**CHAPTER 12 – THERMAL STRESS**

**Introduction**

Thermal stress is a significant physical agent in many workplace environments.

Just considering routine out-of-doors work, air temperatures ranging from -20°F to 110°F can reasonably be expected in many places throughout the U.S.

**Degrees of Thermal Stress**

Conceptually, work can occur in one of five zones along the continuum of thermal stress.

In the middle is the *comfort zone*, where the demands for physiological adaptation are modest and productivity should be the greatest.

On either side of the comfort zone are the *discomfort zones* for heat and cold stress.

Under these conditions, most people should be able to safety work without experiencing a disorder related to the stress.

Note: They will report sensations of cold or heat, productivity and quality of work may decrease, and the risk of accidents may increase.

The *health risk zones* for heat and cold stress are the outer zones of the thermal stress continuum.

The physiological adaptations have reached their limits and work capacity is severely limited.

In the health risk zone, the likelihood of heat and cold stress-related disorders increases markedly.

The goal of most evaluation schemes for occupational heat and cold stress is to limit exposures at the transition to the health risk zone.

Note: Of course, there are no firm boundaries to these zones because the boundaries depend on the environment (e.g., wind, altitude), individuals (e.g., body fat content, physical health), and season as well as many unknown variables (e.g., acclimation).

Example: In the fall, when the temperature drops to around 50°F, students start to bundle up.

In the spring, when the temperature climbs to around 50°F, students start running around in shorts and T-shirts.

**Thermal Balance**

**Model of Thermal Balance**

Three factors influence the degree of thermal stress:

- climatic factors (most obvious);

- work demands; and

- clothing.

The tradition has been to describe thermal balance by an equation with major avenues of heat exchange between the body and the environment represented by terms in an equation.

*S = (M – W) + R + C + K + (Cresp – Eresp) – E*

where: *S* = heat storage rate (gain [+] or loss [-])

 *M* = metabolic rate (internal heat generation)

 *W* = external work rate (energy delivered to environment)

 *R* = radiant heat exchange rate (gain [+] or loss [-])

 *C* = convective heat exchange rate (gain [+] or loss [-])

 *K* = conductive heat exchange rate (gain [+] or loss [-])

 *Cresp* = rate of convective exchange by respiration (gain [+] or loss [-])

 *Eresp* = rate of evaporative heat loss by respiration

 *E* = rate of evaporative heat loss

Note: Heat exchange represented by *R*, *C*, *K*, and *Cresp* can be in either direction.

- A positive value for any of these terms means that heat is gained by the body.

 - A negative value means that heat is lost from the body.

Note: The values for *M* and *(M – W)* are only positive and represent a heat gain.

Note: The values for *W*, *Eresp*, and *E* are negative and always represent a heat loss.

** *S* – Heat Storage Rate**

If the value for *S* is zero, the body is in thermal equilibrium, and the heat gain is balanced by heat loss from the body.

- If *S* is positive, the body is gaining heat at the rate indicated by the value of *S*.

- If *S* is negative, the body is losing heat at the rate indicated by the value of *S*.

** *M* – Metabolic Rate**

Chemical reactions occur continuously inside the body.

These serve to sustain life (basal metabolism) and meet the demands of work (muscle metabolism).

Because the conversion from chemical energy to kinetic energy is inefficient, increased metabolism results in increased rates of heat gain to the person.

** *W* – External Work Rate**

*W* is the amount of energy that is successfully converted from internal chemical energy to mechanical work on external objects.

This route of energy transfer is called external work and it does not contribute to body heat.

** *R* – Radiant Heat Exchange Rate (Radiation)**

Solid bodies of different temperatures have a net heat flow from the hotter surface to the cooler surface by electromagnetic radiation (primarily infrared radiation.

The rate of heat transfer by radiation depends on the average temperature of the surrounding solid surfaces, skin temperature, and clothing.

** *C* – Convective Heat Exchange Rate (Convection)**

The exchange of heat between the skin and the surrounding air is referred to as convection.

The direction of heat flow depends on the temperature difference between the skin and air.

- If air temperature > skin temperature, *C* is positive and heat flows from the air to the skin.

- If the air is < skin temperature, *C* is negative and heat flows from the body.

** *K* – Conductive Heat Exchange Rate**

When two solid bodies are in contact, heat will flow from the warmer body to the cooler body.

The rate of heat transfer depends on the difference in temperatures between the skin and the solid surface.

In addition, the thermal conductivity of the solid body that the person contacts and clothing (insulation) that may separate the person from the solid surface play a role.

** *Cresp*– Rate of Convective Heat Exchange by Respiration**

Air is moved in and out of the lungs, which have a large surface area.

This means that there is an opportunity to gain or lose heat.

The rate of heat exchange depends on the air temperature and the volume of air moved in and out of the lungs.

** *Eresp* – Rate of Evaporative Heat Loss by Respiration**

The large surface area of the lungs provides ample opportunity to lose heat by evaporation.

The rate of heat exchange depends on the humidity of the inhaled air and the volume of air moved in and out of the lungs.

** *E* – Rate of Evaporative Heat Loss**

Sweat on the skin surface will absorb heat from the skin when evaporating into the air.

The rate of evaporative heat loss depends on the amount of sweating, air movement, ambient humidity, and clothing.

Note: Because *W*, *K*, *Cresp*, and *Eresp* are small relative to the other routes of heat exchange in industrial applications, they are usually ignored.

Thus, the original formula may be re-written as a general statement of heat balance:

*S = M + R + C – E*

Note: Excessive heating or cooling of a small portion of the skin can occur when it comes in contact with a hot or cold surface.

The contact can be either intentional or incidental.

Injury occurs when there is sufficient heat gain to cause a burn, or sufficient heat loss to cause the tissue to freeze (or at least become very cold).

In these cases, the *local storage rate* (*S*local) becomes important:

*S*local = *K* + *D*

where: *K* = conductive heat transfer between the skin

 and an object

 *D* = rate of heat transfer to or from the local areas

 by conduction

**Factors that Affect Thermal Balance**

Three factors play an important role: climatic conditions, work demands, and clothing.

** climatic conditions**

Climatic conditions are widely used to describe the degree of stress (e.g., comments regarding air temperature, relative humidity, wind chill).

** work demands (metabolic rate)**

The role of metabolic rate in heat balance is very important because it is a substantial contributor to heat gain.

In heat stress, metabolic rate can add 10 to 100 times more heat to the body than radiation and convection combined.

In cold stress, metabolic rate affects heat balance on the same order as radiation and convection losses.

** clothing**

Clothing has three characteristics: insulation, permeability, and ventilation.

- insulation

A measure of the resistance to heat flow by radiation, convection, and conduction.

- permeability

A measure of the resistance to water vapor movement through the clothing by diffusion.

It influences the amount of evaporative cooling that can be achieved.

Some clothing fabrics designed as a contamination barrier can reduce the magnitude of permeability.

- ventilation

A measure of the resistance (or lack thereof) to air movement through the clothing.

Depending on the nature of the fabric, garment construction, and work demands, ambient air can move through the fabric or around garment openings.

Clothing that support the movement of air can enhance evaporative and convective cooling.

*.***Heat Stress**

*Heat stress* is a combination that tends to increase body temperature, heart rate, and sweating.

These physiological adaptations are collectively known as *heat strain*.

** core body temperature**

The heat generated by muscular work heats the deep body tissues.

There is a tendency for core temperature to increase.

Blood circulating through the core picks up heat energy, and is then directed to the skin where the blood is cooled.

The cooler blood returns to the core to pick up more heat energy.

The skin is the site of heat exchange with the environment.

Convection and radiation depend on temperature differences between the skin and the environment.

In addition, the skin secretes sweat on to the surface.

As the water evaporates, it removes more heat energy from the skin, cooling the skin surface.

** heart rate**

Heart rate is an important factor in assessing heat strain because it reflects the demands on the cardiovascular system to move blood (and heat) from the core to the skin.

The total blood flow through the heart is proportional to the metabolic rate and inversely proportional to the temperature difference between the core and the skin.

Sometimes, skin temperatures increases because evaporative cooling is limited or the net heat gain from R + C is high.

As the skin temperature increases toward core temperature, more blood must be delivered to the skin to achieve the same rate of cooling.

** sweat rate**

Sweat rate (and total sweat volume) is another physiological parameter in the measure of physiological strain.

The greater the level of heat stress, the greater is the sweat loss.

Under ideal conditions, the body balances heat gains with losses so that the storage rate (*S*) is zero.

This is accomplished by increasing the sweating rate until evaporative cooling is sufficient to remove the heat generated by metabolism plus any heat gained from (or lost to) the environment through *R* + *C*.

The required evaporative cooling is denoted as *Ereq*.

The earlier equation: *S = M + R + C – E* becomes *Ereq = M + R + C*

Note: *Ereq* marks the degree of physiological adjustment required to establish a thermal equilibrium between the body and the environment so that the body does not store heat.

Note: The body has a natural ability to increase the tolerance to heat stress exposures through a process called *acclimation (acclimatization)*.

As people become acclimated, they are able to sweat more and, therefore, increase their cooling capability.

Further, people behave in adaptive working (pacing) to avoid extreme heat buildup in the core temperatures.

**Recognition of Heat Stress**

Heat stress in the workplace can be recognized in terms of workplace risk factors and in terms of the effects it has on workers.

The workplace risk factors are:

- hot or humid environments;

- high work demands; and

- protective clothing requirements.

Note: The added weight of PPE may increase the metabolic heat load and, therefore, the level of heat stress.

The responses of workers are a good tool for the recognition of heat stress in the workplace.

At the extreme end is a pattern of heat-related disorders.

Intermediate markers are physiological adjustments (e.g., notable sweating) and worker behaviors.

** heat-related disorders**

Heat-related disorders are manifestations of over-exposure to heat stress (see Table 12-A in text, p. 339).

This table provides:

- signs a trained observer may see

- symptoms the person may report

- likely causes of the disorder

- first aid, and

- steps for prevention.

***heat stroke***

The most serious heat-related disorder.

It must be immediately recognized and treated to minimize permanent damage.

The risk of death is high in heat stroke.

It is important to have an emergency response plan for heat stroke.

***heat exhaustion***

The most commonly seen heat-related disorder when treatment is ought.

Dehydration is a precursor to heat exhaustion, but is it is usually not noticed or reported by workers.

Note: As part of the recognition process, the health and safety professional examines reports to a medical or first aid facility.

Because no specific heat-related disorders are listed does not mean heat stress is not present.

It is worthwhile to examine the records for reports of faintness, weakness, nausea, cramps, headaches, and skin rashes.

There may also be an increase in the number of accidental injuries that are related to heat stress conditions.

** physiological markers**

The most readily accessible are oral temperature, heart rate, and water loss.

Based on these readings, the health and safety professional can begin to see if a more detailed evaluation is necessary.

When selecting workers to sample, it is important not to be biased toward those that appear to be the most tolerant.

The sampling process should be random or favoring those who appear to be having more problems.

- measuring temperature

If using oral temperatures, it is important that the individual not have anything to eat or drink for 15 minutes prior to taking the temperature and that the person keep their mouth closed during the measurement process.

Core temperature is estimated by adding 0.5°C or 1°F to the oral temperature reading.

\* If core temperature is above 100.4°F, then heat stress is high enough to warrant evaluation.

- measuring heart rate

Among heart rate methods, recovery heart rate is the most useful as a tool for recognition.

Recovery heart rate methods require that the person stop in at the end of a work cycle, sit down, and determine the pulse rate at a given point in recovery.

One method proposes that the heart rate at 1 minute after sitting down be at or below 110 beats per minute (*bpm*).

Another method recommends that the hear rate at three minutes resting be below 90 *bpm*.

\* If the average heart rate over a day is greater than 110 *bpm*, the work and heat stress may be excessive.

\* If peak heart rates are above a nominal threshold of 160 *bpm*, then the demands of the work should be evaluated.

- measuring water loss

Monitoring dehydration is accomplished by noting the change in body weight form the beginning to the end of a shift.

\* If there is more than 1.5 percent loss of body weight (1.5 *lbs* for every 100 *lbs* body weight), then excessive dehydration is likely and an evaluation is appropriate.

**Worker Behaviors**

Heat stress not only induces physiological changes, but also affects behavior.

Likely behaviors associated with heat stress are:

 actions that reduce exposures

- adjusting clothing to increase evaporative losses

- slowing the work rate

- taking small breaks

- taking short-cuts in work methods

 changes in attitudes

- irritability

- low morale

- absenteeism

 unsafe acts

- increased number of errors

- increased number of machine breakdowns

- taking short-cuts in work methods

**Summary of Recognition**

Basically, there are four questions you may ask to determine whether the work conditions should be evaluated for heat stress.

1. Is the environment recognized for being hot, are the work demands high, or is protective clothing required?

2. Are worker behaviors indicative of attempts to reduce heat stress, is morale low or absenteeism high, or are people making mistakes and getting hurt?

3. Do the medical records show a pattern of fatigue, weakness, headache, rashes, or high body temperature?

4. Are body temperatures, heart rates, or sweat losses high on a sample of workers?

If the answer to any of theses question is “yes”, an evaluation is probably in order.

**Evaluation of Heat Stress**

In 1969, the World Health Organization (WHO) set the tone for worker protection against heat stress.

- core temperatures should not exceed 100.4°*F* during prolonged daily exposures to heat stress.

- core temperatures up to 102.2°*F* is acceptable for short periods followed by an adequate recovery period.

- the average heart rate over a day should not exceed 110 *bpm*.

Prolonged daily exposures to heat stress are evaluated assuming that the work conditions are prevalent for a full eight hours with nominal breaks.

Often, the heat stress exposure may be episodic.

In this case, heat stress is evaluated in terms of safe exposure times for a given level of heat stress.

The safe exposure times are prescribed through work-rest cycles based on prolonged daily exposure criteria or through heat-balance analyses.

The prolonged daily exposure goal set forth by WHO is the foundation of evaluation schemes proposed by NIOSH and the basis for heat stress assessment described by ACGIH.

**ACGIH TLV for Heat Stress and Strain**

The current ACGIH TLV for heat stress and strain recognizes the difference between eight-hour and short-duration exposures, and the value of physiological monitoring in the evaluation and control of heat stress.

(see Figure 12-3 in text, p. 342)

The first decision centers on the availability of a wet bulb globe temperature (WBGT) based clothing adjustment factor (CAF) for clothing that may be worn.

(see Table 12-B in text, p. 343)

If a CAF is not available, then the usual means to evaluate heat stress do not apply and heat strain monitoring is the most feasible approach for evaluation.

The second decision is a simple screening test.

Using available information on WBGT in the environments, the CAF, and the work demands, a table of WBGTeffective limits for broad categories of work and work/rest proportions is provided in the TLV.

(see Table 12-C in text, p. 343)

If the action limit is not exceeded, then heat stress is low.

Note: If the data are not available for a detailed analysis, then physiological monitoring is necessary.

**Assessment of Metabolic Rate**

Metabolic rate is the rate of internal heat generation, which must be dissipated from the body to maintain thermal equilibrium.

First, there is a base level of metabolism that is necessary to support life.

Beyond basal metabolism, there is a work-driven metabolism that is largely the result of muscular effort.

The greatest metabolic rate resulting from muscular effort occurs when the muscles exert a force with motion (dynamic work), and much less metabolic demand is required to exert a force with no motion (isometric contraction or static work).

- a very simple method to assess metabolic rate is to assign the work demands into one of three to five categories of metabolic rate (e.g., light, moderate, heavy).

- another simple method is to look for similar activities in published tables of metabolic rates for specific activities.

Some discipline is required in the assessment of metabolic rate.

The first step is to divide the job into discrete, homogenous tasks, and then determine their duration.

Then a metabolic rate can be assigned to each task.

Finally, the time-weighted average for metabolic rate can be determined (TWA-*M*).

The metabolic rate can be estimated by summing together five components.

*Mtask = B + P + A + H + V*

where: *B* = basal metabolism

 *P* = posture

 *A* = activity based on body movement

 *H* = horizontal travel

 *V* = vertical travel

 **Average Range**

 **(watts) (watts)**

**Basal metabolism (*B*)** 70

**Posture Metabolism (*P*)**

 sitting 20

 standing 40

 walking 170 140-210

**Activity Metabolism (*A*)**

 hand (light) 30 15-85

 hand (heavy) 65

 one-arm (light) 70 50-175

 one-arm (heavy) 120

 both-arms (light) 105 50-175

 both-arms (heavy) 175

 whole-body (light) 245 175-1050

 whole-body (mod) 350

 whole-body (heavy) 490

 whole-body (very heavy) 630

**Assessment of Environmental Conditions**

The environmental factors that are central to the assessment of heat stress are:

- air temperature,

- humidity,

- air speed, and

- average temperature of the solid surroundings

** dry bulb temperature (*Tdb*)**

The dry bulb temperature is the direct measure of air temperature.

The temperature sensor is surrounded by air, which is allowed to move freely around the sensor.

The sensor; however, may be influenced by radiant heat sources and, therefore, should be shielded from them.

** psychrometric wet bulb temperature (*Tpwb*)**

The psychrometric wet bulb temperature is based on the degree of evaporative cooling that can occur.

In practice, a wetted wick is placed around a temperature sensor and enough air is forced over the wick to maximize the rate of evaporative cooling (> 3 *m/s*).

Classically, the device used to measure the psychrometric wet bulb temperature is the sling psychrometer.



Note: The amount of temperature reduction that can be achieved depends directly on the amount of water vapor in the air (i.e., relative humidity).

When humidity is high, the reduction in temperature is low, and *vice versa*.

** ambient water vapor pressure (*Pv*)**

The ambient water vapor pressure is commonly known as humidity.

There are two ways that humidity is expressed: relative and absolute.

- specific humidity

At any given temperature, the amount of water vapor that air can hold has a maximum value -- the *saturation point*.

Hotter air can hold more water vapor than colder air and, therefore, the saturation point of hot air will be higher than that for colder air.

Just because the air is at a certain temperature, it doesn’t mean that it will be holding the maximum amount of water vapor that it can.

Specific humidity relates how much water vapor is actually in the air (*g* of water vapor/*kg* of air).

- relative humidity

Relative humidity is the ratio of how much water vapor the air could possibly hold at that temperature *versus* how much water vapor is actually in the air.

Thus, if air at 30°*C* (86°*F*) can hold a maximum of 28 *g*H20/*kg*air but actually only contains 14 *g*H20/*kg*air, the relative humidity would be 50% (14 ÷ 28 = 0.5 or 50%).



** natural wet bulb temperature (Tnwb)**

Natural wet bulb temperature is similar to the psychrometric wet bulb except that air is allowed to flow over the sensor naturally, rather than being forced.

** air speed (Vair)**

Air speed is measured using an appropriate anemometer.

Because the speed will vary in time and space, an average value is used.

** globe temperature (Tg)**

Globe temperature responds to radiant heat from the solid surroundings and convective heat from the ambient air.

The globe temperature is classically measured using a six-inch, thin-walled, copper sphere that has been painted matte black on the outside.

The temperature sensor is placed at the center of the globe.

Globe temperature is used to estimate the average wall temperature of the surroundings.

** effective temperature (*ET*) and corrected effective temperature (*CET*)**

These are indices of the thermal environment that were first developed to equate thermal sensation, and later used to describe thermal stress.

*ET* is determined from a nomogram that requires knowledge of *Tdb*, *Tpwb*, and *Vair*.

Note: Because *ET* did not account for radiant heat, *CET* was proposed (it uses *Tg* instead of *Tdb*).

Note: Neither *ET* nor *CET* is used to evaluate heat stress today.

Instead, a new index was required that was indicative of thermal stress from the environment.

The wet-bulb globe temperature (*WGBT*) was the evolutionary step from *ET* and *CET*.

** wet-bulb globe temperature (*WBGT*)**

Wet-bulb globe temperature is an index of environmental heat.

- in environments that are indoors, in the shade, or on a cloudy day, it is computed as:

*WBGTin = 0.7Tnwb + 0.3Tg*

- under conditions of direct sunlight (outdoors, no cloud cover), it is computed as:

*WBGTin = 0.7Tnwb + 0.2Tg + 0.1Tdb*

**Evaluation of Prolonged Exposures to Heat**

With a goal of limiting the heat stress dose (core temperature not to exceed 100.4°F [38°C]), the problem becomes one of relating exposure (combinations of environment, metabolic rate, and clothing) to dose.

** upper limit of prescriptive zone concept**

The concept of the upper limit of the prescriptive zone was proposed.

It had been found that for a given metabolic rate, core temperature would remain relatively constant for increasing levels of environmental heat until a critical level.

Then the core temperature would steeply rise with increasing levels of environmental heat, creating an increased risk for heat disorders.

This critical level of heat stress was the *upper limit of the prescriptive zone*, and the person could work eight hours at or below this level without significant risk of a heat disorder.

Note: This concept was adopted by NIOSH in 1972 as the REL for Heat Stress (revised in 1986).

It was adopted by ACGIH in 1973 as the TLV for Heat Stress (revised in 1990).

Because clothing was also a factor in determining the level of heat stress, the ACGIH has provided a table of adjustment factors.

(see Table 12-B in text, p. 343)

The upper limits of the prescriptive zone are expressed in hourly time-weighted averages for both the WBGT and metabolic rate.

To evaluate a job for heat stress, a one- to two-hour interval for time-weighted averaging (TWA) must be selected.

- if the work is repeated in an hourly pattern, a one-hour TWA can be used.

- if the work is intermittent, up to a two-hour TWA may be more representative of the demands.

Both TWA-M and TWA-WBGT must be calculated for the selected interval.

Adjust the WBGT for each location by adding the clothing factor adjustment to the measured value.

With these two TWA values, the work can be located in the graph.

(see Figure 12-4 in text, p.

- if it is below the RAL/Action Limit there is no practical risk for heat-related disorders to develop for even the least heat-tolerant but otherwise healthy workers.

- if it is between the RAL/Action Limit and the REL/TLV, then a program of heat-stress management should be in place.

Note: The program should include at least the general controls described in the section on controls covered later.

- if it is above the REL/TLV, then heat stress is a hazard in the work environment and control actions should be taken.

**Evaluation of Time-Limited Exposures to Heat Stress**

For heat-stress exposures above the REL/TLV, the question may become, how long can someone safety work?

This question can be answered by the empirical WBGT method or the rational heat balance analysis method.

Note: A rule of thumb is one hour in a cool location with low metabolic demands.

** heat balance analysis**

Heat balance analysis uses a rational model of heat exchanged between a hypothetical person and the environment.

This model considers the biophysics of heat exchange:

- if thermal equilibrium can be established, then there is no risk of an excessive level of heat stress.

- if thermal equilibrium cannot be established, then the amount of time to reach an upper limit of heat storage (to a given core temperature) can be determined.

- heat stress index

A classic, but dated, method is called the Heat Stress Index (HSI).

It starts from the premise that the equation: (*S = M + R + C – E*) describes heat balance and the equation: (*Ereq = M + R + C*) describes the evaporative cooling requirements.

The HSI is based on simple relationships for computing *R* and *C*, which have been updated over the years.

The equations that follow are for workers wearing ordinary woven cloth work clothes and the units are watts, degrees, Celsius, meters per second (*m/s*) for air speed and kiloPascals (*kPa*) for water-vapor pressure.

Basically, *R* is equal to a clothing-related constant multiplied by the difference between the mean temperature of the surrounding (*T*r) and a mean skin temperature of 35°*C* (95°*F*).

Obviously, if the average surrounding temperature is greater than skin temperature, there is a gain of heat by radiation.

*R* = 7.7(*Tr* – 35)

where: *Tr* = *Tg* + 1.8*V*air0.5 (Tg – Tdb)

*C* is equal to a clothing-related constant multiplied by a power function of air speed multiplied by the difference between air and skin temperatures.

If the air temperature is greater than skin temperature, there is a heat gain by convection.

If the air temperature is less than skin temperature, there is a heat loss.

The method also provides for the determination of the maximum rate of evaporative cooling (*Emax*), which has either an environmental or physiological limit.

The environmental limit on *Emax* is determined as a clothing-related constant multiplied by a power function of air speed multiplied by the difference between skin and air water-vapor pressure (*Pv*)

*Emax* = 122  *Vair*0.6(5.6 – *Pv*)

Because *Pv* is less than 5.6, *Emax* will have a positive value representing the evaporative heat loss.

The physiological limit is based on the limiting sweat rate of 1 *l/h*, which is equivalent to a heat flow of 675 *W*.

Therefore, *Emax* is the greater value of that computed by the equation: (*WBGTin = 0.7Tnwb + 0.3Tg*) or 675.

$$HSI=100 \frac{E\_{req}}{E\_{max}}$$

- if the HSI is less than 40 (heat stress is low and no further actions are required)

- if the HSI is between 40 and 70, heat stress is a significant workplace hazard)

- if the HSI is between 70 and 100 (heat stress is high and workers are at risk for heat-related disorders)

- if the HSI is greater than 100 (there is a significant heat storage and the exposure is time-limited)

**Evaluation of Physiological Strain**

Physiological strain resulting from heat-stress exposures is seen as elevations in core temperatures, heart rate, and sweating.

They are, therefore, candidates as evaluation tools for heat stress exposures.

Physiological evaluation is a valid approach because it uses direct assessment of the effects of heat stress (dose) rather than an index of exposure.

Physiological evaluation as an alternative or confirming evaluation of heat stress may be worthwhile when protective clothing is required.

It might also be used to demonstrate compliance with the spirit of the NIOSH and ACGIH thresholds.

** core temperature**

Core temperature is a physiological construct used to describe internal body temperature.

The surrogate with the longest history is oral temperature.

Core temperature is approximately equal to oral temperature plus 0.5*°C* (1*°F*).

- as a criterion for core temperature, 38*°C* (100.4*°F*) is the limit if the temperature is sustained over the course of the workday.

- if the work is intermittent, then transient increases to 39*°C* (102.2*°F*) should be acceptable as long as there is sufficient recovery.

Note: As a matter of practice, core temperatures should not exceed 38.5*°C* (101.3*°F*) for industrial exposures to heat stress to allow for measurement errors and for an overshoot before recovery occurs.

** heart rate**

Four methods for assessing heart rate are in use:

- recovery heart rate

To demonstrate effective control of heat stress, the recovery heart rate at one minute (HRR1) should be less than 110 *bpm*.

Alternatively, the heart rate at three minutes (HRR3) should be less than 90 *bpm* (or the value of HRR1 – HRR3 should be at least 10 *bpm*).

- peak heart rate

As a rule of thumb, peak heart rates should not exceed 90 percent of a person’s maximal heart rate (HRmax).

Sometimes this value is known from a stress test, and other times it must be estimated from age (e.g., HRmax = 195 – [0.67  (age – 25 years)].

- average heart rate (over an 8-hour duration)

- average heart rate (over a typical exposure period)

Note: The ACGIH has recommended limiting sustained heart rates over several minutes to 180 – age.

Note: When looking over a history of heart rate for the day (see Figure 12-7 in text, p. 349), an obvious trend towards higher heart rates as the day progresses indicates heat stress above thresholds because the body is having trouble maintaining thermal equilibrium.

** sweat rate**

Sweat rate and volume are theoretical measures of physiological strain, but less practical than core temperature and heart rate.

Sweat volume over a given period of time is equal to an initial body weight plus the weight of food and drink consumed minus the weight of anything excreted minus a final body weight.

The overall weight change in kilograms is equal to the sweat loss in liters.

Note: Over a two- to four-hour interval, the sweat rate should be less than one liter per hour.

**Control of Heat Stress**

The control of heat stress and heat strain centers around the causes of heat stress and the resulting physiological strain.

It takes the form of general controls that are applicable to all heat-related jobs, and specific controls that must be evaluated and selected based on the constraints of the working conditions.

The controls are divided into general and specific controls.

**General Controls**

General controls are those actions that are universally applicable to heat stress work.

** training**

Training is an essential feature of managing heat stress for those employees working on heat-related jobs and their supervisors.

Training is divided into two types:

- pre-placement training

Directed to an employee who is reporting to a heat-related job for the first time.

Can be given during other job training including safety or skill training.

It is not necessary to repeat pre-placement training for an employee.

The formal content of the pre-placement training is the same as that for annual or periodic training.

- periodic training

Should be given to employees working on heat-related jobs to refresh their knowledge of heat stress and controls.

The following topics should be covered during training:

- description of heat stress

- environment, work demands, and clothing

- physiological responses, including acclimation

- recognition of, and first aid for, heat-related disorders

- description of heat-related disorders including symptoms

- description of first aid measures for each disorder

- heat stress hygiene practices

- description of heat stress hygiene practices

- emphasis on individual responsibility

- overview of heat stress policy and guidelines

- company policy

- management responsibilities

- employee responsibilities

Note: It is important to point out these issues that may be particular to the work site.

** heat stress hygiene practices**

The actions taken by an individual to reduce the risks of a heat disorder.

Site management informs the workers of good practices and helps the workers practice them.

The individual is responsible for practicing good heat stress hygiene.

- fluid replacement

Losses of water from the body for evaporative cooling may be up to six liters of water in one day.

Because thirst is not a sufficient driver for water replacement, workers should drink small quantities as frequently as possible.

- self-determination

Limiting an exposure to heat stress is the responsibility of the worker and supervisor.

In self-determination, the worker terminates and exposure to heat stress at the first symptom of a heat-related disorder or extreme discomfort.

Another aspect is reducing the effect of heat stress by lowering peak work demands and making the work demands lighter.

For those working in crews, the pace should be set for the least heat-tolerant worker . . . although this is often not the case in practice.

- diet

A well-balanced diet is important.

Large meals should not be eaten during work breaks because they increase circulatory load and metabolic rate.

Diets designed to lose weight should be directed by a physician (many focus on diuretics).

Weight loss for overweight workers is recommended.

Salt intake as part of a normal diet is usually sufficient.

- lifestyle

A healthy lifestyle that includes adequate sleep, a good diet, and regular exercise is important.

Abuse of alcohol or drugs has been implicated in heat strokes.

Exposures to heat stress immediately before work may increase the risk of a heat disorder at work.

- health status

All workers should recognize that chronic illnesses (e.g., hear, lung, kidney, liver disease) indicate a potential for lower heat tolerance.

Workers suffering from any chronic disorder should inform the physician.

If a worker is experiencing the symptoms of any acute illness and still reports for work, that worker should inform the immediate supervisor.

- acclimation

The adaptation of the body to prolonged daily heat stress exposures.

The ability to work increases and the risk of heat disorders decreases with acclimation.

Acclimation is lost when there are no heat exposures.

This loss is accentuated when an illness occurs.

Workers will be able to work better after several days of heat exposures, and they should expect less of themselves in the early days.

Note: Supervisors need to recognize the role of acclimation, particularly at the beginning of the “hot” season and when dealing with new employees.

** medical surveillance**

Medical surveillance should be under the direction of a licensed physician.

This includes the evaluation of individual risk for heat-stress exposures, provides treatment for heat-related disorders, and helps assess the information collected form heat-related disorder incidents.

** evaluation of risk**

As part of medical surveillance, pre-placement and routine physicals are used to identify those workers who may be at extraordinary risk.

Before an employee is placed on a heat-related job, the employee should receive a pre-placement physical examination that covers:

- comprehensive work and medical history;

- comprehensive physical examination;

- assessment of the use of prescription and over-the-counter drugs, alcohol, or other drugs;

- assessment of the ability to wear and use PPE; and

- assessment of other factors that may affect heat-tolerance.

Note: The physician should provide a written opinion of the results, which is placed in the employees medical file (and a copy given to the employee)

Because an employee’s health status can change over time, periodic re-evaluations are appropriate.

** response to heat-related disorders**

The organization’s medical department is responsible for providing response to reported heat-related disorders.

The physician or designee (e.g., safety personnel) should periodically review heat-stress incidents to update the program.

Heat-alert programs are a collection of activities taken in anticipation of heat-stress conditions or an unusually high level of heat stress.

At a minimum, those individuals appointed to establish a heat-alert program should:

- review training materials and set a training schedule;

- oversee the preparation of the facility for heat stress conditions (e.g., reverse winterization);

- oversee the preparations for changes in staffing and work practices, as appropriate;

- review policies and procedures regarding heat-related disorders; and

- prepare for extraordinary heat stress conditions

** emergency plan**

An emergency plan for heat stroke should be part of the overall emergency plan for the site.

The plan should include:

- the ability to recognize early symptoms of heat stroke by first line supervisors and workers;

- a method for immediate emergency cooling of the victim; and

- arrangements for transport to the hospital.

**Specific Controls**

The two major factors in heat stress are work demands and environmental conditions.

Clothing requirements are a third factor.

For specific jobs, the control of heat stress and the resulting physiological strain on workers is accomplished through engineering controls, administrative controls, and personal protection.

(see Table 12-F in text, p. 353)

To select controls for specific jobs, the first step is to discuss the job among production, engineering, and health and safety functions.

A long list of ideas that emphasizes engineering controls, followed by administrative controls, and finally personal protection should be generated.

Note: Imagination is essential, and no candidate should be rejected out-of-hand.

Controls should then be judged on their merits as they relate to being effective and technically and economically feasible.

The result will be a short list of controls that can be prioritized and implemented over a reasonable timeframe

Note: It is reasonable to have short-term solutions while long-term solutions are planned and executed.

** engineering controls**

Controls that reduce or contain the hazard.

Directed toward reducing physical work demands, adjusting clothing requirements, reducing external heat gain, and enhancing external heat loss (by increasing sweat evaporation and decreasing air temperature).

- reducing physical work demands

Physical work demands represents the metabolic cost off doing work (the greatest contributor to heat gain by a worker).

Reducing work demands (e.g., powered tools, new processes to reduce manual effort), represents a key pathway to reducing heat stress.

- adjusting clothing requirements

Clothing is an important contributor to heat stress if it is not a light-weight cloth work uniform.

Frequently, when clothing is chosen for good barrier properties against contaminants, not enough though is given to the effects on heat stress.

- reducing external heat gain

 reducing radiant heat

When the globe temperature is greater than 43*°C* (109*°F*), radiant heat becomes a significant source of heat stress.

Radiant heat can come from well-defined or diffuse sources with high surface temperatures.

- if the source is well-defined and localized, it can be effectively controlled by shielding.

- for diffuse sources, control can come from shielding, but two other means are also available:

- insulating surfaces, and

- decreasing the emissivity of the surface.

- enhancing external heat loss

 decreasing air temperature

When air temperature is above 40*°C* (104*°F*), workers gain a significant amount of heat from the air.

If the air temperature is below 32*°C* (90*°F*), there is a significant loss of body heat.

Lowering air temperature (e.g., dilution ventilation, active cooling) serves to either reduce heat gain or increase heat loss.

Note: Cool rooms provide a local area of cooling near work areas.

 decreasing air humidity

The rate of evaporative cooling of sweat is affected by the air humidity.

Evaporative cooling can be enhanced by lowering the water content of the air (e.g., using chillers or mechanical refrigeration).

Note: Cool rooms reduce heat stress by lowering air temperatures and lowering humidity levels (increasing evaporative cooling).

 increasing air movement

Air movement functions to increase evaporative cooling and convective cooling if the air temperature is les than 35*°C* (95*°F*).

Between 35*°C* and 40*°C* (104*°F*), heat gain by convection may increase with increases in air movement, but it will be more than off-set by increases in evaporative cooling.

Above 40*°C*, increases in air movement actually increase the overall heat stress.

Note: The greatest reduction in heat stress occurs when air motion is increased from less than one meter per second to two meters per second.

When clothing is fairly heavy, higher air speeds can better penetrate the clothing.

There is no further improvement for air speeds greater than 3 meters per second.

** administrative controls**

Controls that change the way work is performed in order to limit exposures

so that increases in heart rate and core temperature do not exceed acceptable limits.

- acclimation

The process by which workers are allowed to become accustomed to the heat stress.

A powerful adaptation that comes naturally to more than 95% of the workforce.

- pacing the work

Aimed at controlling work metabolism (a powerful contributor to heat stress).

A reduction in the rate of work can be achieved by performing the same amount of work over a longer period of time.

The tendency in cool conditions is to work very fast and have the remaining time idle.

When the environment is hot, the work should be leveled out to reduce the rate of metabolism.

Any idle time should be spent in cooler areas.

- sharing the work

Sharing or distributing the work among other workers is another way to reduce metabolic rate.

This may require some work to be delayed to another time.

Though should be given on how to use the staff most efficiently and effectively.

- scheduling of work

Schedule non-essential work at cooler times of the day or during cooler periods.

Note: Preplanned work times, self-determination, and personal monitoring are all ways to control a high heat-stress exposure.

Generally, these approaches are utilized together.

These kinds of administrative controls apply better to self-paced and non-routine work.

- pre-determined work times

Predetermined work times are assigned to a worker or crew before a job begins.

They may extend the work time (e.g., pacing the work, or work periods (e.g., early mornings to early afternoon).

- self-determination

This approach allows more heat-tolerant workers to work longer than less-tolerant ones by letting the worker stop an exposure.

Self-determination is best instituted as a periodic query to the individual workers about their subjective judgment of heat strain and their ability to continue.

- personal monitoring

Because subjective decisions are unreliable, objective data on heat strain should be obtained from personal monitoring of body temperatures and/or heart rate.

** personal protection**

Controls that provide protection for an individual worker.

For heat stress, personal protection is primarily some form of personal cooling, but can include reflective clothing.

- circulating air systems

Circulating air under the clothing and around the torso to provide personal cooling.

Requires the delivery of air to the worker either through a high-pressure air line and a pressure reducer or through a portable (self-contained) blower.

Note: The circulating air must be breathing-grade air.

Note: While airline systems are best-suited and most appropriate for stationary work, the technique can also be used effectively by workers as temporary relief.

- circulating water systems

Circulating water through tubes and channels around the body.

There are a variety of systems available.

- ice garments

Control heat strain by removing body heat via conduction from the skin to packets of ice.

The typical vest weighs about 5 pounds.

The ability to cool and service time depends on the rate of work, the amount of ice, and the design of the garment.

- reflective clothing

Reflective clothing is designed to reduce the amount of heat reaching the worker.

Best suited for sources of high radiant heat (e.g., molten metal pouring/casting, firefighting).

There is a trade-off in that reflective clothing reduces sweat evaporation.

**Other**

** hot surfaces**

Work in hot environments usually means that there are hot surfaces with the accompanying potential to cause a burn.

Some of these surfaces may elicit pain or a burn with a brief (one second) contact time and burns with longer contact times.

(see Table 12-G in text, p. 356)

Note: For prolonged contact, surface temperatures is the dominant characteristic.

To avoid tissue injury, the surface temperature should be less than 48*°C* (118*°F*) for up to 10 minute contacts, and 43*°C* (109*°F*) for prolonged contact.

** hot air**

Sometimes, there is a concern about the temperature of the air that is being breathed.

If the wet-bulb temperature of the air is less than 45*°C* (113*°F*), breathing the air is not likely to cause extreme discomfort or ill effects.

** respirators**

There is frequently expressed concern about the effects of tight-fitting, full-face respirator face pieces on heat stress.

There are small changes in the level of physiological response, but not enough that the heat-stress guidelines for evaluation should be adjusted.

**Cold Stress**

Cold stress is a fundamentally different kind of problem than heat stress.

While adaptive mechanisms (i.e., sweating, acclimation) are crucial during heat-stress exposures, the physiological adaptations to cold stress have less dramatic affects.

** human responses to cold stress**

- physiological

The first physiological response to cold stress is to conserve body heat by reducing blood circulation through the skin.

This effectively makes the skin an insulating layer.

A second physiological response is shivering, which increases the metabolic rate.

However, it is relatively weak as a protective mechanism.

Note: Shivering is a good sign that the cold stress is significant and that hypothermia may be present.

- behavioral

Behavior is the primary human response to preventing excessive exposure to cold stress.

Behaviors include increasing clothing insulation, increasing activity, and seeking warm locations.

 insulation

Insulation is a critical characteristic of clothing worn during cold-stress exposures.

Generally, the insulating value of clothing ensembles comes from layering clothes rather than having one garment.

The further advantage of layers is that the person can add or remove layers to adjust for differing insulation needs during the work period.

 moisture

The insulating value of clothing is greatly diminished by moisture.

Water-vapor permeability is also important (e.g., Gore-Tex) since this affects moisture accumulation as a result of sweat evaporation.

Note: Once clothing becomes wet, it is important to replace it immediately.

 ventilation

Clothing ventilation is a valuable means to adjust the heat-transfer properties of the ensemble.

The effective insulation of the ensemble can be reduced by increasing the clothing ventilation and, therefore, increasing the air movement under the clothing.

** cold-stress hazards**

Hazards associated with cold stress are manifested in two distinct fashions:

- systemic (hypothermia)

As hypothermia progresses, depression of the central nervous system becomes more severe.

This accounts for the progression of signs and symptoms from sluggishness through slurred speech and unsafe behaviors to disorientation and unconsciousness.

Note: The ability to sustain metabolic rate and reduced skin blood flow is diminished by fatigue.

- local (localized tissue damage)

Because blood flow through the skin is reduced to conserve heat, the skin and underlying tissues are more susceptible to local cold injury.

Note: There is also a concern for manual dexterity.

**Model of Thermal Balance**

Systemic cold stress can be examined in terms of heat exchange:

*S = M + (R + C) + K – E*

where: *M* = metabolic rate (internal heat gain)

 *(R + C)* = combination of heat loss due to cooler air and surroundings

 *K* = conduction to solid surface in contact with the body

 *E* = evaporative cooling by sweat evaporation

Note: Thermal equilibrium is established when *S* = 0.

*M* can be increased as a behavioral response to cold stress.

Significant contributions to thermal balance are reductions in *(R + C)* and *K* with behavioral adaptations like clothing and avoidance of cold environments.

For a given level of clothing, the greater the work demands (i.e., greater the metabolic rate), the greater the level of cold stress that can be tolerated.

Note: The goal of systemic cold-stress control is to avoid hypothermia by limiting the reduction in core temperatures to 36*°C* (96.8*°F*) for prolonged exposures and to 35*°C* (95*°F*) for occasional exposures of short duration.

**Measurement of Cold Stress**

Two climatic factors in the environment influence the rate of heat exchange between a person and the environment.

- air temperature; and

- air speed.

As the difference between skin and ambient temperatures increases and//or the air speed increases, the rate of heat loss from exposed skin increases.

The *Equivalent Chill Temperature (ECT)* was developed by the U.S. Army to account for both.

The ECT is based on the time for water to freeze.

It has been used and updated by the National Weather Service as the *Wind Chill Index (WCI)*, which is described by:

$$T\_{wind-chill}\left[C\right]= 13.12+ \left(0.6215  T\_{air}\right)-11.37V\_{air}^{0.16}+ \left[0.3965  T\_{air}  \left(V\_{air}^{0.16}\right)\right]$$

where: *T* = air temperature (in *°C*)

 *V* = air speed (in *km/hr*)

**Recognition**

Subjective responses of workers are a good tool for recognition of cold stress in the workplace.

Worker behavior response to cold stress exposure will generally be:

- seeking warm locations;

- adding layers of clothing; or

- increasing the work rate;

- loss of manual dexterity;

- shivering;

- accidents; and

- unsafe behaviors.

Note: If there is a noticeable drop in manual dexterity reported by workers or supervision, local cold stress is possible.

In addition, if there is a pattern of cold-related disorders reported in the first-aid logs, injury and illness logs, and workers compensation records, the work conditions should be evaluated.

There is also good evidence that cold stress increases unsafe behaviors and acute injuries.

**Evaluation**

** workplace monitoring**

When temperatures fall below 16*°C* (61*°F*), workplace monitoring should be instituted.

- Below -1*°C* (30*°F*), the dry bulb temperature and air speed should be measured and recorded at least every four hours.

- When air speed is greater than 2 *m/s* (7.2 *km/h*, 5 *mph*), the WCI should be determined (see Table 12-I in text, p. 358).

- When the WCI falls below -7*°C* (*19°F*), it should be noted.

** systemic cold stress**

Hypothermia can occur with air temperatures up to 10*°C* (50*°F*).

The ACGIH recommends that the employer become involved with protective measures when air temperature is less than 5*°C* (*41°F*).

The amount of clothing insulation required for a specific task in a given air temperature and metabolic rate can be approximated by:

$$I\_{clo}=\frac{11.5  \left(33- T\_{db}\right)}{M}$$

where: *I* = insulation (in *clo* units, where 1clo = 0.155 *m*2  *C/W*)

 *T* = air temperature (in *°C*)

 *M* = metabolic rate (in *watts*)

Remember: Clothing must be kept dry.

*I*clo will change with different tasks and environments.

**General Controls**

General controls are actions that should be taken when workers may be exposed to cold stress.

The general controls include training, hygiene practices, and medical surveillance.

** training**

When the air temperature may be below 5*°C* (41*°F*), the workers should be informed:

- that cold stress may be a hazard;

- what is proper clothing;

- that self-determination should be practiced; and

- cold stress hygiene should be practiced.

When work is performed at or below -12*°C* (10*°F*) WCI, additional training topics should include:

- safe work practices; and

- the recognition and first aid treatment of hypothermia and other cold-related practices.

** hygiene practices**

Cold stress hygiene practices center around fluid replacement with warm, sweet, non-caffeinated drinks and self-determination.

Employees should be encouraged to eat a normal, balanced diet.

If a worker experiences extreme discomfort or any of the symptoms of hypothermia (or other cold-related disorder), the person should stop work and seek a place to rewarm.

In air temperatures below 2*°C* (36*°F*), safe work practices include:

- replacing clothing immediately if it becomes wet; and

- treating the workers as if they are experiencing hypothermia.

Note: When handling liquids with boiling points below 4*°C* (39*°F*), special precautions should be taken that clothes do not become soaked in the liquid.

** medical surveillance**

Medical certification is suggested for those who are routinely exposed below -24*°C* (-11*°F*) WCI.

If there is reason to suspect that a person cannot properly thermo-regulate, a medical restriction is appropriate in air temperatures below -1*°C* (30*°F*).

**Specific Controls**

** engineering controls**

Engineering controls attempt to reduce heat loss from the person as a whole or from exposed skin.

Control includes increasing air temperature and decreasing air speed in the work zone, and providing re-warming areas.

- general or spot heating (including hand warming, especially for fine work);

- minimizing air movement (e.g., shielding, adjusting ventilation);

- reduce conductive heat transfer (e.g., no metal chairs, no un-insulated tools);

- redesign equipment, processes, etc. to control systemic and local cold stress; and

- provide warming shelters (if exposures below -7*°C* (19*°F*))

** administrative controls**

Administrative controls attempt to reduce the exposure time, allow individual control over the work, and provide for mutual observation.

- work/rest cycle;

- schedule work to warmest times or move work to warmer areas;

- assign additional workers;

- encourage self-pacing and extra breaks if required;

- buddy system, emphasizing mutual observation;

- avoid long periods of sedentary work;

- allow for productivity reductions and comfort levels (due to extra clothing);

- provide an adjustment or conditioning period for new employees (acclimation); and

- monitor weight changes for dehydration.

** personal protection**

Because clothing is so important, personal protection is fundamental to managing cold stress.

The workers must be educated about the role of clothing items and what may compromise its effectiveness (e.g., moisture, soiling).

Some of these factors include:

- properly selected insulated clothing

- wind barriers;

- special attention to extremities (e.g., toes/feet, fingers/hands, ears, nose, face);

- gloves (when air temperature is less than:

1*°C* (61*°F*) for light work

4*°C* (39*°F*) for moderate work; and

-7*°C* (19*°F*) for heavy work;

- mittens (when air temperature is less than: -17*°C* (1*°F*));

- water barriers to external fluids;

- appropriate active warming systems (e.g., circulating air or water, electric socks/gloves/vests); and

- appropriate eye-protection (for snow- or ice-covered terrain).

**Thermal Comfort**

Thermal comfort is “that condition of mind in which satisfaction is expressed with the thermal environment.”

Factors that affect thermal comfort include:

- air temperature;

- humidity;

- air motion;

- surface temperatures;

- metabolic rate; and

- clothing.

Note: Age, gender, season, cultural background, and intra-individual variation play minor roles.

Factors that can disrupt a theoretically comfortable environment are:

- asymmetric thermal radiation,

- drafts,

- vertical temperature gradients; and

- floor temperatures.