CHAPTER

8

Physical Health Hazards in Industry

Introduction

The first link in the chain of disease or hazard transmission is a disease agent or hazardous agent. Other two links in the chain of disease or hazard transmission are host and environment factors. An agent is defined as a substance, living or non-living, or a force, trangible or intrangible, the excessive presence or relative lack of which may initiate or perpetuate a disease or hazard process. A disease or hazard may have a single agent, a number of independent alternative agents or a complex of two or more factors (agents) whose combined presence is essential for the development of the disease or hazard.

A physical hazard is an agent, factor or circumstance that can cause harm with or without contact. They can be classified as one type of occupational or environmental hazards. Physical hazards include heat, cold, noise, vibration, ionizing radiation, non ionizing radiation, barometric pressure, electromagnetic field. Some control measures are often used to mitigate physical hazards. Physical hazards are a common source of injuries in many industries. They are perhaps unavoidable in certain industries, such as construction and mining, but over time people have developed safety methods and procedures to manage the risks of physical danger in the workplace.

INDUSTRIAL HEAT AND COLD EXPOSURE

Thermal Balance

The human body follows the law of conservation of energy expressed in the equation:

$$M \pm (R + C + K) - E = \pm S$$

where M is the heat generated by metabolism (always positive); R is the radiant heat exchange with the environment (negative for loss from the body); C is the convective heat exchange with the surrounding fluid (negative for loss); K is the conductive heat exchange with any contacting solid (negative for loss); E is the evaporative heat loss resulting from the evaporation of liquid from the body or its clothing (almost always negative or zero); and S is the heat stored (positive) or lost (negative) by the body, and thus reflected in a change in mean body temperature. Basal metabolic heat generally remains relatively constant in health; little bit is diminished in hypothermia, endocrine disorders such as hypothyroidism, certain drug intoxications, etc. It rises following a meal (the specific dynamic effect), and in some endocrine and some other disorders. However, the greatest variation in metabolism is seen in the additional heat generation resulting from physical activity. Depending on the intensity of that activity, total metabolic heat production can vary from less than 80 W when asleep, to over 500 W during short-duration intense exercise. Examples of some

thermal balance: (1) *Sedentary work*: In sedentary work, M will be approximately 100 W. For S = 0, thermal equilibrium, most of that 100 W will be lost in C, with a small loss in E as a result of insensible perspiration (here, M = 100 and S = 0). (2) *Exercise*: In this condition, when M rises to 250 W or more, thermal equilibrium can only be maintained by overt sweating to increase E substantially, to 200 W or more, as C will not increase much. This requires the effective evaporation of upwards of 300 ml of sweat per hour, comfortably within human capability (here, M > 250 and S = 0). (3) *Exercise in occlusive clothing*: Workers who are required to perform physical exercise inside occlusive clothing can find that R, C, K and E all fall close to 0 W, so that all the heat that they generate, perhaps 200 W or more, will be stored at S. This results in a rapid rise in body temperature, perhaps as high as 10°C per hour, and rapid onset of heat illness (here, M = 250 and S = 250). (4) *Cooling when wearing wet clothing*: Inadequate protective clothing can result in excessive evaporative loss too. With a sedentary M of about 100 W, someone whose clothing is soaked might evaporate as much as a litre of water every hour, which would make E become about 700 W. S then becomes very negative and their body cools in spite of shivering attempting to increase M. They will become hypothermic unless their evaporative loss is stopped, perhaps by surrounding them with a plastic bag to act as a water vapour barrier (here, M = 100 and S = –700).

HEAT

Introduction

The character of the thermal environment is determined not only by its total thermal energy content but also by the flow of thermal energy as a result of temperature differences. Heat-transfer analysis is a specialist field, but the environmental heat load can be approximately by a set of simple measurement.

The ramification of human heat exposure is legion: They embrace social relationship, physical and mental well-being, and, ultimately, human productivity. This chapter addresses a major facet, namely physical work in heat: It considers the thermal environment, man's capabilities and limitations during work in heat, strategies to resolve the problems associated with heat exposure, practical procedures to protect workers, and medical recommendations.

Operation involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects or strenuous physical activities has a high potential for inducing heat stress in employees engaged in such operations. Such places include: Iron and steel foundries, nonferrous foundries, brick-firing and ceramic plants, glass products facilities, rubber products factories, electrical utilities (particularly boiler rooms), bakeries, confectioneries, commercial kitchens, laundries, food canneries, chemical plants, mining sites, smelters and steam tunnels. Outdoor operations conducted in hot weather, such as construction, refining, asbestos removal and hazardous waste site activities, especially those that require workers to wear semi-permeable or impermeable protective clothing, are also likely to cause heat stress among exposed workers.

Five main medical disorders can result from excessive exposure to hot environments and they are heat stroke, heat exhaustion, heat cramps, heat syncope, and skin disorders.

A stable internal body temperature requires maintenance of a balance between heat production and loss, which the hypothalamus regulates by triggering changes in thirst, muscle tone, vascular tone, and sweat gland function. Production and evaporation of sweat are a major mechanism of heat removal (however, sweating causes loss of body water and sodium). The transfer of heat from the skin to surrounding gas or liquid (convection) or between two solids in direct contact

(conduction) also may occur, but this decreases in efficiency as ambient temperature increases. The passive transfer of heat via infrared rays from a warmer to a cooler object (radiation) account for 65% of body heat under normal conditions. Radiant heat loss also decreases as temperature increases up to 37.2°C (99°F), at which point heat transfer reverses. At normal temperatures, evaporation accounts for approximately 20% of body heat loss, but at excessive temperature, it becomes the most important means for heat dissipation. It, too, is limited as humidity increases and is ineffective at 100% relative humidity.

The scheduled and regulated exposure to heated environments of increasing intensity and duration (acclimatization) allows the body to adjust to heat by beginning to sweat at lower body temperatures, increasing the quantity of sweat produced, reducing the salt content of sweat, and increasing the plasma volume, cardiac output, and stroke volume while the heart rate decreases.

Health conditions that inhibit sweat production or evaporation and increase susceptibility to heat injury include obesity, skin disease, decrease cutaneous blood flow, dehydration, hypotension, cardiac disease resulting in reduced cardiac output, use of alcohol or medications that inhibit sweating, reduce cutaneous blood flow, or cause dehydration (e.g. atropine, antipsychotics, tricyclic antidepressants, diuretics, laxatives, antihistamines, monoamine oxidase inhibitors, vasoconstrictors, and beta-blockers), and use of drugs that increase muscle activity and thereby increase the generation of body heat [e.g. phencyclidine (PCP), lysergic acid diethylamide (LSD), amphetamines, cocaine, and lithium carbonate]. Infection, cancer, malnutrition, thyroid dysfunction and other medical conditions characterized by debilitation and poor physical condition can reduce the effectiveness of the sweating mechanism and circulatory response to heat. Age and sex also affect susceptibility to heat injury. Older people do not acclimatize as easily as because of their reduced sweating efficiency, and women generally generate more internal heat than men when performing the same task.

Heat Balance Equation

Heat exchange takes place between body and the environment by convection, radiation, conduction and evaporation. Since the contact area between the skin and solid objects is usually very small, conduction is negligible and it is discounted except in the case of body cooling garments. For normal body function, heat exchange between the body and its environment should be balanced.

The exchange of heat between the body and its environment is described by the heat balance equation. All living organisms generate heat, and it is, therefore, necessary to incorporate metabolic heat into the equation. The consumption of oxygen 1 L/min corresponds to 4825 C/min, 20,197 kJ/min, or 337 W. The equation is:

$$H \pm K \pm C \pm R - E = 0$$

The equation representing steady state thermal balance where K represents conduction, C represents convection, R represents radiation and E represents evaporation. The symbol M is often used to denote total energy liberation in the body. To obtain the value for heat production, it is necessary to subtract mechanical work rate (W). The term M – W may, therefore replace H. In practice, the heat balance equation can be 'manipulated', with due cognizance of physiological limitations, to describe various combinations of metabolic and environmental conditions under which thermal equilibrium exists or could be achieved. This approach presumes a comprehensive knowledge of all of the relevant variables and assumptions. Within the scope of occupational health, this approach falls in the province of the specialist biophysicist or bioengineer.

Physiological Responses and Adaptation to Work in Heat

Human thermoregulation remains the subject of intensive research. It is a practical importance to appreciate that it is necessary to postulate a 'set-point hypothesis' for the control of body temperature but, rather, that body temperature will be regulated (within limits) at the lowest level consonant with the maintenance of homeostasis. Although thermal balance can be achieved solely by physical means, at least in theory, physiologic control is invoked whenever thermal balance is challenged. In essence, physiologic thermoregulation is achieved through three main factors: (1) An elevation in metabolic rate to counter heat loss during cold exposure, (2) vasomotor adjustments that either facilitate (dermal vasodilatation) or restrict (dermal vasoconstriction) heat loss from the body, and (3) sweating, which promotes evaporative heat loss.

Comfort Zones

Comfortable thermal conditions are those under which a person can maintain normal balance between production and loss of heat, at normal body temperature and without sweating. Comfort zones evaluation is done with two factors: (1) Effective temperature (ET) or corrected effective temperature (CET): Effective Temperature (ET) is an arbitrary index which combines into a single value of the effect of temperature, humidity and movement of the internal air on the sensation of warmth or cold felt by the human body. Corrected Effective Temperature (CET) is an improvement over the effectiveness temperature index. Instead of the dry bulb temperature, the reading of the globe thermometer is used to allow for radiant heat. That is, the CET scales deal with all the four factors namely air temperature, air velocity, relative humidity and mean radiant heat. Whenever a source of radiation is present, it is preferable to measure CET.

Zone	*Corrected effective temperature (CET)*
Pleasant and cool	69°F (20°C)
Comfortable and cool	69–76°F (20–25°C)
Comfortable	77–80°F (25–27°C)
Hot and uncomfortable	81–82°F (27–28°C)
Extremely hot	83°F+ (28°C+)
Intolerable hot	86°F+ (30°C+)

Predicted four-hour sweat rate (P_4SR): P_4SR can be obtained from any combination of dry and wet bulb temperature of the air, mean radiant air temperature, and air velocity, under different work intensities. McArdle and associates have put P_4SR value of 3 as upper limit of comfort zone.

Zone	*P_4SR*
Comfort zone	1–3 Litres
Just tolerable	3–4.5 Litres
Intolerable	4.5 Litres+

Heat Stress

Heat stress is the amount of heat that is to be eliminated from human body to remain the body in thermal equilibrium and measured as metabolic heat load and heat loss or gain through the process of convection, conduction, radiation and evaporation. The equation of store (S) heat of the body due to heat stress is:

$$M + (R + C + K) - E = S$$

The American Conference of Governmental Industrial Hygienists (in 1992) states that workers should not be permitted to work when their deep body temperature exceeds 30°C (100.4°F). Heat is a measure of energy in terms of quantity. A calorie is the amount of heat required to raise 1 gram of water 1°C (based on a standard temperature of 16.5 to 17.5°C).

Conduction (K) is the transfer of heat between materials that contact each other. Heat passes from the warmer material to the cooler material. For example, a worker's skin can transfer heat to a contacting surface if that surface is cooler and vice versa.

Convection (C) is the transfer of heat in a moving fluid. Air flowing past the body can cool the body if the air temperature is cool. On the other hand, air that exceeds 35°C (95°F) can increase the heat load on the body.

Radiation (R) is the transfer of heat energy through space. A worker whose body temperature is greater than the temperature of the surrounding surfaces radiates heat to these surfaces. Hot surfaces and infrared light sources radiate heat that can increase the body's heat load.

Evaporation (E) cooling takes place when sweat evaporates from the skin. High humidity reduces the rate of evaporation and thus reduces the effectiveness of the body's primary cooling mechanism.

Metabolic heat (M) is always positive which a byproduct of the body's activity.

Globe temperature is the temperature inside a blackened, hallow, and thin copper glob.

Natural wet bulb (NWB) temperature is measured by exposing a wet sensor, such as a wet cotton wick fitted over the bulb of a thermometer, to the effects of evaporation and convection. The term natural refers to the movement of air around the sensor.

Dry bulb (DB) temperature is measured by a thermal sensor, such as an ordinary mercury-in-glass thermometer, that is shielded from direct radiant energy sources.

Causal Factors of Heat Stress

1. Age, weight, degree of physical fitness, degree of acclimatization, metabolism, use of alcohol or drugs, and a variety of medical conditions such as hypertension all effect a person's sensitivity to heat to develop heat stress. However, even the type of clothing worn must be considered. Prior heat injury predisposes an individual to additional injury.
2. It is difficult to predict just who will be affected and when, because individual susceptibility varies. In addition, environmental factors including air temperature, radiant heat, air movement conduction, and relative humidity, all affect an individual's response to heat.

Heat Stress Criteria

The most practical and accurate criteria of physiological heat stress are body core (rectal) temperature and heart rate. Qualitatively both show a positive relationship to increasing work rates and heart loads (including combination therefore), although the respective response pattern may differ significantly. For example, during prolonged work (54 W for 4 hours) in hot humid conditions (33.2°C dry-bulb, 31.7°C wet-bulb), the increase in heart rate relative to rectal temperature for unacclimatized persons exceeds the value for acclimatized persons. This implies that while dual upper limits certainly enhance safety precautions, care should be exercised to ensure that they are realistically adjusted to one another for set conditions.

For general industry, there is a consensus that deep body temperature should not be permitted to rise above 38°C, and accordingly this standard has been built into, perhaps, the most universally accepted heat stress index—the WBGT index. While the choice of 38°C may seem to be too conservative, especially to exercise physiologists, it should be borne in mind that it must serve for a considerable cross-section of the workforce, workers who differ in age, sex, inherent work capacity, and fitness. On the other hand, for a youthful, healthy, all-male group in the South Africa mining industry, this value may be set at a much higher level, 39.5°C. This value is based on an analysis of Wyndham and co-workers' findings, which clearly indicate that sweat production and physiologic heat conductance become 'saturated' when rectal temperature approaches 39.5°C; for example, sweat rate and conductance are at a maximum. Obviously, an upper-limit rectal temperature criterion of 39.5°C can only be applied under conditions of strict individual supervision, where rectal temperature and heart rate are

constantly monitored; it should under no circumstances be incorporated into 'indices' based on environmental conditions and eliminated work rates.

Heart rate is not only related to work load but also reflects the influences of other factors, such as the environmental heat load. For sustained work (e.g. an 8-hours shift), there is general consensus that work rate should not tax more than 40% of an individual's maximum work capacity (Vo_2MAX). For untrained men aged 20 to 60 years, an analysis of Shephard's data reveals an average Vo_2MAX of 3.01 L/min (range 2.27 to 3.90 L/min). This suggests that, an average, sustained work should not be performed at rates exceeding an oxygen consumption of 1.2 L/min, with a range of 0.9 to 1.6 L/min. Corresponding heart rates are of the order of 110 to 130 beats/min, the implication being that 110 represents an upper limit. In as much as Vo_2MAX is systematically eroded with increasing heat loads, it follows that lower work rates are indicated to conform to this limit.

General relation between work rate, heart beat rate and oxygen consumption

Category	*O_2 consumption (L/min)*	*Heart beat rate (beat/min)*
Light	0.5–1.0	75–100
Moderate	1.0–1.5	100–125
Heavy	1.5–2.0	125–150
Very heavy	2.0–2.5	150–175
Extremely heavy	2.5	175

With training and heat acclimatization, when the individual is well capable of sustained work at much higher fractions of Vo_2MAX, these restrictions are no longer relevant and rectal temperatures approaching 38.5°C and heart rates of up to 135 beats/min are well-tolerated.

From the above it is evident that considerable benefit could be derived in any given work situation, without sacrificing safety, from individual monitoring. Unfortunately, in most instances, individual monitoring is impractical, and consequently, indices of the environmental heat load that correlate most closely with the physiologic response to work in heat are applied. Of these, the WBGT index is internationally recognized, especially where physical work is involved, while the effective temperature (ET) or corrected effective temperature (CET) is intended as an index of comfort. However, irrespective of the particular index or its degree of sophistication, they all suffer a common shortcoming: Metabolic rate is either omitted or estimated with no consideration of individual reaction. Of necessity, therefore, such indices are inaccurate and have to err on the side of conservatism.

Heat Stress Investigation Guidelines

These guidelines for evaluating employee heat stress approximate those found in the 1992–93 ACGIH publication, Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.

A. *Employer and employee interviews*: The inspector will review the OSHA 200 Log and, if possible, the OSHA 101 forms for indications of prior heat stress problems. Following are some questions for employer interviews: What type of action, if any, has the employer taken to prevent heat stress problems? What are the potential sources of heat? What employee complaints have been made? Following are some questions for employee interviews: Which heat stress problems have been experienced? What type of action has the employee taken to minimize heat stress? What is the employer's involvement, i.e. does employee training include information of heat stress?

B. *Walk-around inspection*: During the walk-around inspection, the investigator will determine building and operation characteristics; determine whether engineering controls are functioning properly; verify information obtained from the employer and employee

interviews; and perform temperature measurements and make other determinations to identify potential sources of heat stress. Investigators may wish to discuss any operations that have the potential to cause heat stress with engineers and other knowledgeable personnel. The walk-around inspection should cover all affected areas. Heat source, such as furnaces, ovens, and boilers, and relative heat load per employee should be noted.

C. *Workload assessment*: Under conditions of high temperature and heavy workload, one should determine the workload category of each job. Workload category is determined by averaging metabolic rates for the tasks and then ranking them:
   1. Light work: Up to 200 kcal/hour
   2. Medium work: 200–350 kcal/hour
   3. Heavy work: 350–500 kcal/hour

Cool rest area: Where heat conditions in the rest area are different from those in the work area, the metabolic rate (M) should be calculated using a time-weighed average, as follows:

$$\text{Average } M = \frac{(M_1)(t_1) + (M_2) + t(t_2) \ldots . (M_n) + (t_n)}{(t_1) + (t_2) \ldots . (t_n)}$$

where M = metabolic rate
t = time in minutes

In some cases, a videotape is helpful in evaluating work practices and metabolic load.

Activity examples:

- Light hand-work: Writing, hand knitting.
- Heavy hand-work: Typewriting.
- Heavy work with one arm: Hammering in nails.
- Light work with two arms: Filing metal, planning wood, raking the garden.
- Moderate work with the body: Cleaning of floor, beating a carpet.
- Heavy work with the body: Railroad track laying, digging, barking trees.

Sample calculation: Assembly line work using a heavy hand tool

- Walking along 2.0 kcal/min
- Intermediate value between heavy work with two arms and light work with the body 3.0 kcal/min
- Add for basal metabolism 1.0 kcal/min

Total 6.0 kcal/min

Assessment of work: Body position and movement:

- Add for basal metabolism 1.0 kcal/min
- Sitting 0.3 kcal/min
- Standing 0.6 kcal.min
- Walking 2.0–3.0 kcal/min
- Walking uphill: add 0.8 kcal/min every meter (yard) rise

Type of	*Type*	*Average kcal/min*	*Range kcal/min*
Hand work	Light	0.4	0.2–1.2
	Heavy	0.9	
Work:			
One arm	Light	1.0	0.7–2.5
	Heavy	1.7	
Both arm	Light	1.5	1.0–3.5
	Heavy	2.5	
Whole body	Light	3.5	2.5–15.0
	Moderate	5.0	
	Heavy	7.0	
	Very heavy	9.0	

Heat Stress Sampling Methods

1. *Body temperature measurements:* Instruments are available to estimate deep body temperature by measuring the temperature in the ear canal or on the skin or oral temperature or rectal temperature.
2. *Environmental measurement:* Environmental heat measurements should be made at, or as close as possible to, the specific work area where the worker is exposed. When a worker is not continuously exposed in a single hot area but moves between two or more areas having different levels of environmental heat, or when the environmental heat varies substantially at a single hot area, environmental heat exposures should be measured for each area and for each level

of environmental heat to which employees are exposed.

3. *Wet bulb globe temperature index:* ISO 7243 prescribes a standard method for the estimation of heat stress using three temperature measurements: Those of a standard dry bulb, a wet bulb and one inside a blackened globe of 150 mm diameter. The three temperatures are combined into the WBGT index using the following equation:

$$\text{Outdoor WBGT} = 0.7T_{\text{wet bulb}} + 0.2T_{\text{globe}} + 0.1T_{\text{dry bulb}}$$

Under this ISO standard, it is permissible to ignore the dry bulb temperature if there is little difference between it and that of the globe (e.g. indoors with title radiant heat load), in which case the equation becomes:

$$\text{Indoor WBGT} = 0.7\text{T}_{\text{wet bulb}} + 0.3\text{T}_{\text{globe}}$$

Wet bulb globe temperature (WBGT) should be calculated using the appropriate formula. The WBGT for continuous all-day or several hour exposures should be averaged over a 60-minute period. Intermittent exposures should be averaged over a 120 minute period. These averages should be calculated using the following formula:

$$\text{Average WBGT} = \frac{(WBGT_1)(t_1) + (WBGT_2)(t_2) + ... + (WBGT_n)(t_n)}{(t_1) + (t_2) + ... + (t_n)}$$

Portable heat stress meters or monitors are used to measure heat conditions. These instruments can calculate both the indoor and outdoor WBGT index according to established ACGIH Threshold Limit Value equations. With this information and information on the type of work being performed, heat stress meters can determine how long a person can safely work or remain in a particular hot environment.

These TLVs are based on the assumption that nearly all acclimatized, fully clothed workers with adequate water and salt intake should be able to function effectively under the given working conditions without exceeding a deep body temperature of 38°C (100.4°F). They are also based on the assumption that the WBGT of the resting place is the same or very close to that of the workplace. Where the WBGT of the work area is different from that of the rest area, a time-weighted average should be used. These TLVs apply to physically fit and acclimatized individuals wearing light summer clothing. If heavier clothing that impedes sweat or has a higher insulation value is required, the permissible heat exposure TLVs must be reduced by the correction as per the ACGIH 1992–93 Threshold Limits Values for Chemical Substances and Physical Agents and Biological Exposure Indices (1992).

WBGT correction factors in °C

Clothing type	*Clo value*	*WBGT correction*
Summer lightweight working clothing	0.6	0
Cotton overalls	1.0	–2
Winter work clothing	1.4	–4
Water barrier, permeable	1.2	–6

Clo: insulation value of clothing. One clo = 5.55 kcal/hr of heat exchange by radiation and convection for (Degree) °C difference in temperature between the skin and the adjusted dry bulb temperature.

Permissible heat exposure threshold limit value (ACGIH)

Work/Rest regimen	*Workload (WBGT)*		
	Light	*Moderate*	*Heavy*
Continuous work	30.0°C (86°F)	26.7°C (80°F)	25.0°C (77°F)
75% Work, 25% rest, each hour	30.6°C (87°F)	28.0°C (82°F)	25.9°C (78°F)
50% Work, 50% rest, each hour	31.4°C (89°F)	29.4°C (85°F)	27.9°C (82°F)
25% Work, 75% rest, each hour	32.20°C (90°F)	31.1°C (88°F)	30.0°C (86°F)

Work rate categories				
Category	*Metabolic rate*			
	O_2L/min	*kcal/hr*	*kJ/hr*	*W/hr*
Light	≤0.60	≤200	≤840	≤233
Moderate	0.70–1.0	201–350	841–1465	234–407
Severe	>1.0	>350	>1465	>407

Other thermal stress indices: (a) Effective temperature (ET): Effective temperature is an index that combines into a single value of the subjective thermal sensation resulting from air temperature (or globe temperature when radiant heat exceeds air temperature by more than 1°C), humidity, air movement. The index does not take into account metabolic rates other than for light or sedentary work, and its use is, therefore, limited to an index of comfort or as a guide to analyze productivity. In summer, the maximum number of people should be comfortable at an ET of 21.7°C (range: 18–26°C), in winter at 20°C (range: 15–23°C). These values are subject to variation in different geographic regions. Although useful, the index does have a number of shortcomings: (1) It gives insufficient weight to the detrimental effect of air movement below 0.5 m/sec in hot, humid conditions; (2) it exaggerates the effect of high dry-bulb temperature at air movements in the range of 0.5 to 1.5 m/sec during physical work, and it underestimates the harmful effects of air movement in excess of 1.5 m/sec at dry-bulb temperature of 49°C and higher; and 3 environmental conditions inducing the same physiologic stress, in terms of rectal temperature, heart rate, sweat rate, and tolerance, do not constitute the same ET, especially in severe heat stress. ET remains a useful measurement technique in mines and other places where humidity is high and radiant heat is low. When ET is corrected by adding radiant heat where applicable, it is known as corrected effective temperature (CET). (b) The heat stress index (HSI): HSI was developed by Belding and Hatch in 1965. It represents the percentage of heat storage capacity of an average man. HSI are as follows:

HSI	*Interpretation*
0	No thermal stress
10–30	Moderate-to-mild heat strain
40–60	Severe heat strain
70–90	Very severe heat strain
100	Upper limit of heat tolerance

Although the HSI considers all environmental factors and work rate, it is not completely satisfactory for determining an individual worker's heat stress and is also difficult to use. (c) Psychrometric chart: In many situations, radiant heat loads are fairly small in comparison to the heat exchange by convection and evaporation. The psychrometric chart (ironically, derived from the Greek psychron meaning cold) is a clear graphical way of understanding the effect of changing humidity and temperatures alone. Use of the chart requires a measurement of the water content of the air and the dry bulb temperature. Limits may be defined on the chart appropriate to a given group of individuals for specified activities and clothing, thus allowing the user to make recommendation as to how their physiological requirements may be met. The chart may also be used to understand the relative effects of lowering air temperature and humidity when trying to control an environment. (d) P_4SR: A potentially very attractive approach to the assessment of heat stress is to attempt to relate it to the amount of evaporative heat loss required for thermal balance; this was originally incorporated into a 'predicted 4-hour sweat rate' (P_4SR), but has more recently evolved into the required sweat rate and 'predicted heat strain', as defined in ISO 7933. Measurement essentially consists of a semi-empirical solution of the equation of heat balance, to arrive at an estimate of the sweat rate required for the maintenance of thermal equilibrium. It is thus considerably more complex than the WBGT index and more suited to experimental investigations rather than routine monitoring. The latest studies confirmed its efficacy in predicting average

and limits to exposure, although modifications have been required to the calculation of the evaporative efficacy of sweating. (e) More modern thermal stress may need to be assessed by more complex methods than the simple WBGT index, as the transfer of heat by each physical mode is usually more sensitive to subtle changes. Detail accounts of the 'predicted mean vote' (PMV) and 'predicted percentage of dissatisfied' (PPD) indices are given in ISO 7730, based on measurement of air temperature, mean radiant temperature, humidity, air velocity, metabolic rate and clothing insulation. Indeed, in any situation in which clothed individuals are being assessed, reference will need to be made to the estimation of the thermal insulation and assistance to evaporative heat loss imposed by clothing; ISO 9920 provides a sound practical basis for this.

Assessment of Heat Strain

'Stress' is the force applied to an object/subject, whilst 'strain' is the response within the object/subject to the applied stress.

Heat strain can be defined as the physiological and pathological changes of the body due to heat stress. The principal measurement of heat strain, like that of cold, is core body temperature. However, core temperature can rise rapidly in the heat and the fact that rectal temperature changes later and more slowly than other sites make it less suitable for safety purposes. Accordingly, it is more common to estimate deep body temperature in the heat from a tympanic membrane or auditory canal reading; this has the added advantage that this site should be a good indicator of the temperature of the brain, which is not only the central temperature controller, but is also one of the more critical organs in heat illness. Unfortunately, the otherwise convenient infrared tympanic membrane thermometers that have become so popular in general clinical practice are again a potential source of error, and should not be trusted: A thermistor or thermocouple needs to be placed just short of the tympanic membrane, and the auditory meatus occluded and carefully insulated if the temperature recorded is to be a reliable estimate of core temperature.

Three other variables are commonly recorded in heat studies: Heart rate is the simplest of all to measure, loss of body mass due to sweating is also very easily determined, whilst skin temperature is sometimes of value if judiciously interpreted.

Heart rate is well-correlated with heat strain, provided that changes due to exercise are taken into consideration. It is often used, in conjunction with aural temperature, in establishing criteria for the withdrawal of people exposed to heat loads. Simple estimate of body weight loss is a useful measure of fluid loss in laboratory conditions. Skin temperature can prove misleading. As they fall if there is good evaporation from the skin, but climb close to core if evaporation is limited or absent. These methods are described in ISO 9886.

Heat Disorders and Health Effects

1. **Heat exhaustion:** Heat exhaustion may be seen in military personnel during fitness training and moderately well-trained athlete competing in a marathon during the warmer months in a temperate country as well as in groups of manual workers with moderate environmental heat loads. Heat exhaustion is attributed to an inability of the circulation to meet simultaneously the demands of thermoregulation (i.e. by affecting a vast flow of blood to the skin) and those of vital organs such as the brain and active skeletal muscle. Chronic heat exhaustion, in contrast to the common acute version, may have its origin in salt depletion, for example, dietary imbalance.

   Heat exhaustion is more likely to occur during the un-acclimatized state and in individuals with some form of circulatory insufficiency. Obviously, the condition is aggravated by dehydration. However, it

may also occur completely independently of dehydration as a result of an improper redistribution of the circulation. Irrespective of the precise origin, it follows that the trigger mechanism is an effective reduction in circulating blood volume. The first sign of impending heat exhaustion is usually hyperventilation, in someone who appears ill at ease with the exercise that they are performing. Classical signs and symptoms from the disturbance of the body's acid–base balance and the calcium–phosphate ratio in the blood flow, with dizziness, nausea, paraesthesia in the peripheries and around the mouth, progressing to confusion, collapse, vomiting and even seizures. Further investigation may reveal high heart rates and low arterial blood pressure, the signs of circulatory shock. Core temperature at this stage is below 40°C, and usually between 37°C and 39°C. Early cases respond rapidly to rest in a recumbent position, re-breathing from a paper bag to restored end-tidal CO_2 levels and simple cooling. Fluids may also be beneficial and should always be given by appropriate means. If these patients are allowed or even encountered to continue exercising, they rapidly develop frank heat stroke.

2. **Heat cramps:** Heat cramps are usually caused by performing hard physical labour in a hot environment. There are painful and spasmodic contractions of the skeletal muscles. These 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 15–20 minutes in hot environments. Classical salt depletion, due to salt loss in sweat while on a low salt diet, with adequate water intake, is now rarely seen. The classical accompaniment of cramp (e.g. Miner's cramp) only occurs in association with hard exercise. Plasma sodium only falls in more severe cases, with milder cases showing a fall in extracellular fluid volume with normal plasma sodium. In the worst cases, vigorous treatment with oral or intravenous saline may be required. Subacute and other variants of this condition sometime attributed to different combination of water and electrolyte depletion. They are best treated by cooling, rest, rehydration and the restoration of a normal diet. The blind administration of salt, even with the copious quantities of fluid that are required, is potentially dangerous and should be avoided. Recent studies have shown that drinking commercially available carbohydrate–electrolyte replacement liquids is effective in minimizing physiological disturbances during recovery.

   One possible danger is that of hyperkalaemia; many young people often rehydrate following exercise in the heat using some form of orange juice, or a 'spot rehydration' fluid, which may be high in potassium. They should be advised to ensure that their rehydration fluid is well diluted with water.

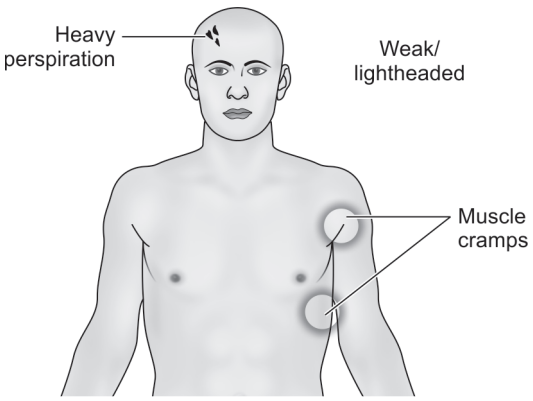

Fig. 8.1: Heat cramps

3. *Skin disorders: Prickly heat or miliaria is an acute, inflammatory disease of the skin.* Perhaps the most common of the 'mild' heat disorders is prickly heat or miliaria rubra. It occurs, especially in the summer, in the tropics, and following prolonged sweating. The pathology is well known: Sweat gland ducts become blocked by a plug of keratinized cells, and the accumulating sweat is forced through the wall of the duct into the surrounding tissues; an inflammatory reaction ensues due to irritants and infection. There are three forms of miliaria: Miliaria crystallina, miliaria rubra and miliaria profunda. As the site of duct obstruction becomes deeper in the skin, the severity increases and presentation varies like vesicles, erythema, desquamation, macules. There are three possible causes are listed: (1) excessive wasting away of the natural skin oil, (2) infection, and (3) electrolyte imbalance and the effect thereof on sweat composition. Prickly heat is manifested as red papules and usually appears in areas where the clothing is restricted which give rise to a prickling sensation. Treatment is symptomatic and preventive, but topical applications of corticosteroids may be used in some cases. Environmental controls and good personal hygiene are most effective. *Erythema ab igne* is characterized by the appearance of hyperkeratotic nodules following direct contact with heat that is insufficient to cause a burn. *Intertrigo* results from excessive sweating and often is seen in obese individuals. Skin in the body folds (the groin and axillas) is erythematous and macerated. *Heat articaria* (cholinergic articaria) can be localized or generalized and is characterized by the presence of wheals with surrounding erythema (hives). Treatment for these disorders consists of reduction or removal of heat exposure, reduction of sweating, and control of symptoms. Antihistamines may help to relieve pruritus in patients with urticaria. Corticosteroids are not beneficial.

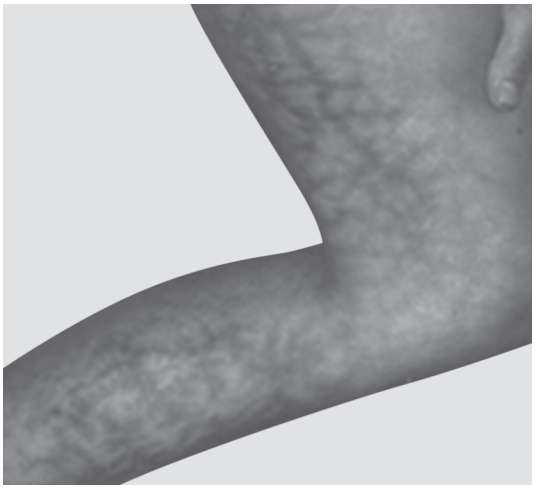

Fig. 8.2: Erythema ab-igne

4. *Heat syncope:* It is also known as heat collapse (fainting). This is the common ill-effect of heat. In its milder form, the person standing in the sun becomes pale, his blood pressure falls and he collapses suddenly. This reaction is similar to that of heat exhaustion and does not affect the body's heat balance; therefore, there is practically no rise in body temperature. The condition results from pooling blood in lower limb due to dilatation of blood vessels (vasodilatation), with the result that the amount of blood returning to the heart is reduced, which in turn is responsible for lowering of blood pressure and lack of blood supply to the brain. The onset of heat syncope is rapid and unpredictable. This condition is quite common among soldiers when they are standing for parades in the sun. Treatment is quite simple. The patient should be made to lie in the shade with the head slightly down; recovery usually comes within 5 to 10 minutes. To prevent heat syncope, the worker should gradually become acclimatized to the hot environment.

5. *Heat fatigue:* A factor that predisposes an individual to heat fatigue is lack of acclimatization. The use of programme of acclimatization and training for work in hot environments is advisable. The signs and symptoms of heat fatigue include impaired performance of skilled sensorimotor, mental, or vigilance jobs. There is no treatment for heat fatigue except to remove the heat stress before a more serious heat-related condition develops.
6. *Heat stroke:* Heat stroke is regarded as one of the few true medical emergencies, and if effective treatment is not instituted promptly, it carries a mortality rate of up to 80%. Earlier heat stroke was defined as a "disorder of thermoregulation characterized by the total absence of sweating, body temperature in excess of 41.1°C (106°F) and severe disturbances of brain function". A major objection of such definition is that sweating cessation is not always a cardinal sign, since heat stroke may occur not only from failure of the thermoregulatory system, as a result of impaired central nervous system function, but also from overloading its capacity. By current definition, heat stroke represents a condition in which elevated body temperatures are causally related to tissue damage, often of an irreversible nature. Although many tissues are damaged in heat stroke, the patient's outcome depends mainly on the degree of injury to the nervous system, kidneys and liver, the latter two organs being damaged almost irreversibly. The accurate diagnosis of heat stroke, by implication, therefore, rests solely on parameters of tissue damage, the most practical being the assay of tissue enzymes in serum.

Those working in very hot surroundings, particularly when evaporative cooling is ineffective due to high humidity, may undergo a rapid rise in core temperature, to the point at which thermoregulation fails. The primary signs and symptoms of heat stroke are: Confusion, delirium, irrational behavior. The classic victim of heat stroke has stopped sweating and is dry to the touch. They may still maintain peripheral circulation and thus be red, or may have undergone circulatory collapse, in which case their skin colour is not diagnostic. They are very hot, semiconscious or comatose, and prone to convulsions, cardiac and respiratory arrest. The onset of this dramatic illness may have been very rapid, although many will have shown evidence of earlier heat exhaustion.

An elevation of serum enzyme levels is a consistent finding in heat stroke of especial prognostic significance is the elevation of aspartate aminotransferase (AST) in that it is regarded as an indicator of the severity of tissue damage, while an elevation in creatine kinase (CK) in cerebrospinal fluid may provide a good index of neurologic damage. Furthermore, AST and lactate dehydrogenase (LD) levels are almost invariably increased in heat stroke. Diagnostic procedures regarding heat stroke call for serum enzyme assays of LD, CK, AST, and alanine aminotransferase (ALT) on admission and 48 hours following admission.

Cooling is best achieved in the field by stripping the patient in the shade, drenching with tepid water and fanning if there is little natural wind. Cold water or ice is less useful in adults because of the intense vasoconstriction which it can precipitate, which limits heat transfer from the core to the skin; however, there are recent claims that ice-water baths may still produce the most rapid fall in core temperature even in adults, as they do in infants with their much greater surface area to volume ratio. Alternating litres of isotonic dextrose and saline intravenously are the best means of fluid administration, but cannot be a substitute for immediate and effective cooling. The precise quantity given may be based on an estimate of fluid loss, but in unconscious cases it is probably best to give the first litre over 15 minutes or less, thereafter reducing the rate of infusion according to

clinical indications and the perceived risk of hypervolaemia leading to pulmonary oedema. Such fluid should not be warmed, but neither should they be cooled below 15°C. Elevation of the legs to assist venous return, administration of oxygen and possibly sedative, are of value. However, vasodilators and platelet inhibitors, such as aspirin, should be avoided. Rapid but careful evacuation to an intensive care unit is essential, where urinary output, blood biochemistry and direct measurement of the central venous pressure can be monitored closely. Cooling is normally discontinued when the rectal or aural temperature has reached 38ºC. The rectal or aural temperature should be monitored continuously, both to monitor the efficacy of hyperthermia treatment and to guard against the development of clinically significant hypothermia, which can occur if cooling is continued too long. Further treatment is supportive and directed towards the many potential complications of hyperthermia. Hypovolaemia, hyperkalaemia, rhabdomyolysis, hypocalcaemia and bleeding diathesis may require intensive supportive treatment. The patient should be kept in bed for several days until the temperature control becomes stable. If core temperature rises to 45ºC, irreversible heat denaturation of protein causes multiple organ failure or disseminated intravascular coagulation. If it is not immediately fatal, renal dialysis may be necessary during recovery.

The host factors reported to increase risk of heatstroke are: Unacclimatization, obesity, lack of physical fitness, fatigue, lack of sleep, dehydration, febrile illness, acute and convalescent infections, reactions to immunizations, conditions affecting sweating, skin disorders (heat rash, sunburn), consumption of alcohol, drug (barbiturate), past history of heat injury, past history of living in climatic areas with more atmospheric cooling power, chronic diseases (diabetes, cardiovascular diseases), lesions of the hypothalamus, brainstem, and cervical part of spinal cord, following certain surgical operations, recent intake of food, sustain output of muscular metabolic heat, and increased susceptibility due to biological variability.

The Effect of Heat on Performance and Productivity

Reconciling of subjective and objective is not easier for the possible effects of heat than were noted for cold. Ramsey has reviewed more than 150 studies that attempted to find differences in 'perceptual motor performance' in the heat and commented on the remarkable lack of objective evidence of dominant effects. It appears that there is no significant detectable impairment in the performance of the great majority of tasks until the level of heat stress reaches a WBGT index of approximately 30ºC. This is broadly in accordance with the criteria originally laid down by NIOSH in their original recommended exposure limit (REL). Paradoxically, when raised 14 years later, NIOSH omitted this REL because of lack of supporting evidence.

A few studies cast interesting and potentially different light on the area. There is much stronger support for adverse effects in circumstances in which core temperature has risen; when core temperature is 38°C or greater a prominent effect is an increase in irritability independent of the rise in subjective discomfort.

Perhaps the most useful tool (beyond tenuous attempts to relate accident statistics to heat stress or strain) in the practical examination of performance effects is the expression of subjective judgment scales. ISO 10551 lays down a standard approach to these, which allows inclusion of comfort, acceptability and tolerance in the assessment of thermal environment.

The competitive demands for adequate perfusion of active skeletal muscle and the skin impose a limit on work capacity, overall performance, and, ultimately, productivity. Irrespective of the complexity of the task, human performance declines significantly in the effective temperature (ET) range of 27° to

30°C. For strenuous physical work in gold mines, the decline is 5% at 29°C, 10% at 30°C, 17% at 31.5°C, and 30% at 32.5°C ET. This study highlights the progressive decline in performance associated with increasing wet-bulb temperatures.

Control Measures

Ventilation, air cooling, fans, shielding, and insulation are the five major types of engineering controls used to reduce heat stress in hot work environments. Heat reduction can also be achieved by using power assists and tools that reduce the physical demands placed on a worker.

However, for this approach to be successful, the metabolic effort required for the worker to use or operate these devices must be less than the effort required without them. Another method is to reduce the effort necessary to operate power assistants. The worker should be allowed to take frequent rest breaks in a cooler environment.

Acclimatization: The human body can adapt to heat exposure to some extent. This physiological adaptation is called acclimatization. After a period of acclimatization, the same activity will produce fewer cardiovascular demands. The worker will sweat more efficiently (causing better evaporative cooling), and thus will more easily be able to maintain normal body temperature. Cardiovascular changes sustain peripheral vasodilatation and the blood flow required by the active sweat gland. Salt of the body is retained by the kidneys and salt content of the sweat starts to decline, so that increased sweating does not result in severe sodium deficiency. This is achieved by an early peak in rennin, followed by an increased in aldosterone levels.

The ability to perform work that is easily done in cool environments is impaired because the initial demands of thermoregulation and skeletal muscle activity are competitive, and the resulting strain is manifested in high heart rates. If these

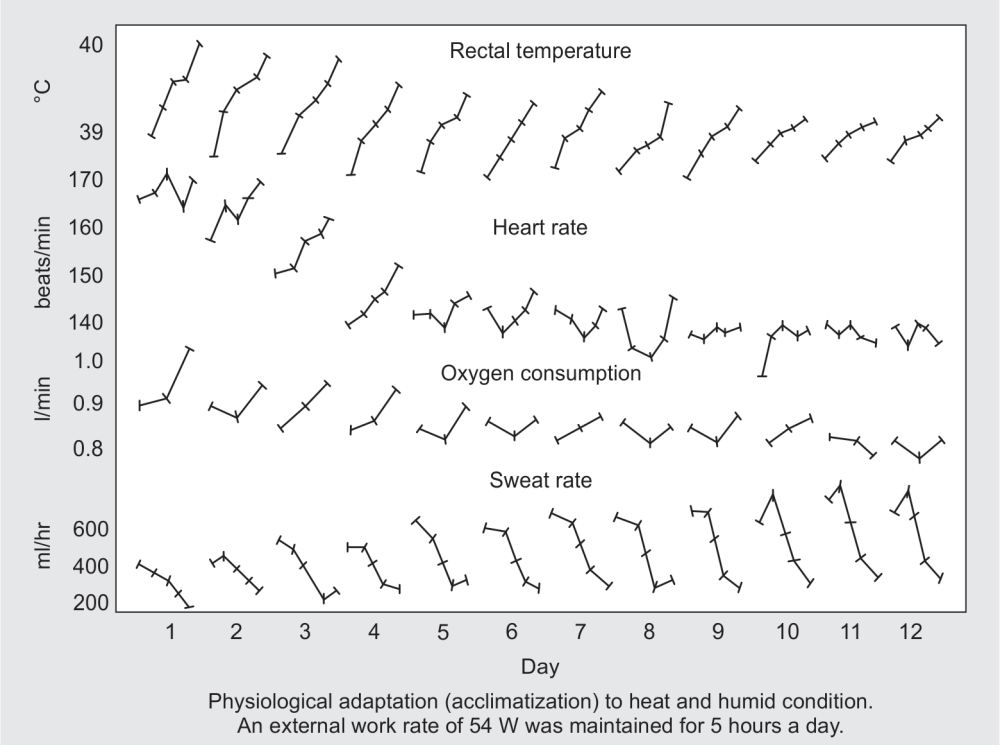

Fig. 8.3: Acclimatization

conditions (work in heat) last for several days, there is a gradual return of the ability to work with little or no discomfort—heat acclimatization has taken place.

De-acclimatization can occur surprisingly rapidly, after just a few days of withdrawal from the heat stress. Those who spend a period working in air-conditioned comfort, or who return to more temperate climates for a holiday, therefore need to undergo supervised re-acclimatization on their return to heat exposure. This introduces a dilemma in choosing optimal living and working conditions in hot climates; while many find it more comfortable and sleep better in conditioned accommodation, more constant exposure to heat stress will maintain a better level of acclimatization.

A proper designed and applied acclimatization programme decreases the risk of heat-related illness. Such a programme basically involves exposing employees to work in a hot environment for progressively longer periods. NIOSH (1986) says that, for workers who have had previous experience in jobs where heat levels are high enough to produce heat stress, the regimen should be 50% exposure on day one, 60% on day two, 80% on day three and 100% on day four. For new workers who will be similarly exposed, the regimen should be 20% one day one, with a 20% increase in exposure each additional day.

Fluid replacement: Cool (50–60°F) water or any cool liquid (except alcoholic beverages) should be made available to workers to encourage them to drink small amounts frequently, e.g. one cup every 20 minutes. Ample supply of liquid should be placed closed to the work area. Although some commercial replacement drinks contain salt, this is not necessary for acclimatized individuals because most people add enough salt to their summer diets.

The aim of drinking during exposure to heat stress should be to replace fluid and electrolyte losses in sweat. Even when acclimatized and fit, few humans are capable of losing more than 2 litres an hour in sweat, so drinking should never exceed that rate. Over a typical extended working day, a ceiling of 10–12 liters of fluid intake is advisable.

Fluid replacement strategies are primarily designed to counter dehydration (and possibly electrolyte loss) induced by profuse, sustained sweating. Although the fundamental approach of replacing exactly what is being lost at the same rate is quite simple in theory, the maintenance of an optimum state of hydration often presents practical problems:

1. Drinking water according to the dictates of thirst is insufficient to prevent a voluntary dehydration up to 1% of body mass.
2. Upon drinking water, a person's thirst is alleviated well before the fluid deficit is recovered, the attenuation of drinking subjectively being attributed to stomach fullness.
3. Once dehydration is set in, the subsequent rate of water absorption from the gut will be reduced as a result of compensatory splanchnic vasoconstriction. This reflex, by which a redistribution of the cardiac output is achieved, occurs at dehydration levels approximating 1.5% of body mass.
4. Sweat is hypotonic fluid with an electrolyte content varying between 0.1 to 0.3 g%. The most important constituent is sodium chloride (salt), which accounts for about 80% of the tonicity of sweat. On a balanced diet, or in the short term (hours), the threat to continued wellbeing does not reside in salt depletion but, rather, in dehydration.

These considerations suggest that optimum hydration is best achieved by drinking relatively small amounts of water at relatively short intervals.

Heat produced by the body and the environmental heat together determine the total heat load. Therefore, if work is to be performed under hot environmental conditions,

the work load category of each job shall be established and the heat exposure limit pertinent to the workload evaluated against the applicable standard in order to protect the worker against exposure beyond the permissible limit. The workload category may be established by ranking each job into light, medium and heavy categories on the basis of type of operation. Where the workload is ranked into one of said three categories, that is, (1) light work (up to 200 kcal/hr), for example, sitting or standing to control machine, performing light hand or arm work, (2) moderate work (200 to 350 kcal/hr): for example, walking about with moderate lifting and pushing, and (3) heavy work (350 to 500 kcal/hr), for example, pick and shovel work.

Workers should be encouraged to salt their food abundantly during the hot season and particularly during hot spells. If the workers are unacclimatized, salted drinking water shall be made available in a concentration of 0.1% (1g NaCl to 1.0 liter). The added salt shall be completely dissolved before the water is distributed, and the water shall be kept reasonably cool.

Engineering Controls

1. General ventilation: General ventilation is used to dilute hot air with cooler air (generally cooler air that is brought in from the outside). This technique clearly works better in cooler climates than in hot ones. A permanently installed ventilation system usually handles large area or entire buildings. Portable or local exhaust systems may be more effective or practical in smaller areas.
2. Air treatment/air cooling: It differs from ventilation because it reduces the temperature of the air by removing heat (and sometime humidity) from the air.
3. Air conditioning: It is a method of air cooling, but it is expensive to install and operate. The alternative to air conditioning is the use of chillers to circulate cool water through heat exchangers over which air from the ventilation system is then passed; chillers are more efficient in cooler climates or in dry climates where evaporative cooling can be used.
4. Local air cooling: It can be effective in reducing air temperature in specific areas. Two methods have been used successfully in industrial settings. One type, cool rooms, can be used to enclose a specific workplace or to offer a recovery area near hot jobs. The second type is a portable blower with built-in air chiller. The main advantage of a blower, aside from portability, is minimal set-up time.
5. Another way to reduce heat stress is to increase the air flow or convection using fans in the work area (as long as the air temperature is less than the worker's skin temperature). Changes in air speed can help workers stay cooler by increasing both the convection heat exchange (the exchange between the skin surface and the surrounding air) and the rate of evaporation. Because this method does not actually cool the air, any increases in air speed must impact the worker directly to be effective. If the dry bulb temperature is higher than 35°C (95°F), the hot air passing over the skin can actually make the worker hotter. When the temperature is more than 35°C (95°F) and the air is dry, evaporative cooling may be improved by air movement, although this improvement will be offset by the convective heat. When the temperature exceeds 35°C (95°F) and the relative humidity is 100%, air movement will make the worker hotter. Increases in air speed have no effect on the body temperature of workers wearing vapour-barrier clothing.
6. Heat conduction: These methods include insulating the hot surface that generates the heat and changing the surface itself.
7. Simple engineering controls, such as shields, can be used to reduce radiant heat, i.e. heat coming from hot surfaces within the worker's line of sight. Surface

that exceed 35°C (95°F) are sources of infrared radiation that can add to the worker's heat load. Flat black surfaces absorb heat more than smooth, polished ones. Having cooler surfaces surrounding the worker assists in cooling because the worker's body radiates heat toward them.

With some sources of radiation, such as heating pipes, it is possible to use both insulation and surface modifications to achieve a substantial reduction in radiant heat. Instead of reducing radiation from the source, shielding can be used to interrupt the path between the source and the worker. Polished surfaces make the best barriers, although special glass or metal mesh surfaces can be used if visibility is a problem.

Shields should be located so that they do not interfere with air flow, unless they are also being used to reduce convective heating. The effective surface of the shield should be kept clean to maintain its effectiveness.

Administrative Controls and Work Practices

1. Training is the key to good work practice. Unless all employees understand the reasons for using new, or changing old, work practices, the chances of such a programme succeeding are greatly reduced.
2. Hot jobs should be scheduled for the cooler part of the day, and routine maintenance and repair work in hot areas should be scheduled for the cooler seasons of the year.
3. NIOSH (1986) states that a good heat stress training programme should include at least the following components:
   a. Knowledge of the hazards of heat stress;
   b. Recognition of predisposing factors, danger signs, and symptoms;
   c. Awareness of first-aid procedures for, and the potential health effects of heat stroke;
   d. Employee responsibilities in avoiding heat stress;
   e. Dangers of using drugs, including therapeutic ones, and alcohol in hot work environments;
   f. Use of protective clothing and equipment; and
   g. Purpose and coverage of environmental and medical surveillance programme and the advantages of worker participation in such programme.

Worker Monitoring Programme

1. Every worker who works in extraordinary conditions that increase the risk of heat stress should be personally monitored. These conditions include wearing semipermeable or impermeable clothing when the temperature exceeds 21°C (69.8°F), working with extreme metabolic loads (greater than 500 kcal/hour).
2. Personal monitoring can be done by checking the heart rate, recovery heart rate, oral temperature, or extent of body water loss.
3. To check the heart rate, count the radial pulse for 30 seconds at the beginning of the rest period. If the heart rate exceeds 110 beats per minutes, shorten the next work period by one-third and maintain the same rest period.
4. The recovery heart rate can be checked by comparing the pulse rate taken at 30 seconds (P_1) with the pulse rate taken at 2.5 minutes (P_3) after the rest break starts. The two pulse rates can be interpreted as mentioned in heart rate recovery criteria.
5. Oral temperature can be checked with a clinical thermometer after work but before the employee drinks water. If the oral temperature taken under the tongue exceeds 37.6°C, shorten the next work cycle by one third.
6. Body water loss can be measured by weighing the worker on a scale at the beginning and end of each work day. The

Heart rate recovery criteria		
Heart rate recovery	*P_3 pattern*	*Difference between P_1 and P_3*
Satisfactory recovery	<90	–
High recovery (conditions may require further study)	90	10
No recovery (may indicate too much stress)	>90	<10

worker's weight loss should not exceed 1.5% of total body weight in a work day. If a weight loss exceeding this amount is observed, fluid intake should increase.

Other Administrative Controls

The following administrative controls can be used to reduce heat stress:

1. Reduce the physical demands of work, e.g. excessive lifting or digging with heavy objects.
2. Provide recovery areas, e.g. airconditioned enclosures and rooms.
3. Use shifts, e.g. early morning, cool part of the day, or night work.
4. Use intermittent rest periods with water breaks.
5. Use relief workers.
6. Use worker pacing.
7. Assign extra workers and limit worker occupancy or the number of workers present, especially in confined or enclosed spaces.
8. Pre-employment medical examination with physical fitness test.

Personal Protective Equipment

A. Reflective clothing: It can vary from aprons and jackets to suits that completely enclose the worker from neck to feet can stop the skin from absorbing radiant heat. However, since most reflective clothing does not allow air exchange through the garment, the reduction of radiant heat must more than offset the corresponding loss in evaporative cooling. For this reason, reflective clothing should be worn as loosely as possible. In situations where radiant heat is high, auxiliary cooling systems can be used under the reflective clothing.

B. Auxiliary body cooling: (1) Ice vest: Commercially available ice vest, though heavy, may accommodate as many as 72 ice packets, which are usually filled with water. Carbon dioxide (dry ice) can also be used as a coolant. The cooling offered by ice packets lasts only 2 to 4 hours in moderate-to-heavy heat loads, and frequent replacement is necessary. However, ice vest does not encumber the worker and thus permit maximum mobility. Cooling with ice is also relatively inexpensive. (2) Wetted clothing: It is another simple and inexpensive personal cooling technique. It is effective when reflective or other impermeable protective clothing is worn. The clothing may be wetted terry cloth coveralls or wetted two-piece, whole-body cotton suits. This approach to auxiliary cooling can be quite effective under conditions of high temperature and low humidity, where evaporation from the wetted garment is not restricted. (3) Water-cooled garments: These are ranged from a hood, which cools only the head, to vests and 'long johns', which offer partial or complete body cooling. Use of this equipment requires a battery-driven circulating pump, liquid-ice coolant, and a container. Although this system has the advantage of allowing wearer mobility, the weight of the components limits the amount of ice that can be carried and thus reduces the effective use time. The heat transfer rate in liquid cooling systems may limit their use to low-activity jobs; even in such jobs, their service time is only about 20 minutes per pound of cooling ice. To keep outside heat from melting the ice, an outer insulating jacket should be an

integral part of these systems. (4) Circulating air: It is the most highly effective, as well as the most complicated, personal cooling system. By directing compressed air around the body from a supplied air system, both evaporative and convective cooling is improved. The greatest advantage occurs when circulating air is used with impermeable garment or double cotton overalls. One type, used when respiratory protection is also necessary, forces exhaust air from a supplied-air hood (bubble hood) around the neck and down inside an impermeable suit. The air then escapes through openings in the suit. Air can also be supplied directly to the suit without using a hood in three ways: by a single inlet, by a distribution tree, or by a perforated vest. In addition, a vertex tube can be used to reduce the temperature of circulating air. The cooled air from this tube can be introduced either under the clothing or into a bubble hood. The use of a vertex tube separates the air stream into a hot and cold stream; these tubes also can be used to supply heat in cold climates. Circulating air, however, is noisy and requires a constants source of compressed air supplied through an attached air hose. The problem with this system is the limited mobility of workers whose suits are attached to an air hose. Another is that of getting air to the work area itself. These systems should therefore be used in work areas where the workers are not required to move around much or to climb. Another concern with these systems is that they can lead to dehydration. The cool, dry air feels comfortable and the worker may not realize that it is important to drink liquids frequently.

(C) Respirator usage: The weight of a self-contained breathing apparatus (SCBA) increases stress on a worker, and this stress contributes to overall heat stress. Chemical protective clothing such as totally encapsulating chemical protection suits will also add to the heat stress problem.

Medical Evaluation of Workers in Hot Jobs

Employees assigned to work in hot jobs should be medically screened at the following times:

1. Pre-employment medical examination: A good occupational medical history should be obtained. Personal history like smoking and drug or alcohol use should be taken. Cardiovascular, respiratory, gastrointestinal, skin, liver and biliary, and renal and urinary systems need to be reviewed. The musculoskeletal systemic review is considered an important component of the overall review, overlapping general fitness status. Psychological (and behavioral) disorders should be taken into consideration, including past history of mental illness. The sensory organs, including vision, hearing, etc. have a bearing on the individual's total health picture. Physical examinations and physical fitness should be done.
2. Periodical medical examination: It is recommended that employees in hot jobs below the age of 45 years undergo medical examinations every two or three years subject to the medical history, clinical judgment, and any unforeseen job conditions. At 45 and thereafter, employees previously selected for work in hot areas at the highest level should receive annual periodical examinations. In assessing the worker's capacity of continue on the same job, the medical examiner might consider and request physiologic monitoring on the job to especially observe recovery heart rates and oral temperature responses.
3. Return-to-work examination after absence of greater than 7 calendar days due to the illness and injury.
4. Special examination whenever considered medically necessary by plant

management on an individual basis or on a physician's recommendation.

Evaluation of each employee for work in hot areas must be on an individual basis, and the final decision as to suitability should be made by the examining physician only after analysis of various types of information, such as:

1. Medical history: (a) General medical history and system review, (b) occupational history with emphasis on any past heat disorders or illness and (c) history of work performance in heat stress jobs.
2. Physical condition: (a) Physical fitness, (b) age, (c) excessive weight, (d) pregnancy and (f) other clinical findings.
3. Diseases (especially chronic): (a) Those interfering with oxygen uptake and/or exchange, particularly atherosclerotic heart disease and chronic pulmonary disease, either restrictive or obstructive, (b) other type of significant acquired or congenital heart disease, (c) circulatory disease, (d) hepatic disease, (e) drug or alcohol intake habits, (f) diseases causing increased body metabolism, (g) renal disease, (h) any medical problems requiring sodium intake restriction, (i) mental illness and psychological disorders and (j) impairment of verbal communication ability.
4. Medications: (a) Hypotensive agents, (b) diabetics, (c) belladonna alkaloids, (d) sedatives and (e) tranquilizers, antidepressants, amphetamines.
5. Other factors: (a) Type of work (light, moderate, heavy), (b) intensity of heat exposure (low, intermediate or high level) and (c) presence of adequate engineering controls, work practices such as rest periods, training and education, personal protective measures and work clothes.
6. In unusual cases, a more thorough determination of heat stress responses may have to be made. In such instances, factors to be considered would include: (a) Job evaluation at the work site, which should involve such factors as heart rate and body core temperature determinations and other physiological responses and their variation in response to the job and heat stress and (b) physical examination with ancillary tests.

Precautions for Some Other Medical Conditions

1. *Myocardial infarction:* A history of myocardial infarction within the past year is sufficient cause for rejection from work under hot condition.
2. *Renal impairment*: Any evidence of renal impairment must also be investigated to determine the underlying basis before a decision can be taken.
3. *Hearing impairment*: A procedure must be devised for the deaf worker who is unable to communicate in order to enable that person to express any deterioration of fitness or the feeling of well-being during work.
4. *Anaemia*: In men, haemoglobin less than 13 g may be considered for up to moderate work in a hot environment; in women, haemoglobin under 12 g may preclude preplacement in a hot job.
5. *Sickle cell*: The presence of sickle cell trait does not limit participation in strenuous physical activity. Since sudden death is most frequently caused by coronary artery disease or other congenital cardiac abnormalities, imputing any undue risk of sudden death to persons with sickle cell trait appear unjustified.
6. *Toxic substances and other factors*: Heat exposure on the job may increase the hazard to some toxic substances (e.g. carbon monoxide) or increase the workers' susceptibility to other physical stresses, such as work at high or low barometric pressure. Dehydration from uncompensated loss of water and electrolytes may impair the tolerance for toxic agents.

Work practice for hot jobs as recommended by the Standard Advisory Committee on Heat Stress of OSHA

Compulsory work practices for all hot jobs	*Special work practices for hot job*	*Work practices required for extreme heat exposure only*
Adequate water supply, acclimatization, first-aid training, training of workers for health and safety procedures and work practices, in case of heat illness, the WBGT (wet bulb globe temperature) must be assessed on the site	Engineering controls, work–rest regimen, additional acclimatization, adaptive work scheduling, protective clothing and/or equipment, freedom to interrupt work during extreme discomfort	Duration of exposure time regulated by experienced workers' judgment (freedom to interrupt work during extreme discomfort), pre-placement and periodical medical examination (also required in any hot job if work load is heavy), observation by trained supervisor, protective clothing (mandatory)

7. *Reproductive effects*: There are possible effects on reproductive functions resulting from high environmental temperature, particularly with respect to embryonic or fetal development. It has been reported that hyperthermia in human pregnancy may cause harm to the developing nervous system in the early pregnancy. Some men in their hot jobs are concern about their sexual potency. Heat stress may be the partial cause for their apparent impotency.

Measurement of Wet Bulb Globe Temperature

Measurement is often required of those environmental factors that most nearly correlate with deep body temperature and other physiological responses to heat. At the present time, the wet bulb globe temperature index (WBGT) is the most used technique to measure these environmental factors. WBGT index is by far the most widely used throughout the world. It was developed in a US Navy investigation into heat casualties during training as an approximation to the more cumbersome corrected effective temperature (CET), modified to account for the solar absorptivity of green military clothing (ILO, 1998). The determination of WBGT requires the use of a black globe thermometer, a natural wet-bulb thermometer and a dry bulb thermometer (ACGIH, 2004).

WBGT values are calculated by the following equations:

Indoor or outdoor wet bulb globe temperature index:

Indoor or outdoor with no solar load:

$$WBGT = 0.7\ NWB + 0.3\ GT$$

Outdoor with solar load:

$$WBGT = 0.7\ NWB + 0.2\ GT + 0.1\ DB$$

where WBGT = Wet bulb globe temperature
NWB = Natural wet bulb temperature
DB = Dry bulb (air) temperature
GT = Globe thermometer temperature

The determination of WBGT requires the use of a black globe thermometer, a natural (static) wet bulb thermometer, and a dry-bulb thermometer. The measurement of environmental factors shall be performed as follows:

1. The range of the dry and the natural wet bulb temperature should be –5°C to +50°C. The dry-bulb thermometer must be shielded from the sun and the other radiant surfaces of the environment without restricting the airflow around the bulb. The wick of the natural wet bulb thermometer should be kept wet with distilled water for at least one-half hour before the temperature reading is made. It is not enough to immerse the other end of the wick into a reservoir of distilled

water and wait until the whole wick becomes wet by capillarity. The wick must be wetted by direct application of water from a syringe one-half hour before each reading. The wick must cover the bulb of the thermometer and an equal length of additional wick must cover the stem above the bulb. The wick should always be clean, and new wicks should be washed before using.

2. A globe thermometer, consisting of a 15 cm (6-inch) in diameter hollow copper sphere painted on the outside with a matte black finish, or equivalent, must be used. The bulb or sensor of the thermometer (range –5°C to +100°C with an accuracy of ±5°C) must be fixed in the centre of the sphere. The globe thermometer should be exposed at least 25 minutes before it is read.
3. A stand should be used to suspend the three thermometers so that they do not restrict free air flow around the bulbs and the wet-bulb and globe thermometer are not shaded.
4. It is permissible to use any other type of temperature sensor that gives a reading similar to that of a mercury thermometer under the same conditions.
5. The thermometers must be placed so that the readings are representative of the employee's work or rest areas, as appropriate.

Once, the WBGT has been estimated, employers can estimate workers' metabolic heat load (as per activity example and assessment of work) and use the ACGIH method of determine the appropriate work/rest regimen, clothing and equipment to use to control the heat exposure of workers in their facilities.

Conclusion

Scientific and technological advances in ergonomics/human factors have greatly contributed to the health promotion and comfort of workers in different working environments around the world. Nevertheless, the heat stress is one of the damaging factors to be treated in various industries and jobs.

Human beings live their entire lives within a very small range of internal temperatures. The maximum tolerance limits for living cells range from about 0°C to about 45°C, however, humans can tolerate internal temperatures below 35°C or above 41°C for only very brief periods. To maintain the internal temperature within these limits, people have developed very effective and, in some instances, specialized physiological responses to acute thermal stresses. These responses-designed to facilitate the conservation, production or elimination of body heat-involve the finely controlled coordination of several body systems (ILO, 1998).

The cardiovascular system is under considerable strain when a person is working in hot environment. In such a situation, peripheral vasodilatation requires an increase in blood flow to the skin and working muscles demands increased blood supply. In long run, worker becomes dehydrated; sweat production decreases and core body temperature increases.

In extreme situations, the thermoregulatory system may be unable to cope. If core body temperature rises above 42°C, blood pressure may drop and insufficient blood is pumped to the vital organs including the heart, kidney and brain. Under such a condition, a worker will collapse with heat stroke (Bridger, 1995).

The committee on biological markers of the National Council (NRC) divided biomarkers into three types: Exposure, effect and susceptibility (NRC, 1989). Clearly, a continnum exists between biologic markers of exposure and effect that can be extended to a continuum between source and disease (Lioy, 1990).

COLD INJURY

Introduction

The primary physiological responses to cold exposure are peripheral vasoconstriction, piloerection, and the increase in metabolic heat production by shivering. Skin temperature falls first, a result of local cooling without a corresponding increase in the delivery of heat to the skin by the flow of blood. This fall in skin temperature stimulates peripheral cold receptors and leads to both locally mediated and centrally regulated vasoconstriction, which in turn allows a further fall in skin temperature. If the rest of the body is sufficiently warm, cyclical cold vasodilatation ('cold induced vasodilatation' or the 'hunting reaction') may ensue, with skin temperatures falling below 12°C, rising with the vasodilatation, and then falling again. The mechanism responsible for this phenomenon remains controversial, but extensive experimentation has shown that it is very variable between and within individuals, and absent if the rest of the body is cold. Sustained peripheral vasoconstriction may be accompanied by fluid shifts resulting in a reduction in plasma volume. Shivering first appears as short bursts in a few groups of muscles, becoming continuous and generalized as a rectal temperature of about 35°C is reached. Further cooling or exhaustion results in shivering gradually tailing off, until it is replaced by generalized rigidity and finally the flaccidity of imminent death.

The list of workers potentially exposed to cold and/or cold wet working conditions is long: Airline maintenance crew, cooling room workers, divers, dry-ice workers, fishermen, ice makers, liquefied gas workers, military personnel, miners, refrigerated warehouse workers, snow removal crews, maintain engineers, food processors in chilled environments and farmers, forestry workers as well as all other outdoor workers in temperate winter and colder conditions.

Time limits that have been recommended for working for various temperature (source: NSC Data Sheet 465, Cold room testing of gasoline and diesel engines) are available. Efforts have been made to develop indices for evaluating cold environments such as the indices for evaluating hot environments. The 'wind chill index' probably is the best known and most used of these indices; the 'shiver index' is another. All have their limitations, as do those for heat stress; but under the right conditions, the information they yield can be useful guidelines.

Physiology of Cold Exposure

The dominating metabolic need of the human body exposed to cold is to maintain core body temperature. Specific physiologic responses enable humans to do this during exposure to mild or moderate degree of cold. However, these are limited and can be overwhelmed with subsequent progressive physiologic and anatomic damage. Because these defense mechanisms are limited, we must depend on

Low-temperature time limits

Temperature range	*Maximal daily exposure*
30°F to 0°F (–1°C to –17°C)	No exposure time limit, if the person is properly clothed
0°F to –30°F (–17°C to –34°C)	Total cold-room work time: 4 hours. Alternate 1 hour in and 1 hour out of chamber
–30°F to –70°F (–34°C to –56°C)	Two periods of 30 minutes each, at least 4 hours apart. Total cold-room work time allowed: 1 hour.
–70°F to –100°F (–56°C to –73°C)	Maximal permissible cold-room work time: 5 minutes over an 8-hour working day. For these extreme temperatures, the wearing of a completely enclosed headgear, equipped with a breathing tube running under the clothing and down the leg to preheat the air, is recommended

Shiver index		
Temperature		*Time to shivering (hours)*
°F	°C	
10	–12	6.0
0	–17	5.0
–10	–23	4.0
–20	–28	2.5
–30	–34	2.0
–40	–40	1.5
–70	–56	0.4

Source: Cold and the worker, National Safety News 100(6):98, 1969.

Shivering is the body's attempt to warm itself. This table shows how long a man can stay in subfreezing weather before temperatures in his extremities drop below 55°F (13°C) and he starts to shiver violently. The table is based on a man dressed in heavy Arctic clothing, boots, and mittens for light, sedentary work.

external protective measures to survive and work under very cold conditions.

The conscious detection of cold temperature by humans depends on cold receptors found in the skin. These are cutaneous nerve endings, but they are not anatomically discrete, specialized organs. They function alone when cold is moderate, but pain receptors are triggered as cold becomes more intense, and pain receptors dominate peripheral cutaneous response altogether at very low temperatures. Sensation is lost entirely when tissue freezes, and local anesthesia occurs in the frozen area. This peripheral nervous response is fed to the hypothalamus, which maintains central control of core body temperature. The hypothalamus response to cold is directly affected by blood temperature and a multiplicity of other signals, in addition to those primary signals sent by the peripheral cold receptors. The hypothalamus, when stimulated by signals of a cold environment, responds with feedback and triggers available body defensive mechanisms to cold. Hypothalamic control is lost, however, when core body temperature falls below a minimum point.

Body defenses capable of being triggered are either increased (i.e. heat production resulting from increased metabolic activity) or decreased (i.e. heat loss resulting from reduced peripheral blood flow). Superficial vasoconstriction occurs as temperature of the air in contact with the skin falls, and heat loss is then reduced. As heat loss continues, shivering begins, and decreased metabolic rate is generated by this intense muscular activity. The superficial circulation in the limbs is quite responsive to cold, and the regulation of core body temperature is both protected by and dependent upon the heat balance of the extremities. Core body temperature must be maintained for the limbs to be warmed, and increased metabolic heat resulting from exercise results in increased warming of the extremities.

Body Heat Loss in Cold Environment

Bodily heat losses in cold environments by conduction, convection and radiation. When protective coverings are wet, heat may also be lost by evaporation. Therefore, evaporation loss via the skin is limited to situations in which clothing becomes wet from sweat or from outside moisture in a cold environment. Conductive loss will occur when there is contact with a cold surface. However, loss of heat by convection will occur as warmed air around the body rises. There is very efficient forced convective heat loss when there is wind. This effect is known as the 'wind chill factor'. Radiant heat loss occurs when surrounding surfaces are cold. Human skin absorbs heat from surroundings of higher temperature and loses heat to surroundings of lower temperature. Consequently, the most dangerous and rapid heat loss takes place when clothing is wet, wind is high, and surroundings are cold, or when the human body is immersed in cold water.

Assessment of Cold Stress

The dominant components of cold stress are the temperature and nature (air or water) of the fluid surrounding the body. Wind speed, and to a lesser extent water movement, can