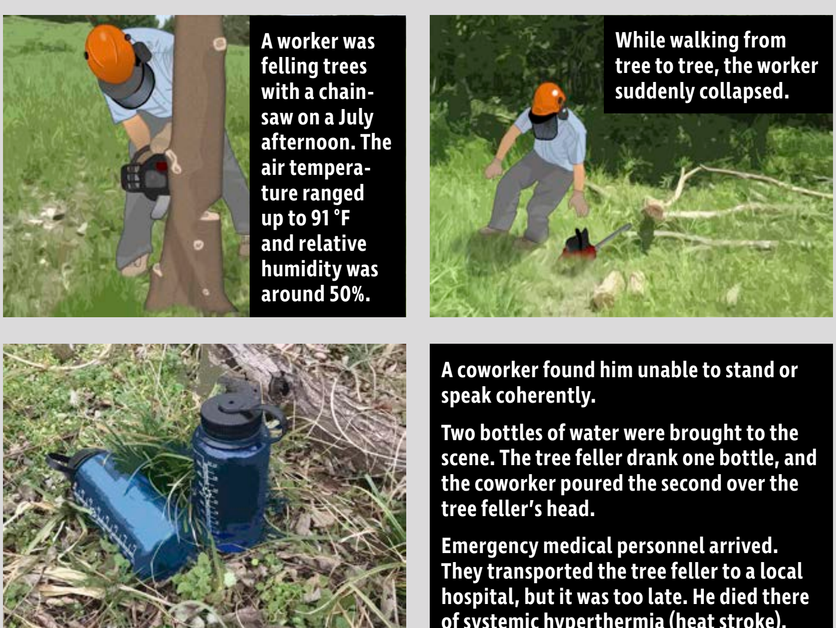
**When exposed to extreme heat,** workers may suffer effects that include heat exhaustion, heat stroke, dehydration, kidney damage and even death (Flouris et al., 2018; Park et al., 2017). Figure 1 illustrates one such case in which a worker perished of heat stroke while cutting trees during a hot West Virginia afternoon.

Another Math Toolbox article, "The Case of the Overheated Construction Worker," discusses formulas for calculating a measure of environmental factors known as wet-bulb globe temperature index (WBGT; Ricketts, 2020). In this article, we examine methods for interpreting WBGT published by the American Conference of Governmental Hygienists (ACGIH, 2021), OSHA (2013), NIOSH (2016) and International Organization for Standardization (ISO, 2017). Although each of these organizations has made original contributions to the interpretation of WBGT, the core of each approach relies on the ACGIH action limit (AL) and threshold limit value (TLV).

WBGT is an index of potential heat stress that incorporates the natural wet-bulb temperature, black-globe temperature and (in some situations) dry-bulb temperature. Natural wet-bulb temperature is incorporated because it relates to the effectiveness of perspiration in removing heat from a worker's body given the ambient air speed, relative humidity and air temperature. Black-globe temperature is included because it relates to the impact of radiant heat sources such as the sun. Dry-bulb temperature is air temperature measured with an ordinary thermometer. By itself, dry-bulb temperature is insufficient to predict heat stress when work rate, relative humidity or radiant heat are extreme.

In the context of heat stress, the TLV specifies the WBGT to which nearly all workers can be repeatedly exposed without adverse health effects, providing they are healthy, unmedicated, adequately acclimatized and hydrated. Acclimatized workers are those who have experienced a steady increase in exposure to heat over several days and whose bodies have thus become more efficient at maintaining a safe and stable core temperature. When workers are unacclimatized, the more protective AL is applied. The AL also serves as a trigger for implementing heat stress management programs. The values of the AL and TLV, respectively, are identical to values of the NIOSH recommended alert limit and recommended exposure limit. They are also identical to the ISO reference limits ($WBGT_{ref}$) for unacclimatized and acclimatized persons.

**FIGURE 1**
**HEAT STROKE FATALITY, WEST VIRGINIA, 2012**

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**Note. Adapted from "Inspection Detail (Inspection No. 550058.015)," by OSHA, n.d., www.osha.gov/pls/imis/establishment.inspection_detail?id=550058.015.**

### TLV for Workers Who Are Acclimatized When Metabolic Rate Is Measured

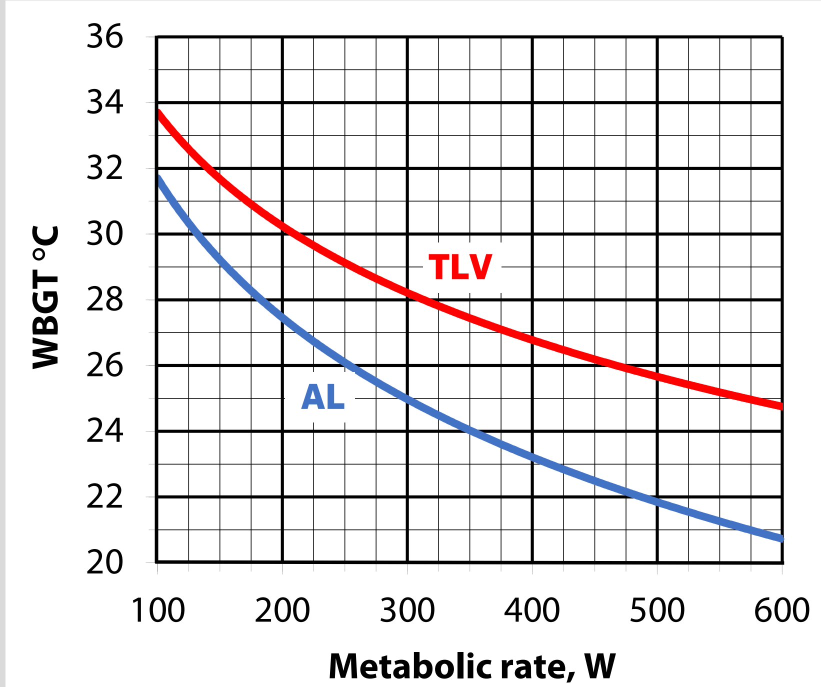
Methods for interpreting the WBGT vary, depending in part on a worker's metabolic rate. Metabolic rate is the total energy consumed within the body over time. Metabolic rate is important because metabolism generates heat within the body. Metabolic heat augments heat from the work environment to increase the probability of heat stress. Metabolic rate can be determined by various means, including calorimetry; however, it is often estimated based on methods discussed later in this article.

When metabolic rate is measured (rather than estimated), we can consult the TLV curve for exposure to WBGT temperatures, as depicted by the red (top) line in Figure 2. Alternatively, for added precision we can calculate the exact value of the TLV using the standard formula upon which the curve is based. This formula assumes that the worker is wearing a conventional one-layer work ensemble (a long-sleeved work shirt and trousers or the equivalent). The TLV formula is identical to the formula for the NIOSH recommended exposure limit and the ISO $WBGT_{ref}$ for acclimatized persons. The formula is as follows:

$$TLV = 56.7 - 11.5 \cdot \log_{10} M$$

FIGURE 2
## WBGT TLV & AL BY METABOLIC RATE

**WBGT threshold limit values (TLV) and action limits (AL) by metabolic rate. Calculated as TLV = 56.7 - 11.5 × $\log_{10} M$ and AL = 59.9 - 14.1 × $\log_{10} M$.**




where:

TLV = threshold limit value; i.e., the maximum recommended WBGT in degrees Celsius as a 1-hour time-weighted average for healthy, acclimatized workers

$log_{10}$ = base-10 logarithm

*M* = metabolic rate in watts (W) as a time-weighted average for an hourly work/rest period; for conversions, one watt = 1.163 kilocalories per hour (kcal/h)

**Calculated example.** The investigation report illustrated in Figure 1 does not include certain information. For example, we do not know whether the worker was acclimatized to the heat. We also do not know the clothing he wore or the WBGT at the time of the incident. To address these uncertainties, we will calculate the TLV for heat exposure based on the following assumptions: First, we will assume that the worker was acclimatized to the heat. Second, we will assume he was dressed in a conventional one-layer work ensemble. Third, we will assume his metabolic rate (*M*) was measured as a time-weighted average of 270 W for this type of work.

With the value of *M* = 270 W, we calculate the TLV as follows:

**Step 1:** Begin with the equation:

$$TLV = 56.7 - 11.5 \cdot \log_{10} M$$

**Step 2:** Insert the known value for metabolic rate (*M* = 270 W), and solve for TLV:

$$TLV = 56.7 - 11.5 \cdot \log_{10}(270) = 28.74\ °C$$
(rounded two places past the decimal)

*Note:* Most calculators have a *LOG* button that will provide the correct answer with keystrokes similar to the following in this case: *56.7-11.5xLOG270=*. Alternatively, in an Excel spreadsheet, the proper formula for this example is: *=56.7-11.5*LOG10(270).*

**Step 3:** The calculation indicates that the TLV is equal to a WBGT of about 28.74 °C for an acclimatized worker with a metabolic rate of 270 W. We can confirm our result by observing the TLV curve in Figure 2. At 250 to 275 W, the TLV curve is approximately 28.6 to 29.1 °C. Note that the calculated TLV is more precise, compared with a visual examination of the curve.

For some purposes, we may wish to convert the value of the TLV to degrees Fahrenheit. When this is desired, we use the formula:

$$°F = °C \cdot 1.8 + 32$$

Inserting the TLV of 28.74 °C, we obtain:

$$°F = 28.74 \cdot 1.8 + 32 = 83.73\ °F$$
(rounded)

After converting to Fahrenheit, we find the TLV of 28.74 °C is equivalent to about 83.73 °F.

These results indicate that the 1-hour time-weighted average WBGT for most healthy, acclimatized workers should not exceed 28.74 °C (83.73 °F) when the measured average metabolic rate is 270 W. Since the actual WBGT, work clothing and acclimatization were not reported for the incident in Figure 1, we cannot speculate about whether the TLV may have been exceeded in this case.

**Alternate example.** Now imagine a different scenario in which a worker is felling trees manually (with a handsaw and axe). Continue to assume that the worker wore a conventional one-layer work ensemble and was properly acclimatized to the heat. In contrast to the previous example, imagine the worker's average metabolic work rate has been measured as 481 W as a time-weighted average for this more strenuous type of work.

With the value of *M* = 481 W, we calculate the TLV as follows:

**Step 1:** Begin with the equation:

$$TLV = 56.7 - 11.5 \cdot \log_{10} M$$

**Step 2:** Insert the known value for metabolic rate (*M* = 481 W) and solve for TLV:

$$TLV = 56.7 - 11.5 \cdot \log_{10}(481) = 25.86\ °C$$
(rounded)

**Step 3:** The calculation indicates that the TLV is equal to a WBGT of about 25.86 °C for an acclimatized worker with a metabolic rate of 481 W. We may convert to Fahrenheit with the formula:

$$°F = °C \cdot 1.8 + 32$$

Inserting the TLV of 25.86 °C, we obtain:

$$°F = 25.86 \cdot 1.8 + 32 = 78.55\ °F$$
(rounded)

These results indicate that the WBGT (as a 1-hour time-weighted average) for most healthy, acclimatized workers should not exceed 25.86 °C (78.55 °F) when the measured average metabolic rate is 481 W. The acceptable WBGT is much lower in this case because of the higher metabolic work rate associated with manual tree felling.

### You Do the Math

Apply your knowledge to the following questions. Answers are on p. 35.

1. Imagine that a carpenter wears a conventional one-layer work ensemble and is properly acclimatized to the heat. The carpenter is repeatedly climbing, carrying and assembling 2 x 6-in. framing members at a fast pace. Imagine the carpenter's metabolic rate for this type of activity is measured as 421 W as a time-weighted average. Answer the following:

a. What is the TLV in degrees Celsius (°C)?

b. What is the TLV when converted to degrees Fahrenheit (°F)?

2. Now imagine that a custodial worker engages in dusting, vacuuming and light cleaning. Also imagine that the custodian's

metabolic rate is measured as 138 W as a time-weighted average for this type of work. Again, the worker wears a conventional one-layer work ensemble and is properly acclimatized to the environment of the workplace. Answer the following:

a. What is the TLV in degrees Celsius (°C)?

b. What is the TLV when converted to degrees Fahrenheit (°F)?

### AL for Workers Who Are *Not* Acclimatized When Metabolic Rate Is Measured

In the previous examples, we assumed that workers had been properly acclimatized to the expected working conditions. Now, let's imagine a worker is unacclimatized to the heat. In that case, the WBGT that should not be exceeded is known as the action limit (AL). The AL formula is identical to the formula for the NIOSH recommended alert limit and the ISO $WBGT_{ref}$ for unacclimatized persons, as follows:

$$AL = 59.9 - 14.1 \cdot \log_{10} M$$

where:

AL = action limit; i.e., the maximum recommended WBGT in degrees Celsius as a 1-hour time-weighted average for healthy, unacclimatized workers

$log_{10}$ = base-10 logarithm

$M$ = metabolic rate in watts (W) as a time-weighted average for an hourly work/rest period

**Calculated example.** As with the first calculated example, let's assume the worker wears a conventional one-layer work ensemble and is working at a measured average metabolic rate of 270 W. The difference is that we will now assume the worker is unacclimatized.

With the value of $M$ = 270 W, we calculate the AL for unacclimatized workers as follows:

**Step 1:** Begin with the equation:

$$AL = 59.9 - 14.1 \cdot \log_{10} M$$

**Step 2:** Insert the known value for metabolic rate ($M$ = 270 W), and solve for AL:

$$AL = 59.9 - 14.1 \cdot \log_{10}(270) = 25.62\ °C$$
(rounded)

**Step 3:** The calculation indicates that the AL is equal to a WBGT (as a 1-hour time-weighted average) of about 25.62 °C for an unacclimatized worker with a metabolic rate of 270 W. We can confirm our result by observing the AL curve in Figure 2 (p. 25). At 250 to 275 W, the AL curve is approximately 25.5 to 26.1 °C.

If desired, we can convert the AL to degrees Fahrenheit with the formula:

$$°F = °C \cdot 1.8 + 32$$

Inserting the AL of 25.62 °C, we obtain:

$$°F = 25.62 \cdot 1.8 + 32 = 78.12\ °F$$
(rounded)

These results indicate that the 1-hour time-weighted average WBGT for most healthy, unacclimatized workers should not exceed 25.62 °C (78.12 °F) when the measured average metabolic rate is 270 W. Because the worker is unacclimatized, the AL is substantially lower, compared with the TLV for acclimatized workers based on the same data.

**Alternate example.** Now imagine a worker is resting, with a measured average metabolic rate of 115 W. The worker is unacclimatized and wears a conventional one-layer work ensemble. We calculate the AL with the value of $M$ = 115 W.

**Step 1:** Begin with the equation:

$$AL = 59.9 - 14.1 \cdot \log_{10} M$$

**Step 2:** Insert the known value for metabolic rate ($M$ = 115 W), and solve for AL:

$$AL = 59.9 - 14.1 \cdot \log_{10}(115) = 30.84\ °C$$
(rounded)

**Step 3:** The calculation indicates that the AL is equal to a WBGT of about 30.84 °C for an unacclimatized worker with a metabolic rate of 115 W. We may convert to Fahrenheit with the formula:

$$°F = °C \cdot 1.8 + 32$$

Inserting the AL of 30.84 °C, we obtain:

$$°F = 30.84 \cdot 1.8 + 32 = 87.51\ °F$$
(rounded)

These results indicate that the 1-hour time-weighted average WBGT for most healthy, unacclimatized workers should not exceed 30.84 °C (87.51 °F) when the measured average metabolic rate is 115 W. This time, the acceptable WBGT is relatively high because of the lower metabolic rate.

**TABLE 1**
## METABOLIC WORK RATES

| Work category | Metabolic rate (W) | Examples |
|---|---|---|
| Rest | 115 | Sitting |
| Light | 180 | Sitting or standing with light arm or hand work and occasional walking; driving |
| Moderate | 300 | Sustained moderate work with hands, arms, trunk or legs; light pushing or pulling; walking at normal pace |
| Heavy | 415 | Intense work with arms or trunk; heavy pushing or pulling; walking at fast pace; carrying; shoveling; manual sawing |
| Very heavy | 520 | Very intense work at a fast to extreme pace |

**Note. Adapted from *TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, by ACGIH, 2021, Table 3.**

### You Do the Math

Apply your knowledge to the following questions. Answers are on p. 35.

3. Imagine that a worker wears a conventional one-layer work ensemble and is unacclimatized to the heat. In this case, the worker is installing plumbing in a building under construction. The worker's average metabolic rate has been measured as 210 W for this type of work. Answer the following:

a. What is the AL in degrees Celsius (°C)?

b. What is the AL when converted to degrees Fahrenheit (°F)?

4. Imagine that a worker is driving heavy road-building machinery, with a measured average metabolic rate of 361 W. Again, the worker wears a conventional one-layer work ensemble and is unacclimatized to the heat. Answer the following:

a. What is the AL in degrees Celsius (°C)?

b. What is the AL when converted to degrees Fahrenheit (°F)?

### Screening Criteria When Metabolic Rate Is Estimated Rather Than Measured

Previous calculations have assumed that each worker's actual metabolic rate was determined using calorimetry or other valid methods during representative work tasks. Rather than measuring metabolic rates, however, we often begin by consulting tables of screening values to identify work activities and environments that present an elevated risk of heat stress. Based on the results of screening, we then prioritize tasks and environments for further evaluation.

Preliminary screening criteria typically consist of data such as those shown in Tables 1, 2 and 3. For example, Table 1 provides estimated metabolic rates for various work tasks. Table 1 assumes that each worker's body weight is approximately 70 kg (154 lb, a "standard" person). Adjustments for workers who are substantially lighter or heavier are discussed later.

**TABLE 2**

## TLV SCREENING CRITERIA (WBGT °C)

**Screening values (more protective than the TLV) to trigger further evaluation of heat exposure for fully acclimatized workers. Certain cells indicate "not recommended" because the physiological strain may be too extreme for workers who are less fit.**

| Percent work | Workload | | | |
|---|---|---|---|---|
| | Light | Moderate | Heavy | Very heavy |
| 75% to 100% | 31.0 | 28.0 | Not recommended | Not recommended |
| 50% to 75% | 31.0 | 29.0 | 27.5 | Not recommended |
| 25% to 50% | 32.0 | 30.0 | 29.0 | 28.0 |
| 0% to 25% | 32.5 | 31.5 | 30.5 | 30.0 |

**Note. Adapted from *TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, by ACGIH, 2021, Table 2.**

**TABLE 3**

## AL SCREENING CRITERIA (WBGT °C)

**Screening values (more protective than the AL) to trigger further evaluation of heat exposure for unacclimatized workers. Certain cells indicate "not recommended" because the physiological strain may be too extreme for workers who are less fit.**

| | Workload | | | |
|---|---|---|---|---|
| Percent work | Light | Moderate | Heavy | Very heavy |
| 75% to 100% | 28.0 | 25.0 | Not recommended | Not recommended |
| 50% to 75% | 28.5 | 26.0 | 24.0 | Not recommended |
| 25% to 50% | 29.5 | 27.0 | 25.5 | 24.5 |
| 0% to 25% | 30.0 | 29.0 | 28.0 | 27.0 |

**Note. Adapted from *TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, by ACGIH, 2021, Table 2.**

Tables 2 and 3 (for acclimatized and unacclimatized workers, respectively) are used in conjunction with estimated metabolic rates from Table 1, actual WBGT measurements and known work/rest schedules to determine whether the risk of heat stress requires additional investigation. As screening tools, the values in these tables are much more protective, compared to ALs and TLVs.

To illustrate how the tables are used, imagine a fully acclimatized worker is required to work 50 minutes and rest 10 minutes every hour during activities characterized as moderate lifting and walking at a normal pace. Table 1 indicates that activities such as this are representative of the "moderate" work category. Next, we consult Table 2 because the worker is fully acclimatized. The percent work in this case is 83.33% per hour because 50 minutes ÷ 60 minutes · 100 = 83.33%. Based on the row for 75% to 100% work in Table 2, we find the screening criteria for moderate work is 28.0 °C. This means that further evaluation is recommended if the WBGT is expected to exceed a time-weighted average of 28.0 °C for acclimatized workers engaged at a moderate work rate.

As another example, imagine that an unacclimatized worker is required to work 40 minutes and rest 20 minutes every hour while performing intense work characterized as carrying heavy loads and walking at a fast pace, representative of the "heavy" work category in Table 1. The work rate is 66.67% per hour (40 minutes ÷ 60 minutes · 100 = 66.67%). Since the worker is unacclimatized, we consult Table 3. Based on the row for 50% to 75% work in Table 3, we find the screening criteria for heavy work is 24.0 °C. This means that further evaluation is recommended for unacclimatized workers engaged at a heavy work rate if the WBGT is expected to exceed a time-weighted average of 24.0 °C.

### Adjusting the Screening Criteria for Differences in Body Weight

The values in Table 1 assume that each worker weighs about 70 kg. Workers who are heavier than 70 kg may be at greater risk of heat stress because heat dissipates more slowly from larger bodies. To account for differences in body weight, the metabolic rates in the second column of Table 1 can be multiplied by the ratio of the actual body weight divided by 70 kg. The result of this calculation is known as the estimated metabolic rate ($M_{est}$):

$$M_{est} = M \cdot \frac{actual\ body\ weight(kg)}{70\ kg}$$

where:

$M_{est}$ = estimated metabolic rate in watts (W)

$M$ = metabolic rate in watts (W) from Table 1

**Calculated example.** In this case, let's imagine that an acclimatized worker has an actual body weight of 110 kg (about 243 lb) and is dressed in a conventional one-layer work ensemble. The worker is engaged in labor that can be characterized as sitting or standing, with light arm work and occasional walking. Based on Table 1, the work category is "light," with a metabolic rate ($M$) of about 180 W. The worker is not taking rest breaks (100% work). Since the worker weights 110 kg (instead of 70 kg), we calculate $M_{est}$ as follows:

**Step 1:** Begin with the equation for $M_{est}$:

$$M_{est} = M \cdot \frac{actual\ body\ weight(kg)}{70\ kg}$$

**Step 2:** Insert the values for metabolic rate ($M$ = 180 W), and actual body weight in kilograms (110 kg). Then solve for $M_{est}$:

$$M_{est} = 180 \cdot \frac{110}{70} = 282.86\text{ W}$$

(rounded)

**Step 3:** The calculation indicates that $M_{est}$ is equal to 282.86 W for a 110 kg (243 lb) worker who is engaged in sitting or standing, with light arm work and occasional walking. Consulting the second column of Table 1, we see that 282.86 W is close to the metabolic rate corresponding to the "moderate" work category. Thus, when consulting Table 2 for this acclimatized worker with a 100% work schedule, we may wish to consider the screening value of 28.0 °C (moderate workload) instead of 31.0 °C from the light category.

**Alternate example.** This time, imagine an unacclimatized worker has an actual body weight of 87 kg (about 192 lb) and is dressed in a conventional one-layer work ensemble. The worker is engaged in intense activities characterized as heavy pushing, pulling and walking at a fast pace. Based on Table 1, the work category is "heavy," with a metabolic rate ($M$) of about 415 W. Imagine the worker is engaged in labor for 25 minutes each hour, while resting in the shade for 35 minutes per hour (25 minutes ÷ 60 minutes · 100 = 41.67% work). Since the worker weights 87 kg, we calculate $M_{est}$ as follows:

**Step 1:** Begin with the equation for $M_{est}$:

$$M_{est} = M \cdot \frac{actual\ body\ weight(kg)}{70\ kg}$$

**Step 2:** Insert the values for metabolic rate ($M$ = 415 W) and actual body weight in kilograms (87 kg). Then solve for $M_{est}$:

$$M_{est} = 415 \cdot \frac{87}{70} = 515.79 \text{ W}$$
(rounded)

**Step 3:** The calculation indicates that $M_{est}$ is equal to 515.79 W for an 87 kg (192 lb) worker who is engaged in intense labor consisting of heavy pushing, pulling and walking at a fast pace. Consulting the second column of Table 1 (p. 26), we see that 515.79 W is closest to the metabolic rate corresponding to a category of "very heavy" work. Since the worker is unacclimatized, we consult Table 3 (p. 27). For this unacclimatized worker with a 41.67% work schedule, we find the screening value of 24.5 °C in the very heavy workload category (instead of 25.5 °C in the heavy workload category).

### You Do the Math

Apply your knowledge to the following questions. Answers are on p. 35.

5. Imagine that an acclimatized worker is dressed in a conventional one-layer work ensemble. The worker is engaged in work for 40 minutes each hour, while resting in the shade for 20 minutes per hour (40 minutes ÷ 60 minutes · 100 = 66.67% work). The work is characterized as sustained moderate lifting with the arms and walking at a normal pace. Answer the following:

a. Assume the worker weighs 70 kg (154 lb). What is the work category and metabolic rate in watts from Table 1 (p. 26) for this work?

b. Based on your answer to 5a, what is the screening value from Table 2 (p. 27), given the 66.67% work rate for this acclimatized worker?

c. Now assume the worker weighs about 95 kg. What is the estimated metabolic rate ($M_{est}$) calculated as

$$M_{est} = M \cdot \frac{actual\ body\ weight(kg)}{70\ kg} \quad ?$$

d. Based on the value of $M_{est}$ you calculated for 5c, what is the closest work category and metabolic rate in watts from Table 1 (p. 26) for this work?

e. Based on your answer to 5d, what is the screening value from Table 2 (p. 27) given the 66.67% work rate for this acclimatized worker?

### Adjusting the Measured WBGT for Differences in Clothing

All preceding calculations assumed that workers were attired in a conventional one-layer work clothing ensemble consisting of a long-sleeved work shirt and trousers or the equivalent. Since clothing affects the retention of body heat, a clothing adjustment factor (CAF) is typically added to the measured WBGT when work attire is expected to increase the potential for heat stress. Some commonly used CAFs are shown in Table 4 (see ISO 7243:2017 Annex E for an alternate, more comprehensive listing).

**TABLE 4**
**CLOTHING ADJUSTMENT FACTORS**

| Clothing worn | CAF |
|---|---|
| Work clothes (long sleeves and pants); examples: standard cotton shirt and pants | 0 |
| Coveralls (with only underwear beneath); examples: cotton or light polyester material | 0 |
| Double-layer woven clothing | 3 |
| SMS polypropylene coveralls | 0.5 |
| Polyolefin coveralls; examples: microporous fabric (e.g., Tyvek) | 1 |
| Limited-use vapor-barrier coveralls; examples: firefighter turnout gear, chemical protective suits (but not for completely encapsulating Level A suits) | 11 |

**Note. Adapted from Note. Adapted from *TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, by ACGIH, 2021, Table 1; and "OSHA Technical Manual (OTM; OSHA instruction TED 01-00-015)," by OSHA, 2013, Table 2.**

The CAF is added to the measured WBGT to derive an effective WBGT ($WBGT_{eff}$). The TLV, AL or screening values are then compared with $WBGT_{eff}$ to evaluate the potential for heat stress. The formula is:

$$WBGT_{eff} = WBGT + CAF$$

As an example, imagine the WBGT has been measured as 25 °C. Further imagine that a worker is wearing a double layer of woven clothing. Table 4 indicates that a CAF of 3 would be added to the measured WBGT in this case. Adding the CAF of 3 to the measured WBGT of 25 °C results in a $WBGT_{eff}$ of 28 °C. Thus, we compare the TLV, AL or screening value with the $WBGT_{eff}$ of 28 °C.

As another example, imagine the measured WBGT is 20 °C and a worker is wearing limited-use vapor-barrier coveralls. Table 4 indicates that a CAF of 11 should be added to the measured WBGT when this clothing is worn. The $WBGT_{eff}$ is then 31 °C because 20 °C + 11 °C = 31 °C. Again, we compare the TLV, AL or screening value with the $WBGT_{eff}$, which in this case is 31 °C.

### You Do the Math

Apply your knowledge to the following questions. Answers are on p. 35.

6. Imagine that the WBGT has been measured as 22 °C. Further imagine that a worker is dressed in polyolefin Tyvek coveralls. Answer the following:

a. What is the CAF from Table 4?

b. Based on the CAF, what is the $WBGT_{eff}$ in degrees Celsius (°C) for the worker dressed in polyolefin Tyvek coveralls?

7. Imagine that the WBGT has been measured as 28 °C. Further imagine that a worker is dressed in ordinary cotton coveralls (with only underwear beneath). Answer the following:

a. What is the CAF from Table 4?

b. Based on the CAF, what is the $WBGT_{eff}$ in degrees Celsius (°C) for the worker dressed in ordinary cotton coveralls?

### Concluding Comments

While it is a straightforward matter to calculate the WBGT from environmental measures (Ricketts, 2020), it is more challenging to establish safe levels of exposure to hot environments. Ideally, we monitor each worker's metabolic rate for representative work tasks and calculate appropriate ALs and TLVs for each situation. When this is not feasible, we consult tables of screening values that are more protective than the actual AL and TLV.

When screening criteria indicate that workers may be exposed to hazardous WBGTs, we conduct detailed investigations that may include a thorough analysis of work tasks, refinement of metabolic rate estimates, heat stress modeling and physiological monitoring for signs of heat stress such as accelerated heart rate, elevated core body temperature and profuse sweating.

If analyses indicate that workers may be exposed to WBGTs that exceed the AL (or if workers must wear clothing that limits heat loss), we implement a comprehensive program of heat stress management that includes engineering, administrative controls, PPE, monitoring and a quick response to any signs of excessive heat stress. In most cases, we strive to ensure time-weighted average exposures do not exceed the AL for unacclimatized workers or the TLV for workers who are fully acclimatized.

### How Much Have I Learned?

Try these problems on your own. Answers are on p. 35.

8. Imagine that a worker wears a conventional one-layer work ensemble and is properly acclimatized to the heat. In this case, the worker is painting houses. Further imagine that this worker's metabolic rate is measured as 245 W as a time-weighted average for this type of task. Answer the following:

a. Since the worker is acclimatized, what is the TLV in degrees Celsius (°C)? Metabolic rate was measured, so use the formula:

$$TLV = 56.7 - 11.5 \cdot \log_{10} M$$

and check your work using Figure 2 (p. 25).

b. What is the TLV when converted to degrees Fahrenheit (°F)?

9. Imagine that a worker wears a conventional one-layer work ensemble and is unacclimatized to the heat. In this case, the worker is manually loading and unloading delivery trucks with heavy packages. This worker's metabolic rate has been measured as 455 W as a time-weighted average for this type of activity. Answer the following:

a. Since the worker is unacclimatized, what is the AL in degrees Celsius (°C)? Metabolic rate was measured, so use the formula:

$$AL = 59.9 - 14.1 \cdot \log_{10} M$$

and check your work using Figure 2 (p. 25).

b. What is the AL when converted to degrees Fahrenheit (°F)?

10. Imagine that an unacclimatized worker is dressed in a conventional one-layer work ensemble. The worker is engaged in work for 12 minutes each hour, while resting in the shade for 48 minutes per hour (20% work). The work is characterized as intense heavy arm or trunk activity and walking at a fast pace. Answer the following:

a. If the worker weighs 70 kg, what is the work category and metabolic rate in watts from Table 1 (p. 26) for this work?

b. Based on your answer to 10a, what is the screening value from Table 3 (p. 27), given the 20% work rate for this unacclimatized worker?

c. Now assume that the worker weighs about 85 kg. What is the estimated metabolic rate ($M_{est}$) calculated with the formula:

$$M_{est} = M \cdot \frac{actual\ body\ weight(kg)}{70\ kg}\ ?$$

d. Based on the value of $M_{est}$ you calculated for 10c, what is the closest work category and metabolic rate in watts from Table 1 (p. 26) for this work?

e. Based on your answer to 10d, what is the screening value from Table 3 (p. 27), given the 20% work rate for this unacclimatized worker?

11. Imagine the WBGT has been measured as 29 °C. Further imagine a worker is dressed in SMS polypropylene coveralls. Answer the following:

a. What is the CAF from Table 4?

b. Based on the CAF, what is the $WBGT_{eff}$ (in °C) for the worker dressed in SMS polypropylene coveralls? Use the formula:

$$WBGT_{eff} = WBGT + CAF$$

## The Language of Heat Stress

You may encounter the following concepts in certification exams and conversations with engineers and healthcare professionals. Match the numbered concepts with their paraphrased definitions (lettered). All concepts have been defined in the text, formulas and illustrations. Answers are on p. 35.

**Concepts**

12. Acclimatized worker
13. Action limit (AL)
14. Black-globe temperature
15. Conventional one-layer work ensemble
16. Dry-bulb temperature
17. Heat stress management program
18. Metabolic rate
19. Natural wet-bulb temperature
20. Threshold limit value (TLV)
21. Unacclimatized worker
22. Wet-bulb globe temperature index (WBGT)

**Definitions (in random order)**

a. A comprehensive program of heat stress management that includes engineering, administrative controls, PPE, monitoring and a quick response to any signs of excessive heat stress.

b. A worker who has not experienced a steady increase in exposure to heat over several days and whose body has thus not become more efficient at maintaining a safe and stable core temperature.

c. A worker whose body has become more efficient at maintaining a safe and stable core temperature after a steady increase in exposure to heat over several days.

d. Air temperature measured with an ordinary thermometer.

e. An environmental measure that relates to the effectiveness of perspiration in removing heat from a worker's body given the ambient air speed, relative humidity and air temperature.

f. An environmental measure that relates to the impact of radiant heat sources such as the sun.

g. An index of potential heat stress that incorporates the natural wet-bulb temperature, black-globe temperature and (in some situations) dry-bulb temperature.

h. Standard that specifies the WBGT to which nearly all acclimatized workers can be repeatedly exposed without adverse health effects (assuming they are healthy, unmedicated and adequately hydrated).

i. Standard that specifies the WBGT to which nearly all unacclimatized workers can be repeatedly exposed without adverse health effects (assuming they are healthy, unmedicated and adequately hydrated). This standard is also recommended as a trigger for implementing a heat stress management program.

j. The total energy consumed within the body over time. It is important in this context because it generates heat within the body. It is often measured using calorimetry.

k. Work clothing consisting of a long-sleeved work shirt and trousers or the equivalent. **PSJ**

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### Providing Employees Access to Service & Support

The other big opportunity is making sure leaders know where and how to get help. As noted, sharing mental health resources was recognized by 94% of survey respondents as important. Yet, only 46% said they knew where to access care, according to the survey (American Psychiatric Association Foundation Center for Workplace Mental Health, 2021). So, here you have more than half of the managers in the dark, which is not helpful when you consider that managers are the ones we count on to guide employees toward help. What is the best way to address this issue?

Mental health training for managers was rated in the survey as the top way to reach people. Whereas only 25% of the respondents said their organizations offer supervisor training, 69% thought it would be useful to offer such training. Training for employees was also seen as useful: 66% agreed that it should be on offer. Yet, only 25% said their organization offered such training. Clearly there is an opportunity to offer more training to both supervisors and employees. Toolbox talks were also rated as helpful by 64% of the respondents. Fact sheets were rated as useful by 51%.

Employee assistance programs (EAPs) were rated as helpful by only 48% of the survey respondents. Some cited difficulties with calling a toll-free number. Others expressed doubt that the EAP is confidential, feeling that employers will learn employees are seeking help. I have seen some very effective EAPs, but we clearly need to improve the perception of EAPs and make them more credible. For example, let's make people aware of other useful services within an EAP, such as setting up a will, finding assisted-living services for parents, financial-planning assistance and other services.

Clients that have had me come and speak to them about mental health and listened as I opened up about my story have responded well when I've emphasized the need for paying more attention to mental health. I recently had a client tell me about a success that one of his managers had in the firm's Florida office when an employee came forward asking for some help. The trainings are working, we just need to have more of them.

Your local National Alliance for Mental Health offers a great class called QPR: Question, Persuade and Refer. It trains supervisors on how to recognize signs of suicidal thoughts and how to provide help. I have had many clients put all their supervisors in those training sessions.

Locally, we started a group called Wisconsin Construction Wellness Community (**https://wisconwel.com**). It is a group of contractors that came together to train each other on mental health, what resources are out there and how to get them into the industry. I hope to form a nonprofit group that will allow us to distribute resources that are not affiliated with one group so people can feel comfortable using them. I can put on a technical meeting for the industry for no cost or low cost. We also want to collaborate with local providers so that people know they can call a trusted person in an emergency. We recently had my fitness trainer, Kat Musni, come talk to our group. Her message was about how self-care can contribute to one's physical health and mental health.

By getting the message out through so many contractors, supervisors, vendors, relatives and training classes, we are trying to make a difference. The more normal we make the conversations, the more the stigma will lift, and the more people will get the assistance they need, whatever that may be. I hope one day that it is natural to talk about mental health. **PSJ**

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### Need Help or Know Someone Who Does?

**Contact the National Suicide Prevention Lifeline. Call 9-8-8. Use the online Lifeline Chat at https://988lifeline.org. Both are free and confidential.**

## Math Toolbox, continued from pp. 24-29

### Answers: The Case of the Heat-Stressed Tree Feller

#### You Do the Math

Your answers may vary slightly due to rounding.

1a. $TLV = 56.7 - 11.5 \cdot \log_{10}(421) = 26.52$ °C (rounded)

1b. °F = 26.52 · 1.8 + 32 = 79.74 °F (rounded)

2a. $TLV = 56.7 - 11.5 \cdot \log_{10}(138) = 32.09$ °C (rounded)

2b. °F = 32.09 · 1.8 + 32 = 89.76 °F (rounded)

3a. $AL = 59.9 - 14.1 \cdot \log_{10}(210) = 27.16$ °C (rounded)

3b. °F = 27.16 · 1.8 + 32 = 80.89 °F (rounded)

4a. $AL = 59.9 - 14.1 \cdot \log_{10}(361) = 23.84$ °C (rounded)

4b. °F = 23.84 · 1.8 + 32 = 74.91 °F (rounded)

5a. Moderate, 300 W

5b. 29.0 °C

5c. $M_{est} = 300 \cdot \frac{95}{70} = 407.14$ W (rounded)

5d. Heavy, 415 W

5e. 27.5 °C

6a. CAF = 1

6b. $WBGT_{eff} = 22 + 1 = 23$ °C

7a. CAF = 0

7b. $WBGT_{eff} = 28 + 0 = 28$ °C

#### How Much Have I Learned?

8a. $TLV = 56.7 - 11.5 \cdot \log_{10}(245) = 29.22$ °C (rounded)

8b. °F = 29.22 · 1.8 + 32 = 84.60 °F (rounded)

9a. $AL = 59.9 - 14.1 \cdot \log_{10}(455) = 22.42$ °C (rounded)

9b. °F = 22.42 · 1.8 + 32 = 72.36 °F (rounded)

10a. Heavy, 415 W

10b. 28.0 °C

10c. $M_{est} = 415 \cdot \frac{85}{70} = 503.93$ W (rounded)

10d. Very heavy, 520 W

10e. 27.0 °C

11a. CAF = 0.5

11b. $WBGT_{eff} = 29 + 0.5 = 29.5$ °C

#### The Language of Heat Stress

12. c; 13. i; 14. f; 15. k; 16. d; 17. a; 18. j; 19. e; 20. h; 21. b; 22. g.