Heat Stress

Understanding factors and measures helps SH&E professionals take a proactive management approach

By Stephanie Helgerman McKinnon and Regina L. Utley

HEAT STRAIN and the effects of heat stress are the subject of many news reports and even some national headlines (e.g., *Macon Telegraph, USA Today*). In 2002, Bureau of Labor Statistics (BLS) reported 40 fatalities resulting from exposure to environmental heat. Forty percent of those deaths occurred in the construction industry, 25 percent in agriculture forestry and mining, 10 percent in transportation and public utilities, and 7.5 percent in manufacturing. A BLS report with summary statistics shows double-digit fatalities from exposure to environmental heat in each year from 1992 to 2001: 1992 = 12; 1993 = 22; 1994 = 28; 1995 = 35; 1996 = 18; 1997 = 22; 1998 = 34; 1999 = 35; 2000 = 21; and 2001 = 24. Based on what is known about heat strain and illness as a result of heat stress, one can argue that all of these reported cases were preventable.

In 29 CFR 1910.132, Personal Protective Equipment (PPE), OSHA requires employers to assess workplace hazards that require use of PPE. If hazards are present, employers must select PPE that will protect employees. Paragraph (c) requires that the PPE be of safe design and construction for the work to be performed. Paragraph (f)(1)(iv) requires training to address the PPE's limitations. Certain types of PPE are offered as protection when heat stress is an identified hazard, while use of certain types of PPE may increase the potential for heat strain. Some PPE selected as a control may also present a limitation. For example, some early models of cooling vests were heavy and may have contributed to cardiovascular strain.

Several tools are available to help manage and prevent heat strain. The first part of this article focuses on the identification of readily available tools that are inexpensive, easy to understand and easy to use. The second part of the article identifies PPE available to help prevent heat strain; PPE that meets the requirements of 29 CFR 1910.132 Paragraph (c); and PPE that can complicate management of heat-related conditions [Paragraph (f) limitations].

Proactive Management

Three broad areas should be considered when establishing a proactive management program:

1) training and (early) recognition;
2) management of personal factors;
3) understanding and using evaluation tools (including measurement instruments).

Recognition & Training

Early recognition is key since heat-related disorders generally occur in progression. Early recognition of symptoms and intervention will prevent progression to a more medically serious phase. Understanding the body's physiological response to reduce the increased heat load is useful when discussing this progression. The primary cooling actions that occur include increased heart rate to move blood and heat to the skin, and increased sweating. These actions prevent a rise in the core body temperature. The hypothalamus works to keep core body temperature at 37ºC ±1. Normal body temperature taken rectally is 37.6ºC (99.6ºF) or 37ºC (98.6ºF) taken orally. Efforts to control heat-related conditions attempt to prevent a rise in core body temperature above 38ºC (100.4ºF)—or less than 1ºC. American Conference of Governmental Industrial Hygienists (ACGIH) recommends a peak of 38.5ºC (101.1ºF) to allow for a margin of safety [ACGIH(a)].

When providing training on heat-related disorders and heat-stress management, the philosophy is no different than it is for other safety training: The trainer should provide the information most useful to the audience. For example, workers should understand how to recognize signs and symptoms of heat-related disorders in themselves and as they occur in coworkers, and should be aware of preventive actions. If they will participate in personal monitoring, employees should know what to expect and how they can make sure accurate and useful results are collected. Those being trained as first-aid responders will also benefit from understanding the body's physiological response to heat in addition to the description of the different heat-related illnesses (sidebar pg. 42).

Management of Personal Factors

Many personal factors can improve one's ability to adjust to hot working

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Heat Disorders & Health Effects

Heat Fatigue. Lack of acclimatization is one factor that predisposes an individual to heat fatigue. Therefore, a program of acclimatization and training for work in hot environments is advisable. Signs and symptoms of heat fatigue include impaired performance of skilled sensorimotor, mental or vigilance jobs. The only treatment is to remove the heat stress before a more serious heat-related condition develops.

Heat Rashes. These are the most common problem in hot work environments. Prickly heat is manifested as red papules and usually appears in areas where the clothing is restrictive. As sweating increases, these papules give rise to a prickling sensation. Prickly heat occurs in skin that is persistently wetted by unevaporated sweat, and heat rash papules may become infected if they are not treated. In most cases, heat rashes will disappear when the affected individual returns to a cool environment.

Heat Collapse (fainting). In heat collapse, the brain does not receive enough oxygen because blood pools in the extremities. As a result, the exposed individual may lose consciousness. This reaction is similar to that of heat exhaustion and does not affect the body's heat balance. However, the onset of heat collapse is rapid and unpredictable. To prevent heat collapse, the worker should gradually become acclimatized to the hot environment.

Heat Cramps. These are usually caused by performing hard physical labor in a hot environment. The cramps have been attributed to an electrolyte imbalance caused by sweating. It is important to understand that cramps can be caused by both too much and too little salt. Cramps appear to be caused by the lack of water replenishment. Because sweat is a hypotonic solution (±0.3% NaCl), excess salt can build up in the body if the water lost through sweating is not replaced. Thirst cannot be relied on as a guide to the need for water; instead, water must be taken every 15 to 20 minutes in hot environments.

Under extreme conditions, such as working for six to eight hours in heavy protective gear, a loss of sodium may occur. Recent studies have shown that drinking commercially available carbohydrate-electrolyte replacement liquids is effective in minimizing physiological disturbances during recovery.

Heat Exhaustion. Signs and symptoms include headache, nausea, vertigo, weakness, thirst and giddiness. This condition responds readily to prompt treatment. Heat exhaustion should not be dismissed lightly, however, for several reasons. One is that the fainting associated with heat exhaustion can be dangerous because the victim may be operating machinery or controlling an operation that should not be left unattended; in addition, the victim may be injured when s/he faints. Signs and symptoms seen in heat exhaustion are similar to those of heat stroke, a medical emergency. Workers suffering from heat exhaustion should be removed from the hot environment and given fluid replacement. They should also be encouraged to get adequate rest.

Heat Stroke. This condition occurs when the body's system of temperature regulation fails and body temperature rises to critical levels. It is caused by a combination of highly variable factors and its occurrence is difficult to predict. Heat stroke is a medical emergency. Primary symptoms are confusion; irrational behavior; loss of consciousness; convulsions; lack of sweating; hot, dry skin; and an abnormally high body temperature (e.g., a rectal temperature of 41°C or 105.8°F). If body temperature is too high, it causes death. The elevated metabolic temperatures caused by a combination of work load and environmental heat load, both of which contribute to heat stroke, are also highly variable and difficult to predict.

Source: OSHA Technical Manual, Chapter 4.

environments. These include personal fitness, diet and level of hydration. These same factors, as well as age and use of certain medications, can also decrease one's ability to adjust to hot working environments.

Age is one personal factor beyond an employee's control. As people age, they have less reserve and compensate less effectively (Multcher; DiNardi). The sweat glands respond more slowly, which translates to more heat storage; this results in an increase in core temperature and longer recovery time. The thirst mechanism takes longer to activate as well, which contributes to dehydration. In addition, the total body water content decreases with age. The literature does report that older healthy workers will be fine if they can pace themselves accordingly (Multcher; DiNardi).

Good personal fitness can improve the body's response to heat stress (Multcher; DiNardi). The heart rate and core temperature remain lower. The cardiovascular system's capacity is increased and decreased strain is placed on the circulatory system. Obesity or percent of body fat is often associated with poor physical condition. An obese individual expends more energy to conduct tasks. As a result, body temperature may rise more quickly than in a "fit" individual. In addition, the body surface to body weight ratio is less favorable for heat dissipation (Multcher; DiNardi).

An adequate level of hydration helps keep body temperature in the safe range and improves cardiovascular response. Inadequate hydration increases the risk of heat-related illness. Dehydration reduces the body's ability to cool by sweating as it may not be able to produce enough sweat. This can result merely from an inadequate fluid intake (Multcher; DiNardi).

Other personal factors that may negatively affect the body's ability to respond to heat stress include:

- previous heat illness;
- heart disease, high blood pressure or diabetes;
- skin disease, sunburn or skin rash;
- liver, kidney or lung problems;
- pregnancy;
- fatigue;
- acclimatization;
- diarrhea or vomiting;
- infections, fever, recent illness or injury;
- recent inoculation or immunization;
- taking medications that limit sweating (e.g., sleeping pills);
- beta-blocker medications (used for heart rate control);
- vasoactive medications (control blood vessel size), which influence heat loss and blood supply;
- low-salt diets.

As noted, other work conditions such as use of PPE can make it difficult to manage heat stress as well. However, good physical condition and good health ("controllable" personal factors) can minimize the difficulties that may arise as a result of using PPE in a hot work environment. This topic is covered in greater detail beginning on pg. 44.

Table 1

NWS Heat Index Chart

Descriptive Zone	Heat Index	Possible Heat Disorders for People in Higher Risk Groups
Extreme danger	130ºF or higher	Heat stroke/sun stroke **highly likely** with continued exposure.
Danger	105ºF to 130ºF	Sun stroke, heat cramps or heat exhaustion **likely**, and heat stroke **possible** with prolonged exposure and/or physical activity.
Extreme caution	90ºF to 105ºF	Sun stroke, heat cramps and heat exhaustion **possible** with prolonged exposure and/or physical activity.
Caution	80ºF to 90ºF	Fatigue possible with prolonged exposure and/or physical activity.

Understanding & Using Evaluation Tools

As noted, several easy-to-use tools are available to help an SH&E professional manage heat stress. Several are reviewed in the following discussion (presented by the measurement being collected). In addition, a checklist may prove useful when evaluating the hot environment [ACGIH(b); DiNardi].

Core Temperature Measurement

Rectal temperature measurement is considered by many to be the most reliable measure in most situations, but few workers are likely willing to submit to this while at work. Viable alternatives include measurements that are considered direct measures of core temperature—tympanic and esophageal—and indirect measures—oral, ear canal, axillary and tympanic (by infrared).

The challenge for practitioners is to select a measurement strategy that can be used in the work environment and will provide meaningful data. Oral temperature may be lower than core and may be influenced by the environment or by the fact that a worker breathes through the mouth (U.S. Dept. of Defense). Rectal temperature may be slightly higher than core (U.S. Dept. of Defense). Tympanic and ear canal measurements can be influenced by the external environment, and head, face and skin temperatures. Technique used to measure temperature can also influence the readings (McKenzie).

As a result, it is not easy to recommend a single best temperature measurement. Thus, it may be best to take more than one reading; use the measurement in combination with other tools; and have an experienced practitioner collect the measurements.

One other fact may influence the decision to use body temperature measurements: Body temperature naturally varies throughout the day without outside influence. For example, it may be lower upon first waking up. This information must be considered when determining a measurement strategy.

Heart Rate Measurement

Some data support the use of heart rate as a reliable indicator of response to heat stress, while other data supports the opposite conclusion. Therefore, one should not rely solely on this measure. ACGIH threshold limit values (TLVs) support monitoring recovery heart rate after one minute of rest. A measurement of 110 bpm or less is considered acceptable. ACGIH also recommends that a sustained peak heart rate (e.g., that maintained over a five-minute period) not exceed 180 bpm less the age of the worker in years. Furthermore, if possible, ACGIH recommends that one measure an average heart rate for the day (an eight-hour work shift); the result should not be greater than 115 bpm (essentially a time-weighted average) [ACGIH(a);(b)].

Sweat Loss Measurement

Workers can sweat as much one liter (quart) in an hour. In an eight-hour shift, that can add up to as much as eight liters (quarts). This can equate to 1.5 to 3.0 percent of body weight. Recording body weight measurements at the beginning and end of a shift as a minimum provides an estimate of sweat loss. A midday measurement or additional measurements during the shift will help one monitor the situation more closely.

As noted, fluid replacement is essential. Satisfying normal thirst is not enough to remain hydrated. Recommendations range from drinking one pint (two cups) of water for every pound of weight lost (e.g., American Orthopaedic Society for Sports Medicine) to providing enough to drink during the shift to replace 80 percent of weight lost through sweat [e.g., for a loss of 1 kg (2.2 pounds), the worker should drink 800 mL of fluid]. Although 100-percent replacement is often considered impossible, workers should continue to hydrate away from work and return each day completely hydrated or rehydrated.

Electrolyte (salt) loss and replacement is another critical part of this equation. However, it is difficult to find an applicable evaluation tool that works as easily or is as readily available as a thermometer, heart rate measurement or scale. As part of an overall management plan, a workable guideline is that electrolyte replacement fluids can contain 40 to 80g/L of sugar and 0.5 to 0.7 g/L of sodium.

Outside Air Temperature & Relative Humidity

OSHA's "The Heat Equation" provides a simple tool based on air temperature and relative humidity measurements. The pamphlet depicts a tricolor thermometer. A combination of temperature and humidity readings in the yellow area of the graphic is described as less hazardous; the pink zone is the caution area; and the red zone is the danger zone. This tool can be applied to nondemanding tasks or work environments that do not require protective clothing which would add to the heat load. Air temperature ranges from 26.7ºC (80ºF) to 37.8ºC (110ºF) and the relative humidity from 30 to 70 percent [OSHA(a)].

NWS Heat Index Program

National Weather Service (NWS) has developed a heat index that provides a heat index chart which uses air temperature (dry bulb) and relative humidity (similar to OSHA) (NWS). The chart provides four descriptive zones: caution, extreme caution, danger and extreme danger. Air temperature ranges from 26.7ºC (80ºF) to 37.8ºC (110ºF) and the relative humidity from 40 to 100 percent. A value referred to as the "heat index" is taken from this chart and applied (Table 1).

NWS also issues advisories or warnings to the general public when the heat index is expected to have a significant impact on public safety. These statements describe the extent of the hazard, advise who is most at risk and offer guidelines to reduce risk (NWS). At the least, if one of these warnings is issued, it is best to consider monitoring workers.

A note of caution about using the OSHA method or NWS scale is necessary. Both scales begin at an outside air temperature of 80ºF. Heat-related illnesses can occur below this temperature. The addition of complicating factors such as high humidity or PPE, for example, can contribute to the problems as well. Therefore, in such cases, using tools such as wet-bulb globe temperature (WBGT) should be considered.

WBGT

ACGIH includes an evaluation method based in part on WBGT in its annual TLVs [ACGIH(b)]. Although this method is more detailed and complex than those already reviewed, with some understanding of what is involved, one can use it without being an expert.

The ACGIH method incorporates how clothing affects the hot environment, key for work that requires some type of work uniform or protective equipment. It also addresses the level of physical activity involved in performing a task and how that should be accounted for. Finally, it considers worker acclimatization to the hot environment [ACGIH(a); (b)].

WBGT actually combines three readings: natural wet-bulb, globe temperature and dry-bulb temperature. All three measurements are not readily available, although a monitoring instrument is available that can collect all three temperatures. The logic programmed into the instrument properly combines the measurements and calculates WBGT. ACGIH uses this result to recommend work-rest regimens as a means of controlling heat exposure. Use of WBGT has also been recommended by NIOSH and OSHA [NIOSH; OSHA(a); (b); (c)].

As noted, this approach also considers work demands and worker acclimatization. Acclimatization (physiological adaptation) is another important control. Although it is not a parameter that is measured, review of ACGIH's WBGT screening table reveals the benefit of using acclimatization as a part of a proactive management strategy. According to ACGIH, full acclimatization takes up to three weeks under conditions similar to those anticipated for the work. ACGIH cautions that a noticeable loss of acclimatization can occur after just four days when "activity under those heat-stress conditions is discontinued" [ACGIH(b)].

Applying the Knowledge

How does an occupational SH&E practitioner decide which tools to use and when? Since the goal is to be proactive, the tools for monitoring environmental conditions identify levels of risk and recommend actions. For example, using OSHA's Heat Equation or NWS's Heat Index, one would record air temperature and relative humidity at the start of the shift and periodically throughout the day. This helps identify risk as work begins and indicates whether that risk increases throughout the day. As a next step (toward a more comprehensive approach), one should include some physiological measurements. For example, the use of heart rate, specifically recovery rates and comparing results day to day, will indicate whether workers are acclimatizing and whether workload can be safely increased.

When using other physiological measurements, one must recognize the limitations and devise a strategy to minimize their impact. Therefore, for any one measurement, collecting multiple readings at multiple time points might be considered.

Impact of Protective Clothing

Two considerations are key in the use of protective clothing: 1) PPE selected as a control or preventive measure for heat stress and 2) PPE that may complicate heat stress management.

PPE as a Control

Some PPE is for specialized applications and others are a more general control. The focus here is on PPE offered as a general control to manage and prevent heat stress; the article does not address specialized applications nor does it cover fabrics that offer sun protection.

When selecting PPE, one should refer to the physiological response that occurs to prevent a rise in the core body temperature. As noted, the hypothalamus works to keep core body temperature at 37ºC ±1. The body relies on radiation (heat transfer via waves) and evaporation (heat is dissipated as liquid changes to vapor) for heat loss in hot environments. As long as the air temperature remains below body temperature, approximately 65 percent of the body's heat loss occurs by radiation.

If air temperature exceeds 95ºF, radiation of heat basically stops and the body is almost totally reliant on evaporation for heat loss. Evaporation accounts for approximately 30 percent of the body's heat loss. When humidity climbs to 100 percent, evaporation is no longer possible. One must also realize that the body loses much of its heat through the head. Wearing a hat when it is cold slows this loss. Conversely, if the skin is hot, shading the head will facilitate heat loss as cooler skin will help the body's natural cooling mechanisms.

Selection of Cooling PPE

PPE to manage and prevent heat stress works primarily by promoting cooling. The sidebar at right highlights various types of cooling PPE. When selecting gear, several factors must be considered.

One factor is the physiological response (heat dissipation to prevent the rise of core body temperature). Worker acceptance and comfort is another key issue. If a worker does not accept the PPE, it will likely go unused or be used improperly. To encourage worker acceptance, one might, for example, allow the worker to select the fabric print on a bandana or hat.

Technical performance of PPE must be considered as well. For example, suppose the manufacturer's literature for a bandana states that it will stay cool for up to 72 hours. The conditions that produced this reported result may not represent the specifics of the work situation or environment in which it will be used. Therefore, it may not be possible to predict how long the cooling effect will last without trying it.

One must also assess whether the selected PPE will interfere with the work to be performed. Will it create any limitations? For example, early cooling vests featured heavy ice packs, which created more physiological strain on workers.

PPE Limitations

As noted, in addition to environmental and personal factors, the impact of protec-

Types of Cooling PPE

PPE to manage and prevent heat stress works primarily by promoting cooling. Several types of cooling PPE were identified from various manufacturer and supplier literature. (Descriptions are largely from manufacturer literature.)

Head & Neck

Sweat Bands

Sweat bands absorb perspiration and facilitate evaporation. In addition, by drawing moisture away from the skin, they may help prevent heat rash or prickly heat, which can result from the skin remaining sweaty for long periods. Sweat bands may be worn around the forehead or inserted into/under hardhats. Some styles are designed to be prewetted before donning to promote cooling. They are available in reusable and disposable styles.

Bandanas/Neck Bands

Bandanas can be worn around the head or neck, or against other parts of the body. Some bandanas have a crystal material that absorbs and holds cool water before donning. Unlike sweat bands, they are not necessarily designed to absorb perspiration.

Hats/Skull Caps

Hats are also available with cooling crystals, usually as an insert. Styles include bucket hats, garden hats, baseball hats, visors, triangle and tie hats, and ranger hats. Styles without cooling crystals are still useful, as they provide shade, which keeps the head cool, and maintain the temperature difference, which promotes heat dissipation.

Hardhat Liners & Shades

Hardhat liners are available in various styles. Some liners are made of an absorbent material like cotton terry, which absorbs perspiration. Other liners use the same cooling crystals found in bandanas and hats. Liners may completely line the hardhat or attach to the harness suspension. Shades, available with or without cooling crystals, are designed primarily to block sun on the back of the neck and facilitate evaporation of perspiration.

Torso

Vests

Vests are currently available in three technologies. One system uses a frozen gel or ice pack inserted into vest pockets (early versions actually froze the entire vest). A second type has a circulation system that pumps air or cool water throughout the vest. The third is a phase-change cooling system, which uses a pretreated pack that is frozen or soaked in water prior to inserting into the vest. The pack contains a liquid that changes to a semi-solid when treated; as heat is absorbed from the body, the material changes back to a liquid. The amount of time that each system provides cooling varies.

Hydration Backpacks

Hydration backpacks provide a source of fluids to help prevent dehydration. Although the primary purpose is not to cool like the vest, the liquid in the reservoir provides some cooling (until the liquid is gone).

Special Fabric Clothing

Many special fabrics are available to assist in cooling. They feature breathability and enhance moisture transport away from the skin. These fabrics have been used to make such items as T-shirts, shirts, undergarments and hats.

Wrist Bands

Wrist bands are also available with the same cooling crystals technology found in bandanas, hats and liners. This design puts the cooling mechanism next to the pulse point, which reportedly helps transport the cooling sensation.

Preventing Heat Stress

Most heat-related health problems can be prevented or the risk of developing them reduced. Following are some basic precautions that can be taken.

Engineering Controls. These include general ventilation and spot cooling by local exhaust ventilation at points of high heat production. Shielding is required as protection from radiant heat sources. Evaporative cooling and mechanical refrigeration are other ways to reduce heat. Cooling fans can also reduce heat in hot conditions. Eliminating steam leaks will help as well. Equipment modifications, use of power tools to reduce manual labor, and personal cooling devices or protective clothing are other ways to reduce the hazards of heat exposure for workers.

Work Practices. One excellent example is to provide plenty of drinking water—as much as one quart per worker per hour—at the workplace. It is also essential to train first-aid workers to recognize and treat heat-stress disorders and to make the names of trained staff known to all workers. Employers should also consider an individual worker's physical condition when determining his/her fitness for working in hot environments. Older workers, obese workers and personnel on some types of medication are at greater risk.

Alternating work and rest periods with longer rest periods in a cool area can help workers avoid heat stress. If possible, heavy work should be scheduled during the cooler parts of the day and appropriate protective clothing provided. Supervisors should be trained to detect early signs of heat stress and should permit workers to interrupt their work if they are extremely uncomfortable.

Acclimatization. Short exposures to work in the hot environment followed by longer periods can reduce heat stress. New employees and workers returning from an absence of two weeks or more should have a five-day period of acclimatization that should begin with 50 percent of the normal workload/time exposure the first day, gradually building to 100 percent on the fifth day.

Employee Education. This component is vital. Workers must be aware of the need to replace fluids and salt lost through sweat and can recognize dehydration, exhaustion, fainting, heat cramps, salt deficiency, heat exhaustion and heat stroke as heat disorders. Workers should also be informed of the importance of daily weighing before and after work to avoid dehydration.

Source: OSHA Factsheet No. 95-16.

tive clothing on the heat stress equation must be considered. OSHA's HazWOPER Standard (29CFR 1910.120), addresses this in Paragraph (g)(5)(x): "Limitations during temperature extremes, heat stress and other appropriate medical considerations." This consideration is reiterated in Appendixes B and C. (Keep in mind that the HazWOPER Standard does not apply to all industrial settings.)

The following relationships describe how protective clothing may influence work environments:

- As insulating value of clothing increases, potential heat loss decreases.
- As permeability of clothing decreases, sweat evaporation decreases.
- As clothing weight increases, metabolic rate and, therefore, heat production increases.
- As clothing stiffness increases, the metabolic cost of movement increases.
- As clothing thickness increases so does the potential for heat stress.

In Chapter 4 of its T*echnical Manual*, OSHA uses the WBGT index to sample and evaluate hot work environments [OSHA(b)]. In its TLV documentation, ACGIH modifies the result of the WBGT value before entering it in the table, depending on the type of clothing worn by the worker [ACGIH(a)]. An unadjusted WBGT value assumes that the worker is wearing lightweight summer work clothing, defined in the documentation as long-sleeve shirt and pants. The TLVs provide adjustments to the WBGT value for cloth (woven) coveralls and double-cloth coveralls. ACGIH cautions that these values cannot be used for encapsulating suits or clothing that is impermeable or highly resistant to water vapor or air movement through fabric [ACGIH(a)].

The TLVs offer two clothing adjustment values (in addition to the summer work uniform on which WBGT is based). Additional studies have been performed to document other clothing adjustment values to WBGT. For example, Chapter 24 of *The Occupational Environment* lists adjustments for 11 work ensembles (two are cotton coveralls from different sources) (DiNardi Table 24.3). O'Connor and Bernard suggest WBGT adjustment factors for several clothing ensembles (119-125). This additional published information has been peer-reviewed but not to the extent required for inclusion in the TLVs.

To better understand the impact of the clothing adjustment values, consider the following scenario. On a given day, monitoring with the WBGT monitor yields a value of 28.5. For an acclimatized worker performing moderate work in the standard summer lightweight work clothing, the work/rest ratio would be 75 percent work and 25 percent rest. If this same worker wore cloth coveralls with a WBGT addition of +3.5, resulting in a new WBGT value of 32, the work/rest ratio would be 25 percent work and 75 percent rest.

It is difficult to quantify the effects of increased temperature on work performed. DiNardi summarizes one study which suggests that an increase in WBGT from 17º to 27ºC reduces work load capacity by 20 percent for a lifting work task, 16 percent for a pushing work task and 11 percent for a carrying work task (DiNardi). This is a start, but it barely scratches the surface. This is such a multifaceted problem that accurate quantification is a challenge.

Two clothing factors have been reported to affect the maximum rate of evaporative cooling: fabric characteristics, and clothing construction and configuration (Boeniger). An important fabric characteristic is the ability to allow air, which carries water vapor, to move through fabric, thus influencing evaporative cooling. The second factor, clothing construction, impacts air flow (referred to as garment ventilation). The more loose-fitting the clothing, the more air can move through openings in the fabric and around the employee, which improves the rate of evaporation. Boeniger also notes that layers of protective clothing cause evaporative resistance which reduces evaporative cooling. He further suggests covering only what is essential for protection. Uncovered areas will not experience a reduction of evaporative cooling, at least not due to clothing.

Protective clothing that is impermeable or highly resistant to vapor or air movement is designed to provide specific protection. Such gear can severely limit evaporative cooling and air movement across the skin surface. Essentially, it creates a microenvironment under the clothing. In very hot environments, this affect can be a ceasing of sweat evaporation—that is, the microenvironment inside the protective clothing nears 100 percent relative humidity. (As noted, evaporation can account for up to 30 percent of body heat loss.) In addition, since air movement is limited or nonexistent, convective cooling is also prevented.

The table of WBGT additions (DiNardi) suggests an adjustment of +10.6ºC for a vapor barrier suit. The impact of this adjustment on the work/rest regimen is readily apparent. Other recommendations in the same table include +5 for a completely enclosed suit; +6 for a permeable water barrier; and +10 for a full-body suit. When military personnel wear full chemical gear to perform light to moderate work, they use an adjustment of +10ºF; for moderate to heavy work, they make an adjustment of +18ºF.

How does this affect the work/rest regimen? A WBGT value of 29.5 or less permits the acclimatized worker to perform light work 100 percent of the time. Moderate work requires a WBGT value of 27.5 and heavy work a value of 26. Adding 10.6 to the light-work WBGT value results in an adjusted WBGT of 40.1, a value not even included on the TLV table. TLVs are considered to be conservative. Since waiting for cooler weather to perform the work is rarely an option, this example highlights the need to address and attempt to influence the other factors that impact heat stress.

Conclusion

A proactive strategy for managing heat-related illnesses encompasses many factors—from training workers and response personnel to understand early signs and symptoms to the use of various controls to recognizing the role of PPE, both as a cooling control and as a contributor to heat-related conditions. By understanding the various measurement tools available and their application, SH&E professionals can reduce the risk of heat-related illnesses and protect the safety and health of workers in environments where heat is a concern. ■

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