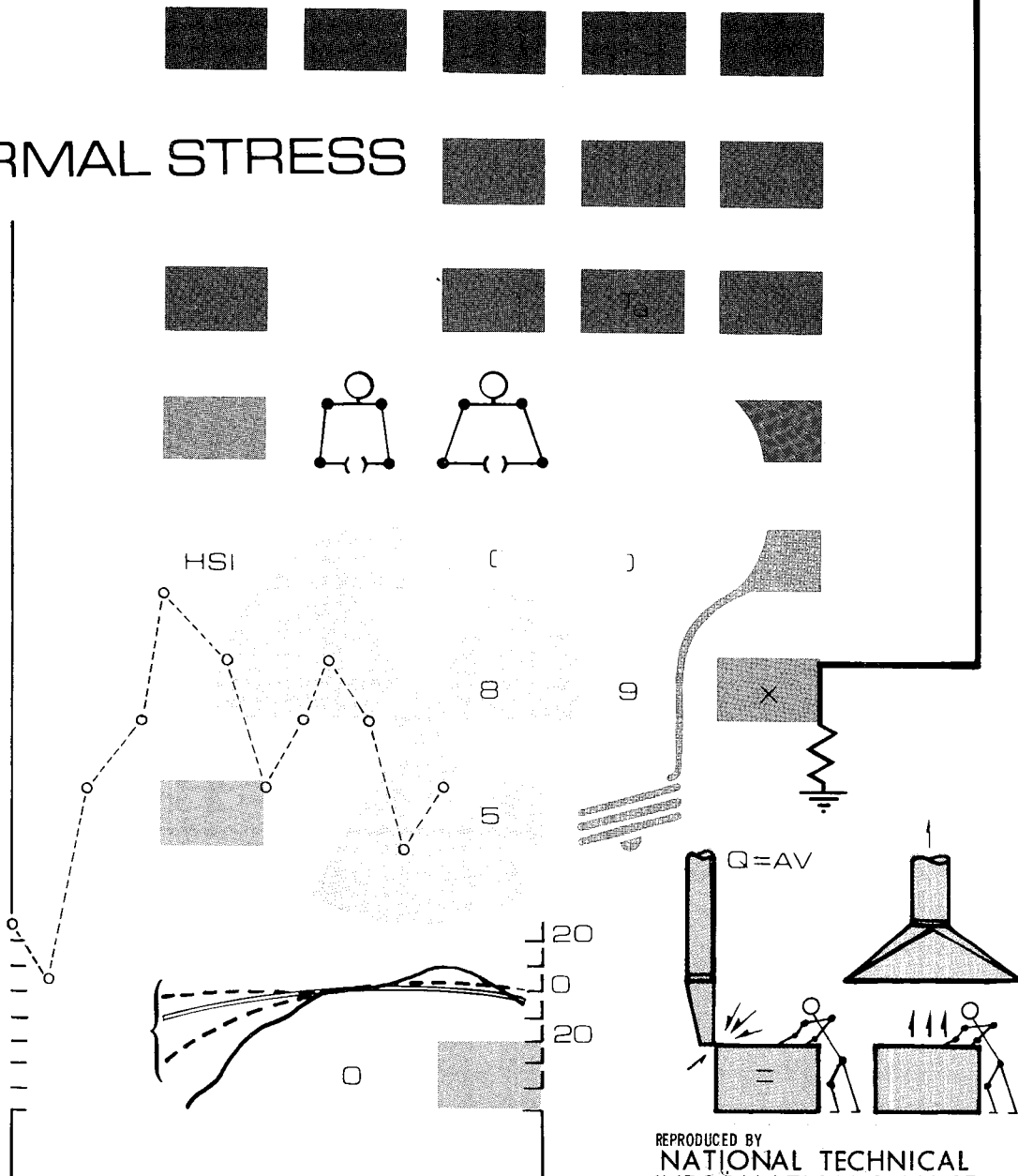


552

INDUSTRIAL HYGIENE ENGINEERING & CONTROL

THERMAL STRESS



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Student
Manual

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

Division of Training and Manpower Development

INTRODUCTION TO INDUSTRIAL HYGIENE ENGINEERING AND CONTROL (552)

This is a modularized course designed for use as a one, two, or three week short course or as a one or two semester academic course at either the undergraduate or graduate level. It examines the fundamentals for design of controls to eliminate or satisfactorily deal with occupational health hazards. Lectures, augmented by problem solving sessions, are intended to assist the trainee in selecting, designing, and applying control methods in the work environment. Primary attention is given to industrial ventilation, noise and vibration control, heat stress, and industrial illumination as well as new engineering topics.

The training course manual has been specially prepared for the trainees attending the course and should not be included in reading lists of periodicals as generally available.

Section 3 — Student Manual

THERMAL STRESS

Division of Training and Manpower Development
National Institute for Occupational Safety and Health

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control

Cincinnati, Ohio

November 1978

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FOREWORD

This text is designed for use by individuals at an advanced level of study in industrial hygiene. The emphasis is on the control of exposures to occupational health hazards. A series of lesson plans has been developed around the material presented in the text that can be utilized in a formal classroom setting for presentation as a course or a series of courses.

The text was developed under the sponsorship of the National Institute for Occupational Safety and Health, Division of Training and Manpower Development, Cincinnati, Ohio (Contract CDC-210-75-0076). Serving as Project Officer for the development of the text and lesson plans was Robert B. Weidner, J.D., Branch Chief, Division of Training and Manpower Development.

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INTRODUCTION

The creation of this text came out of an attempt to design a course to teach the fundamentals of industrial hygiene engineering as related to the design of controls for exposure to health hazards in the workplace. During the design of the course, it was necessary to research the existing literature in the field of industrial hygiene. As this research was being conducted, it became evident that no single source provided sufficient coverage of the subject to be adequate for use as a text for the course. In fact, to the dismay of the authors, the subject of control received very little attention in many of the existing texts on industrial hygiene. For the most part, existing texts emphasize the recognition, measurement and evaluation of occupational health hazards. Though this is an important concern of the industrial hygienist, the sparse coverage of control topics indicated a need for an additional text.

The objective of this text is to fill this gap that was discovered; to provide a text that can act as a single reference source on the subject of industrial hygiene engineering and control. In the preparation of this text, the authors soon discovered a reason for the prior omission of such a single source. The control of occupational health hazard exposures requires a broad knowledge of a number of subject areas. To provide a text that includes the necessary theoretical foundation as well as the practical application of the theory is a significant undertaking. It is the hope of the authors that in some way the objective has been reached and that this text will prove to be a valuable and needed addition to the literature of industrial hygiene.

A second objective, or perhaps a hidden agenda, during the preparation of this text was to provide the reader with a systematic approach to problem solving in the field of industrial hygiene. Throughout the text, the systems approach to problem solving is emphasized. In fact, at one point consideration was given to titling the text "A Systems Approach to Industrial Hygiene Control." The systems approach has been utilized effectively in the area of occupational safety: witness the many texts on the topic of systems safety. However, the same emphasis has not been found in industrial hygiene. Systems analysis techniques are not limited in their application and thus should be equally applicable and useful to the field of industrial hygiene as they are to the field of occupational safety.

The text has been divided into eight (8) sections, each of which covers a subject area. This structure allows for reference to a single topic area without the need to consult other sections of the book, thus allowing for the use of the text as a basis for classroom instruction in a number of separate courses. For example, Section 2—Industrial Ventilation can serve as the basis for a one- or two-semester course.

The authors are indebted to the many who labored in the past to develop the field to the level at which it now exists. Much of that which is presented herein does not represent new knowledge but rather a reorganization of existing bodies of knowledge into a single document. Many of those responsible for the original work in the field are referenced within this text.

Bruce B. Byers
Ronald J. Hritz
James C. McClintock
1978

SECTION 3
THERMAL STRESS

CHAPTER 1
HEAT EXCHANGE AND ITS EFFECTS ON MAN

Heat Exchange

Heat is a form of energy, while cold is the absence of heat or the absence of this energy. Quite often there exists a confusion between the terms "heat" and "temperature." Heat itself is a measure of the energy in terms of quantity. Temperature, on the other hand, is a measure of the intensity of the heat or the hotness of an object.

Perhaps a review of two examples presented in Section 2, Chapter 1, will help to clarify the difference between heat and temperature. Consider a large block of iron and a small block of iron that are being heated with the same amount of energy. If the source of energy is removed after a given amount of time, the temperature of the smaller block will be higher than that of the larger block. The same amount of heat has been transferred to the blocks of iron, but the temperature readings differ. On the other hand, suppose a small quantity of water and a large quantity of water are both brought to the boiling point. The temperature of both quantities of water will be the same; i.e., 100°C or 212°F. However, it will take a longer period of time to bring the large quantity of water to the boiling point; thus, the amount of heat required will be greater. In this case, the temperature of each body of water is the same, but the amount of heat required to raise the body to this temperature is different.

Temperature is measured in terms of degrees. This measurement may be in degrees Fahrenheit, degrees Celsius, degrees Kelvin, or degrees Rankine. Conversion from one temperature scale to another can be accomplished using the following formulas:

$$(3.1.1) \quad ^\circ\text{F} = 9/5^\circ\text{C} + 32$$

$$(3.1.2) \quad ^\circ\text{C} = 5/9(^{\circ}\text{F} - 32)$$

$$(3.1.3) \quad ^\circ\text{K} = ^\circ\text{C} + 273$$

$$(3.1.4) \quad ^\circ\text{R} = ^\circ\text{F} + 460$$

Note: The actual values for the constants in (3.1.3) and (3.1.4) are 273.16 and 459.69, respectively. However, the rounded values are accurate enough for most work.

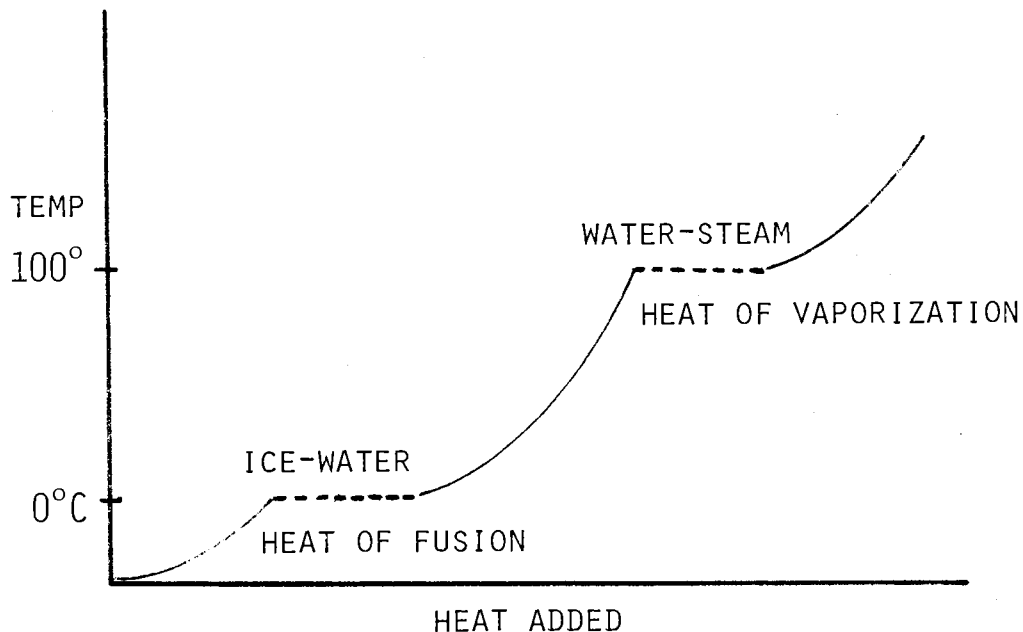
The measurement of heat energy is in terms of either calories or British Thermal Units (BTU). The calorie is defined as the quantity of heat necessary to raise the temperature of 1 gram of water 1°C . Since there is some variance between quantities of heat required depending on the beginning and ending temperature, the calorie is based on a standard temperature of 16.5°C to 17.5°C . The BTU is the quantity of heat necessary to raise the temperature of 1 pound of water 1°F .

Not all materials require the same amount of heat to raise their temperature one degree Celsius or Fahrenheit. The concept of specific heat has been conceived to handle this fact. The specific heat of a material is the quantity of heat that is necessary to raise 1 gram or 1 pound of the substance 1°C or 1°F . Again, this figure is based on a standard of 16.5°C to 17.5°C . The heat capacity is related to the specific heat in that it is the quantity of heat necessary to raise the temperature of a given material 1° . Heat capacity is stated as the amount of heat necessary to raise a unit mass of a substance 1 degree ($^{\circ}\text{C}$ or $^{\circ}\text{F}$ resulting in calories or BTU's).

As heat is added or removed from a substance, there is a point when the substance will undergo a change in phase. That is, the substance, if a solid, will become a liquid or, if a liquid, will become either a solid or a gas. For example, as heat is added to water, it finally reaches a point called the boiling point where the water begins to change its phase to a vapor. On the other hand, as it is removed from water, it reaches a point where it freezes and becomes a solid. The change of phase does not occur instantaneously. A quantity of heat is required to cause this change in phase. As this phase change is occurring, the temperature does not vary, and the heat appears to be lost in the substance. Two concepts have been introduced to quantify this occurrence. The heat of vaporization is the quantity of heat that is required to vaporize one unit mass of a liquid without changing its temperature. The heat of fusion is the quantity of heat necessary to melt one unit mass of a solid without changing its temperature. The concept of enthalpy or stored energy is somewhat similar to that of heat absorbed during a change of phase.

Figure 3.1.1

CHANGE OF PHASE

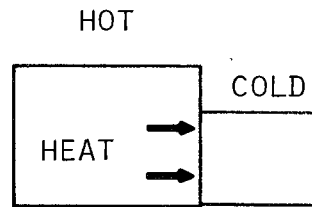


Since heat is energy, a hot body has more energy than a cold body, given the same mass and material for both bodies. The flow of energy is from the highest to the lowest level. Thus, a hot body gives off heat or energy to a colder body. A process in which heat is given off is termed an exothermic process. The converse, or a process in which heat is absorbed, is called an endothermic process.

Methods of Heat Exchange. There are three basic methods for the transfer or exchange of heat between materials. The first method of exchange is by conduction. In conduction heat passes from one part of the body to another. If two bodies are in direct contact, the heat will pass from one body directly to the other as if the two bodies were one single body. Conduction takes place only if a difference in temperature exists between the two bodies or parts of a single body. The conduction of heat is different for different materials. Metals usually conduct heat well; solids are generally better conductors of heat than liquids; and gases are the poorest conductors. For the most part, conduction is of little importance when considering problems involving hot environments and heat stress situations since the worker must be in contact with the surface for conduction to take place.

Figure 3.1.2

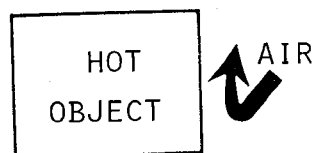
CONDUCTION



The second method of heat transfer is convection. Convection is a process where the transfer of heat occurs as a result of the movement of a fluid past a source of heat. The rate of convection is affected by the characteristics of the fluid that is moving past the source of heat, the surface of the heat source, the position of the source surface, the velocity of the fluid, and the relative temperature of the source and fluid. In most situations, the fluid is air; and the heat is transferred to the surrounding environment by induced air current movement. Convection itself causes the movement of the fluid. As the air is heated, it expands and becomes lighter. The lighter air rises away from the hot source, and colder air flows in to replace the heated air. The heated air mixes with the environment to cause a general increase in temperature. If the air and source are the same temperature, no movement will be induced. The transfer of heat can be increased by increasing the flow in the fluid using mechanical means. Convection is of major significance as a method of heat transfer in a hot environment. Thus, the industrial hygienist must be very concerned with convective heat transfer.

Figure 3.1.3

CONVECTION



The third method of heat transfer is radiation. Radiation differs from convection and conduction in that no fluid or solid need be present for the heat to be transferred from one object to another. The heat energy is transferred from a hot body to its surroundings in the form of electromagnetic waves or infrared radiation. An example of radiant heat is the thermal energy that is transferred to the earth from the sun. Generally, the wave length of radiant heat is not visible; however, as an object becomes hotter, the wave length shortens and enters the visible spectrum. When an object is termed "red hot," this means that it is hot enough to emanate radiation in the red spectrum which is approximately 700°C . The color of light from the hot object indicates its approximate temperature. Thus, white hot is an extremely high temperature (approximately 1200°C).

Figure 3.1.4

RADIATION



Radiant heat may be either reflected or absorbed. Highly polished surfaces, such as aluminum, are generally good reflectors. On the other hand, black bodies are good absorbers. A common example of this phenomenon can be seen by the fact that dirty snow, which is darker, melts faster than clean, white snow which reflects more of the radiant energy.

The rate of heat exchange by radiation depends on a number of factors. The difference in absolute temperature of the surfaces of the body and its surroundings affects the rate of heat exchange by radiation. If a body and its surroundings are the same temperature, then no radiant heat energy will be transferred from the body to its surroundings. A second factor is the relative emissivity of the body and its surroundings. Emissivity is the ratio of the energy radiated by a given surface and that which would be radiated by a perfect black body at the same surface

temperature. This leads to a general statement of Kirchoff's law of radiation. This law states essentially that a body is as effective as a radiator as it is as an absorber. Thus, a poor absorber is likewise a poor radiator; a good absorber is a good radiator; and a poor absorber is a good reflector. This information is of significant value when determining control methods for radiant heat stress.

Sources of Heat

Two major sources of heat that are of concern to the industrial hygienist are the environment itself and metabolic heat generated by the workers within the environment. In order to provide adequate control of heat within the workplace, it is necessary to identify the source from which this heat is being generated.

Often the climate and the solar radiation that are present generate significant amounts of heat within a workplace. Workers who are required to perform their job functions out of doors in hot climates are subjected to the heat and humidity present in the air as well as solar radiation. These factors are also present within plant structures themselves. Outside air entering a hot plant may be such as to provide no relief from the heat within the plant. Also, solar radiation absorbed by the plant roof can add an additional heat load within the industrial building.

In many cases, the industrial process adds significant heat to the workers' environment. The air temperature may be increased as convectional currents pass by hot processes. Radiation emanating from high temperature processes can provide an additional heat load. Steam that is used in many processes adds not only heat but also humidity to the air. Mechanical and electrical equipment can generate large quantities of heat in their normal operation. Finally, normal plant facilities, such as illumination and steam distribution piping, can also be a significant factor in increasing the overall heat load in the environment.

A second source of heat that is of concern to the industrial hygienist is metabolic heat. Heat is a normal by-product of the body's activity. As the cells work to perform their functions, heat is generated. This heat is generally termed basal heat. If the individual is involved in physical work, additional heat is generated as a by-product of the muscular activity. The basal heat and work heat must be dissipated into the atmosphere, or they can present a hazard to the worker. If the environmental conditions in the workplace do not provide appropriate relief

to the worker for this metabolic and work heat, an accumulation of heat will occur in the worker's body. Such an accumulation of heat can result in various physiological reactions that can be harmful to the worker's health. The resulting heat induced illnesses will be further discussed later in this chapter.

Physiological Responses to Extreme Temperatures

The hypothalamus, located in the base of the brain, is the regulatory center that controls the response of the human system to heat. The hypothalamus acts to attempt to maintain a thermal balance within the body. This balance is maintained with a deep body or core temperature of approximately 37°C (98.6°F). The skin temperature normally varies between 33°C and 34°C (91.4°-93.2°F), but it may be near the core temperature or be 10° lower than the core temperature if the individual is exposed to extreme temperature ranges. The oral temperature that is familiar to all ranges from 36°C to 37°C (97° to 98.6°F).

As the body begins to build up heat, the hypothalamus acts to initiate certain physiological reactions. The heart rate increases and the blood vessels dilate which in turn increases the circulation in the body. This increased blood flow carries heat away from the inner core of the body to the skin surface where heat is dissipated into the surrounding environment. Increased respiratory activity also occurs. In this manner, exhaled air carries heat away from the body. Along with this increased circulation and respiration, the body begins to sweat. The heat of vaporization, that is, the heat necessary to cause a liquid to vaporize, requires a significant expenditure of heat energy. As the body sweats and this sweat is evaporated into the atmosphere, significant amounts of heat are required to cause this vaporization. In this manner, heat generated within the body is dissipated without raising the body temperature.

On the other hand, the absence of heat, or cold, can also present a problem. In general, man's tolerance to cold is less than his tolerance to heat. It is the fact that man wears clothing that makes up for this lack of tolerance and allows him to work in temperatures that are far below that which a nude human would be able to tolerate. The general physiological response that occurs when a human is exposed to extreme cold is shivering. This shivering creates muscle activity and results in the generation of heat. Shivering is the method that the body uses to generate heat to maintain its core temperature in equilibrium.

When the body is exposed to cold, the blood vessels contract to restrict the flow of blood to the surface, thus conserving heat within the core of the body. Humans will also attempt to remain active during exposure to cold thus, though they may not be aware, generating additional heat as a result of this physical activity to maintain thermal equilibrium. The lethal lower core temperature for the human body is 26°C (78°F).

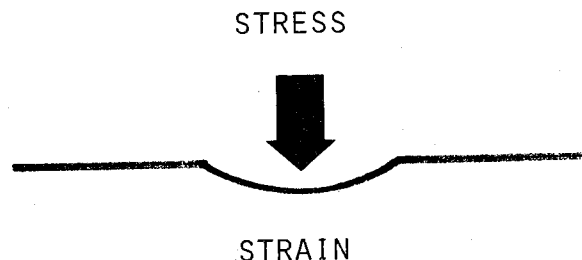
Stress and Strain

Stress is the acting force on the body. Thermal stress is either the presence of excess heat or the absence of sufficient heat. Stress may be thought of as the cause of a given human response.

Strain, on the other hand, is the result of stress. Strain may be thought of as the cost or consequence in the human body of a given stress being placed upon it. When the response of the human system is abnormal, then this is a result of some strain that has been experienced. Strain can be measured in terms of the physiological response, in terms of heart rate, respiratory rate, etc.; or it may be indicated from the disorders that arise.

Figure 3.1.5

STRESS VS. STRAIN



Indicators of Thermal Strain

As was discussed above, the objective of the physiological response of the human system is to maintain a core temperature in equilibrium. If the core temperature drops below 26°C or rises above 41°C (106°F), damage and potential death

will occur. In particular, as the temperature rises above 41°C, the regulating ability of the hypothalamus is depressed. Thus, the body's ability to regulate its temperature is depressed, resulting in a vicious cycle in which the core temperature continues to rise. Only external action, such as an alcohol bath or immersion in cold water, will prevent death to such an exposed individual.

A chain of events is initiated when the human system is exposed to heat stress. The first response of the body is for the regulatory functions to begin to work. If these functions can work properly and if excessive heat stress is not present, the body will attain thermal equilibrium. On the other hand, if the heat stress is such that the regulatory functions cannot control the buildup of heat, the result is a heat disorder.

There are generally four categories of heat disorders that are of interest. The first disorder that is recognized by many medical personnel is termed heat syncope. Because of excessive pooling of the blood in the extremities resulting from the body's attempt to dissipate heat by increased circulatory activity and dilation of the blood vessels, the brain does not receive an adequate supply of oxygen. The result is that the exposed individual loses consciousness. This reaction is similar to heat exhaustion except that it is likely to occur much more quickly without any accompanying physical exertion on the part of the worker. Heat syncope is directly related to the circulatory response of the affected individuals.

A second disorder is heat exhaustion. As the worker performs physical tasks in the hot environment, profuse sweating occurs; and the circulatory and respiratory activity is increased. If the worker sustains the physical activity for an extended time period, the body will become dehydrated and/or the circulatory system will become overworked. The result is that the worker will experience fatigue, nausea, headache, and giddiness. The skin will be moist and clammy, indicating that sweating is still present, but the circulatory system may result in pooling of blood causing fainting to occur. The skin may appear either pale or flushed.

The third disorder that may occur is heat cramps. Heat cramps are a result of profuse sweating that dissipates body salt along with the loss of fluids. The general sign of such a disorder is a painful muscle cramp spasm. Heat cramps are generally caused by sweating and hard work without adequate fluid and salt replacement.

Finally, the most severe heat disorder is heat stroke. Heat stroke is a failure of the body's thermal regulatory system. Unless controlled immediately, heat stroke can result in an increased body temperature beyond which cell damage occurs. Death is likely unless external action is taken to control the rising temperature. Heat stroke is evidenced by hot, dry, red skin, rapid pulse, and an absence of sweating. Figure 3.1.6 illustrates the progression of the human physiological response to heat stress.

In terms of treatment, heat cramps are generally easily prevented by providing adequate salt for the worker. This may be either in the form of salt tablets or in a one-tenth percent (0.1%) salt and water solution that the worker should ingest frequently. For heat syncope, the worker can be acclimatized (to be discussed later in this chapter) or encouraged to remain somewhat active to stimulate return circulation to the heart. If a worker is suffering from heat exhaustion, it is adequate to remove the worker from the source of heat and provide fluid and salt replacement along with adequate rest to allow the body to recover. It should be noted that provision of salt should be done with care since an excess of salt can be harmful to individuals suffering from cardiovascular disorders.

Heat stroke requires immediate positive action. The worker should be removed from the heat and action taken to cool the body, either through cold compresses, immersion in cold water, or an alcohol bath. Fluids should be replaced as soon as possible since one of the initial causes of heat stroke is the dehydration of the body.

EFFECTS OF HEAT STRESS

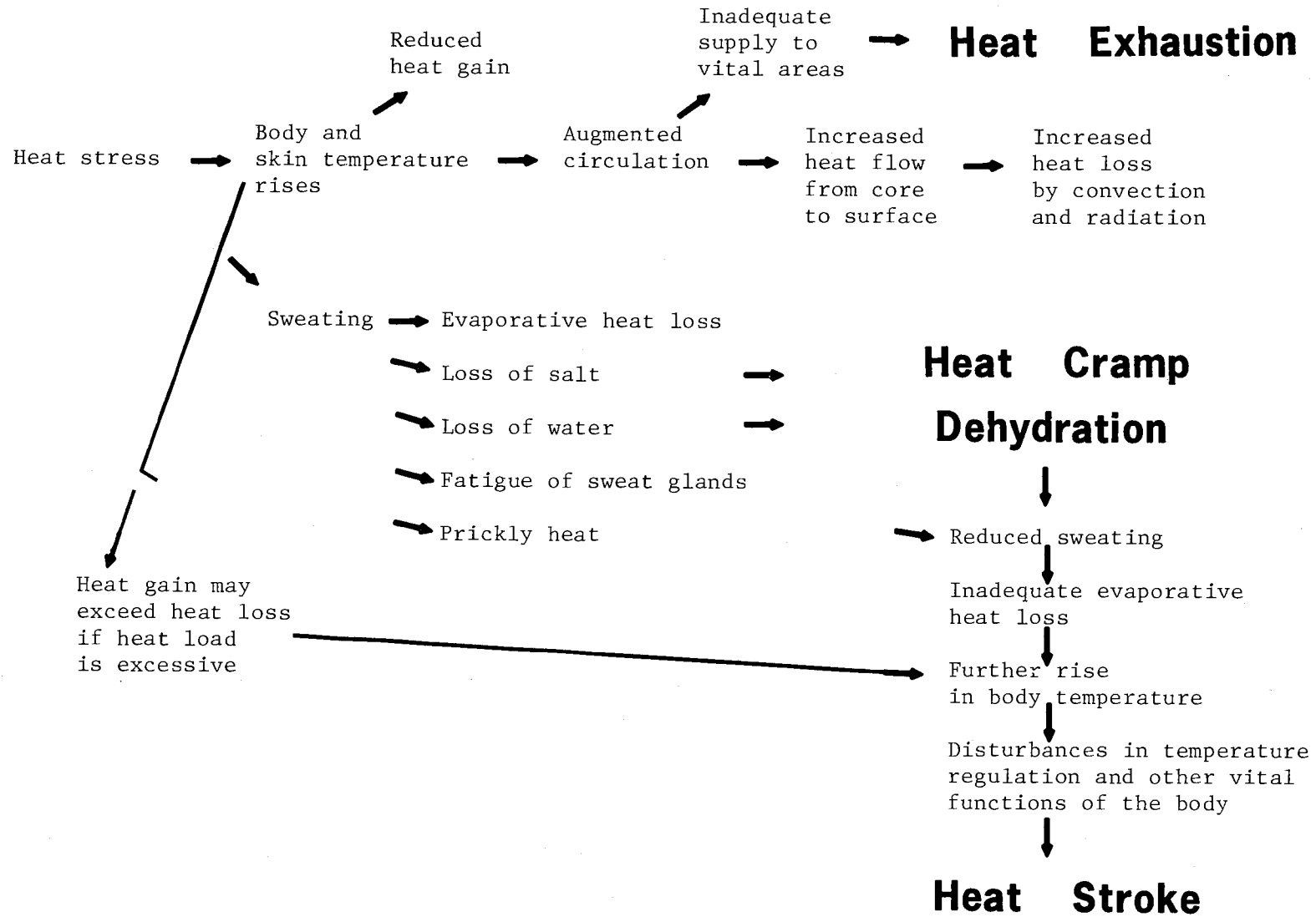


Figure 3.1.6

Factors in Heat Stress

For a given temperature, the thermal stress that is placed on an individual varies. There are a number of factors, both environmental and individual, that cause this variance.

The environmental factors that affect stress are the movement of air, the moisture content of the air, and the radiant heat load. Air movement is important in reducing heat stress. As the air moves past the worker, it carries away vapor from the evaporated sweat on the worker's skin, thus cooling the body. Without such air movement, the body would, in effect, become insulated by the surface sweat and sufficient cooling could not take place.

The moisture content of the air, or humidity, is also of importance. If the vapor pressure in the environment is high, then sweat does not evaporate. As a result, the cooling that normally occurs during the evaporation of sweat does not take place and heat builds up in the body.

The radiant heat load is in addition to that which results from convection and metabolic heat. This heat load can be sufficiently high to produce an excessive thermal stress on the individual even in cases where adequate air movement is present to allow for evaporative cooling.

The thermal stress that occurs in workers varies between given workers as a result of certain individual factors. The surface to weight ratio for a worker is of importance since heat loss is a function of the area, and heat production is a function of the weight. Because of this, obese or stocky individuals are affected by heat more than slender individuals since they produce a greater amount of heat and have a proportionally smaller area in which the heat can be dissipated.

Age is another factor that can affect the physiological response to heat stress. Workers in the range of 40 to 65 years of age are not so tolerant of heat as are younger workers. This may be somewhat as a result of the fact that young workers have a better respiratory and circulatory response system.

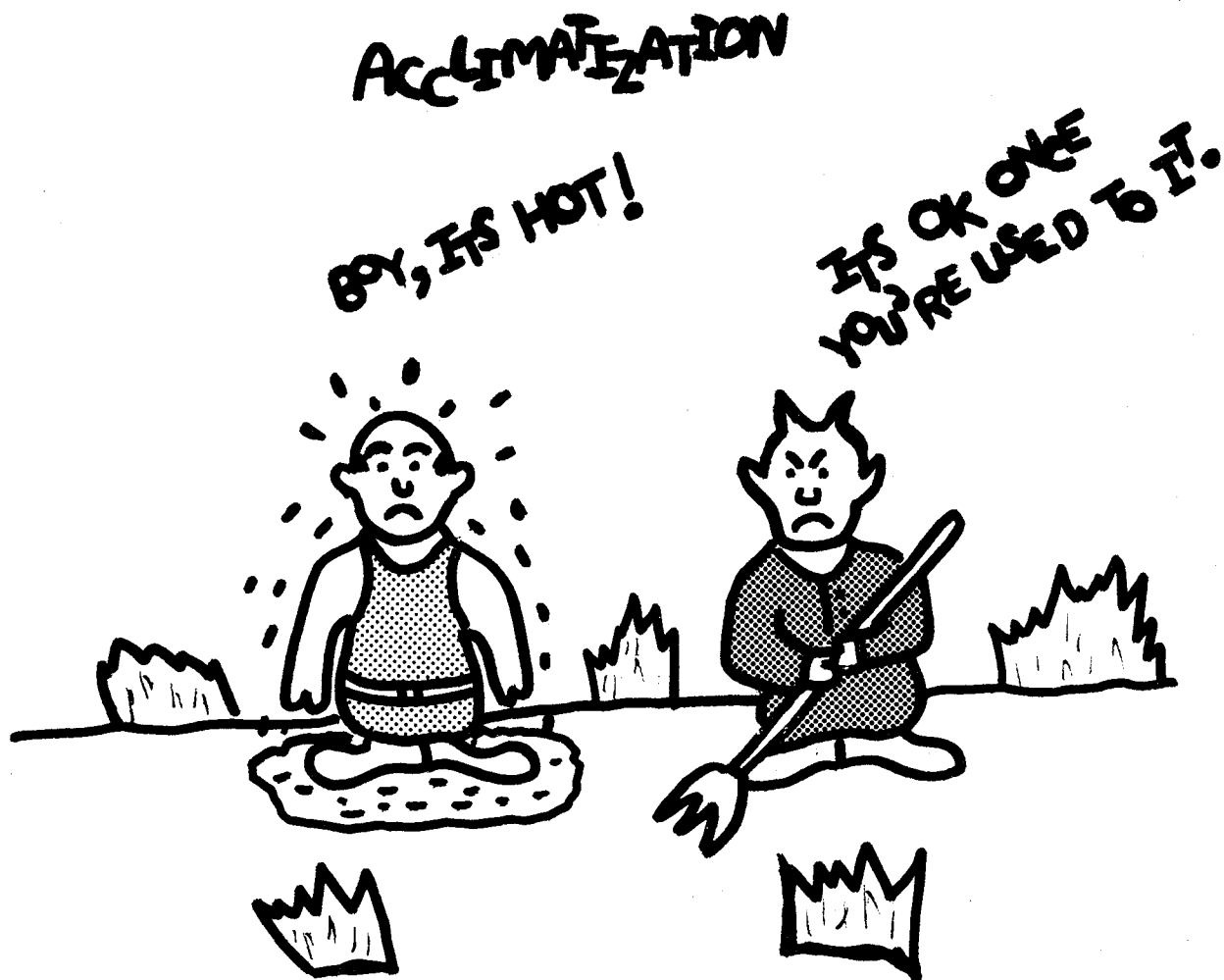
Workers who have a history of cardiovascular disease are especially subjected to strain resulting from heat stress. This is a result of the reduced capacity of the cardiovascular system to react to dissipate heat from the body.

The physical fitness of the worker is also important. Through improved conditioning, the individual develops an increased cardiovascular response and, in addition, an increased efficiency of muscle use. This increased muscular efficiency results in lower heat generation when performing a particular task.

The alcoholic habits of the worker will also affect his tolerance to heat. Alcohol dehydrates the body and, as a result, dehydration can occur more quickly when the worker is subjected to heat stress.

Acclimatization. Experiments have shown that individuals respond to heat stress with strain at the first exposure. If these individuals are exposed regularly to heat stress, the amount of strain is reduced. After one to two weeks of exposure to above normal temperatures, no strain is present. These experiments have led to the practice of acclimatizing workers. During acclimatization, the

Figure 3.1.7



worker is gradually exposed to longer periods of heat stress until the possibility of heat strain is minimized. In general, acclimatized workers exhibit an increased sweat rate (thus, more efficient cooling) with a lower salt loss than those workers who are not acclimatized.

However, acclimatization is lost quickly. In fact, experiments have shown that there is some loss of acclimatization after a weekend away from work. After two weeks away from work, this loss is substantial. Therefore, in order for acclimatization to be effective in reducing heat strain, it must be reinforced regularly.

On the other hand, humans do not generally become acclimatized to cold temperatures. There is no significant difference between the tolerance to cold of Eskimos in Alaska and that of native southern Americans.

Other Effects of Heat Stress. Aside from the physiological effects of heat stress, there are other effects that may result. Psychologically, the individual exposed to heat stress becomes edgy and develops a lassitude toward accomplishing a given task. The performance efficiency of these individuals is lowered, resulting in a potential for increased accidents.

Excessive heat stress can also have an effect on the morale of the worker. As a result, difficulties in handling workers in heat stress areas may be significantly greater than those experienced with workers performing under normal temperature conditions. Also, the performance of individuals exposed to heat stress may be decreased not only as a response to heat but also as a response to the lowered morale of the worker.

Summary

Often within the industrial environment the worker is subjected to extreme temperatures. If these temperatures are above normal, the worker can be subjected to developing illnesses such as heat cramps, heat syncope, heat exhaustion, and heat stroke. In these cases, the thermal load is such that the body's thermal regulatory functions cannot act to dissipate the heat buildup rapidly enough.

Strain resulting from a given thermal stress differs between individuals. Important factors, such as the physical build, age, condition, and alcoholic habits of the worker act to cause these differences to exist.

Upon repeated exposure to thermal stress, the worker can become acclimatized. This acclimatization helps to lower the strain experienced for a given thermal stress.

Practice Exercises

1. A steel steam boiler is fed with water at 52°F. If the boiler contains 500 gallons of water and weighs 1100 pounds itself, how many BTU's will be required to bring the water to boiling point? The specific heat of steel is 0.11.
2. In the above problem, assume that the water is totally vaporized to steam. What temperature will the steam be and how many BTU's will be required? Use standard conditions of pressure and a heat vaporization for water of 972 BTU's per pound.
3. A large furnace operates at 500°F. What methods of heat transfer to the surrounding area are likely to occur? Explain how each method of transfer will occur.
4. If a worker is exposed to the heat generated from the above furnace, what regulatory functions will occur in his body to dissipate the heat?
5. What 4 major disorders is a worker exhibiting heat stress likely to encounter? Explain the symptoms for each disorder and indicate the treatment available.

CHAPTER 2

THERMAL MEASUREMENT

Introduction

When the industrial hygienist sets out to determine the thermal stress to which the worker is subjected, it is quickly recognized that this determination is not a simple one. Obviously the temperature of the work environment is of significant importance. However, temperature alone does not determine thermal stress. The presence of water vapor in the air (humidity) must also be considered since this will be a determining factor in the amount of evaporation of sweat that can occur. Also, the air movement present in the workroom environment must be considered. Without adequate air movement, sweat that is evaporated cannot be carried away from the worker, increasing the vapor pressure around the worker and, thus, reducing the evaporative cooling that can occur. In addition, the industrial hygienist must determine if a radiant heat load is present since radiant heat can be major factor in the thermal stress present in an environment. Also to be considered are the problems associated with the metabolic heat generated by the workers' activities and the individual differences of the workers in response to heat stress. It is obvious, then, that a simple measurement of the temperature of the ambient air in the environment is not sufficient to determine thermal stress.

The temperature reading with which we are all familiar is taken using a dry bulb thermometer. It is obvious from the discussion above that the dry bulb thermometer is not adequate alone for determining the level of thermal stress. Consideration must be given to the presence of water vapor, air movement, radiant heat, and worker activity in order to determine the total thermal stress present in the environment.

Measurement of Air Temperature

Though the measurement of the ambient air temperature is not sufficient to determine the level of heat load that is present, it is necessary that this measurement be a part of the evaluation of the environment. There are various ways to

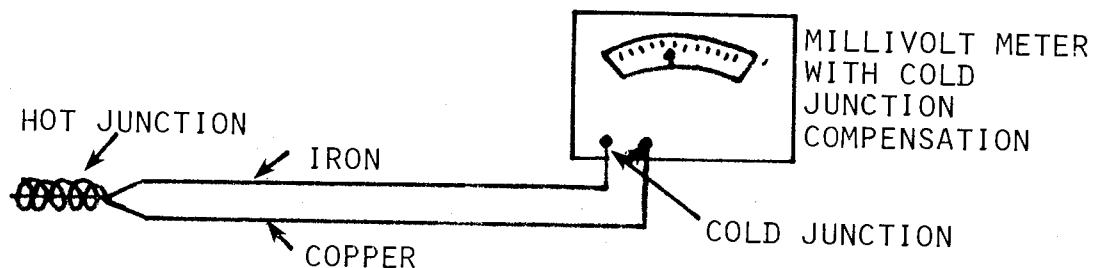
measure the temperature of the ambient air. The first and most common is by using a dry bulb thermometer. A dry bulb thermometer is generally constructed of hollow glass with a column of mercury inside. The thermometer should be graduated by etchings on the stem of the thermometer. The range of the thermometer to be used should be selected to meet the requirements of the thermal environment being measured. A dry bulb thermometer subjected to temperatures beyond its range can break and spill mercury.

Before using a dry bulb thermometer to measure the ambient air, it should be calibrated to assure that it is accurate. In addition, the industrial hygienist should be sure that a total immersion type thermometer has been selected. Partial immersion thermometers, in which only the lower section of the thermometer is used to determine the temperature, exist and will be discussed later. When the measurements are taken, it is important that the dry bulb thermometer be sheltered from any source of radiant heat since the measurement that is desired is that of the ambient air.

The second method that can be used to measure the temperature of the ambient air is a thermoelectric thermometer or thermocouple. The principle of operation of this device is based upon the fact that two dissimilar metals when subjected to a difference in temperature create a small electric current. The thermoelectric thermometer has two junctions; one that is immersed in the ambient air and the other that is held at a reference temperature. A potentiometer or millivolt meter measures the difference in current between the reference surface and the measuring surface. This difference in current is directly related to the difference in temperature that exists between the temperature of the ambient air and the reference temperature. Instruments of this type must be calibrated to assure accuracy in measurement.

Figure 3.2.1

THERMOCOUPLE



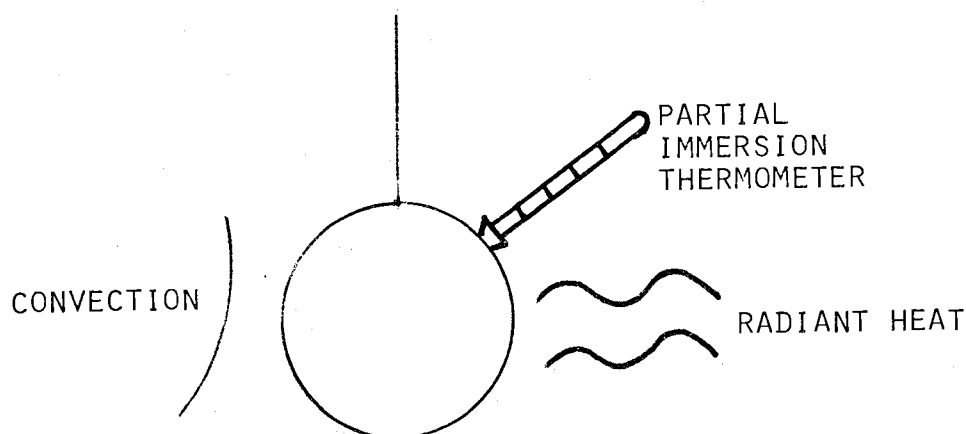
The thermocouple has certain advantages over the dry bulb thermometer. The thermocouple provides a method for obtaining the surface temperature of an object and may be adapted for use when continuous monitoring and recording is required. In addition, since the measurement is based on a difference in current, the indicator can be located in an area remote from the source of heat and wires connected to the junction at the source. Thermocouples also provide for simultaneous readings from multiple sources connected to one potentiometer or millivolt meter located in an area remote from the various heat sources. This allows for one worker to monitor many areas. Perhaps the most important advantage of the thermocouple is the fact that instantaneous readings can be obtained. The time lag what results when using a dry bulb thermometer can be as long as several minutes.

Another method that can be used to measure the ambient air temperature is the thermistor. The thermistor operates on the principle that a semiconductor exhibits a change in resistance with a small change in temperature. Each thermistor must be calibrated to determine its individual change in resistance to temperature changes. The thermistor is small and portable and can be used for obtaining single readings in many areas. It can also be used for remote readings of a source of heat. An advantage of the thermistor over the thermocouple is the fact that it requires no reference junction or cold junction compensation since the measurement is in terms of resistance within the semiconductor itself.

Measurement of Radiant Heat

The standard method for measuring radiant heat is the black globe thermometer (Vernon Globe). A black globe thermometer is constructed of a 6-inch diameter hollow copper sphere that is painted matte black. A hole is drilled in the sphere into which a rubber stopper can be placed. A partial immersion thermometer can be placed into the rubber stopper with the bulb centered inside the globe. The partial immersion thermometer requires only that the lower section of the thermometer be subjected to the temperature that is being measured. Generally there is a mark on the glass indicating the section of the thermometer that is sensitive to thermal changes. Where it is desirable for quicker readings, a thermocouple or thermistor can be used in place of the partial immersion thermometer.

Figure 3.2.2

GLOBE THERMOMETER

The black globe acts to absorb the radiant heat that is being emitted from a source. The thermometer inside the globe reaches equilibrium after a period of time, generally between twenty and thirty minutes.

The globe itself is subject to convective air temperatures on its outer surface. This convection acts to reduce some of the heat that is absorbed by the globe. Thus, it is not the actual radiant energy that is being measured but some lesser amount of energy. The energy being measured is generally termed the "mean radiant temperature." The mean radiant temperature can be calculated after equilibrium has been reached between the convective heat loss on the outside of the globe and the radiant heat gain inside the globe. The mean radiant temperature is calculated as follows:

$$(3.2.1) \quad T_w = [(T_g + 460)^4 + (0.103 \times 10^9 V^{0.5} (T_g - T_a))]^{0.25} - 460$$

where

T_w = the mean radiant temperature $^{\circ}\text{F}$

T_g = the measured globe temperature at equilibrium in $^{\circ}\text{F}$

V = velocity of the air in ft/min

T_a = temperature of the air from a dry bulb reading in $^{\circ}\text{F}$

Notice that the formula above takes into account both the measured globe temperature and the dry bulb temperature. In this way, the formula accounts for heat energy lost by convection around the globe.

Measurement of Air Velocity

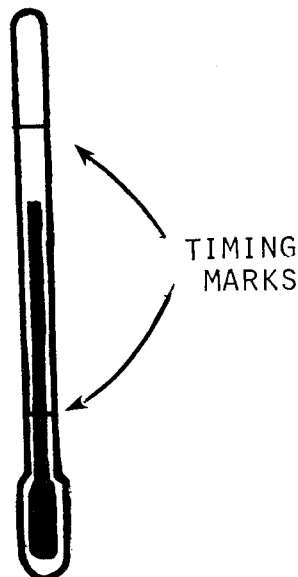
The third factor affecting the thermal stress present in the environment is the velocity of the air. The air acts to remove evaporated sweat from the vicinity of the body, thus allowing for more evaporative cooling to occur. If adequate air motion is not present, then the evaporation of sweat will be suppressed and the worker's body will become soaked. As a result, a major source of relief from thermal stress will become ineffective.

One type of instrument that can be used to measure air velocity in the area of the worker is the thermoanemometer. The thermoanemometer works on the same basic principle as the thermocouple. The difference in current generated is caused by the cooling of the sensing probe as air flows over it, and this difference is measured directly in feet per minute on the scale.

A second method for measuring air velocity in the Kata thermometer. The Kata thermometer is an alcohol-filled thermometer with a large bulb and timing marks. The bulb is heated in warm water until the liquid is above the upper mark. The thermometer is then held or placed in the air, and the time of the fall of liquid between the two timing marks is taken. Using nomograms supplied by the manufacturer, this time can then be translated into a velocity. The cooling of the Kata thermometer is a function of the air speed and the air temperature as measured by a dry bulb thermometer.

Figure 3.2.3

KATA THERMOMETER



It should be pointed out that measuring the air velocity in an open work area is much more difficult in practice than that of determining the air velocity in a ventilation system. Significant turbulence exists in the workroom atmosphere and can affect velocity measurements at various points. It is possible that some areas of the room will be subjected to a relatively high velocity of, say, 30 to 40 feet per minute while in other areas the air will have little or no movement. This along with the fact that the worker is likely to be moving about the area complicates the process of determining the air velocity to which the worker is subjected at any given time.

Because of the nondirectional nature of the air movement, it is not possible to use instruments such as the Pitot tube, velometer, or rotating vane anemometer to measure the velocity in a work area. A nondirectional approach such as the thermoanemometer or the Kata thermometer must be used.

Measurement of Humidity

As the temperature of the air rises, it will hold more water vapor. When the air at a given temperature holds all the water vapor that it can, then it is said to be saturated. The water in the air exerts a vapor pressure which is measured in millimeters of mercury (mm Hg). The term "relative humidity" which we hear mentioned so often on weather forecasts refers to the ratio of the water vapor present in the air to the amount of water the air can hold at a given temperature. Thus, 100% relative humidity is fully saturated air, and 50% relative humidity indicates that the air is holding only one-half of the water vapor that it can hold (measured in millimeters mercury).

Humidity affects the amount of sweat that is evaporated. If the humidity is high, then the rate of evaporation of sweat and, thus, the rate of evaporative cooling is lessened. Heat then builds up in the individual exposed to heat stress. If the air is 100% saturated, then the vapor pressure of the water in the air is at a maximum, and no evaporation of sweat will occur. If the air is 50% saturated and stationary, a lesser amount of evaporation will occur than if the air were 50% saturated and a high air movement were present.

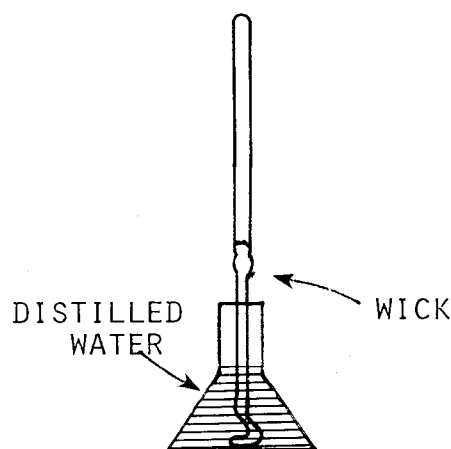
Equipment for Measuring Humidity. Direct measurement of humidity is obtained by using a hygrometer. Hygrometers measure humidity by an increase in the length

of a fiber, often human hair. Another type of hygrometer can measure humidity by determining the effect of the water vapor on a chemical. As the chemical absorbs the water vapor, its electrical resistance changes and can be measured. In general, direct methods of measuring humidity are not normally used to determine the humidity present in the workroom environment.

The wet bulb thermometer is the preferred method for determining the amount of humidity that is present. The wet bulb thermometer consists of a partial immersion thermometer on to which a wetted sleeve wick is placed. A constant supply of water is present to keep the wick wet. As the wick evaporates water, a certain amount of heat energy is dissipated through the evaporative cooling. The bulb is then cooled by the heat absorbed during evaporation of the water, and an equilibrium is reached between the evaporation rate and the water vapor pressure in the air. The temperature is indicated on the thermometer. At full saturation, the wet bulb thermometer temperature will equal the dry bulb temperature since no evaporative cooling will be experienced.

Figure 3.2.4

WET BULB THERMOMETER



A second method for determining the humidity within the air is the sling psychrometer. The sling psychrometer consists of two thermometers, a dry bulb thermometer and a wet bulb thermometer. The unit containing the thermometers is rotated rapidly. After a period of time, the difference between the two readings on the wet bulb and dry bulb thermometers is determined. This adds the additional

effect of air motion to the evaporative cooling that occurs as water evaporates from the wick. If the radiant load is not too high, the sling psychrometer will minimize the effect of radiant heat on the temperature readings.

The Psychrometric Chart. The wet bulb thermometer does not directly measure the presence of humidity in the air. To determine this, it is necessary that a psychrometric chart be used. The psychrometric chart is designed to give the relationship between the temperature of the air as measured on dry and wet bulb thermometers, the relative humidity, the vapor pressure, and the dew point. The dew point is the temperature at which the air becomes saturated without a gain or loss in moisture. The psychrometric chart is constructed assuming standard barometric pressure. As such, conversion to nonstandard conditions must be made if such is the case in the area being measured.

Multiple charts are generally available to simplify reading at various temperature levels. Not all psychrometric charts are constructed providing exactly the same information. However, the similarities are such that it is fairly easy to transfer from one type of chart to another.

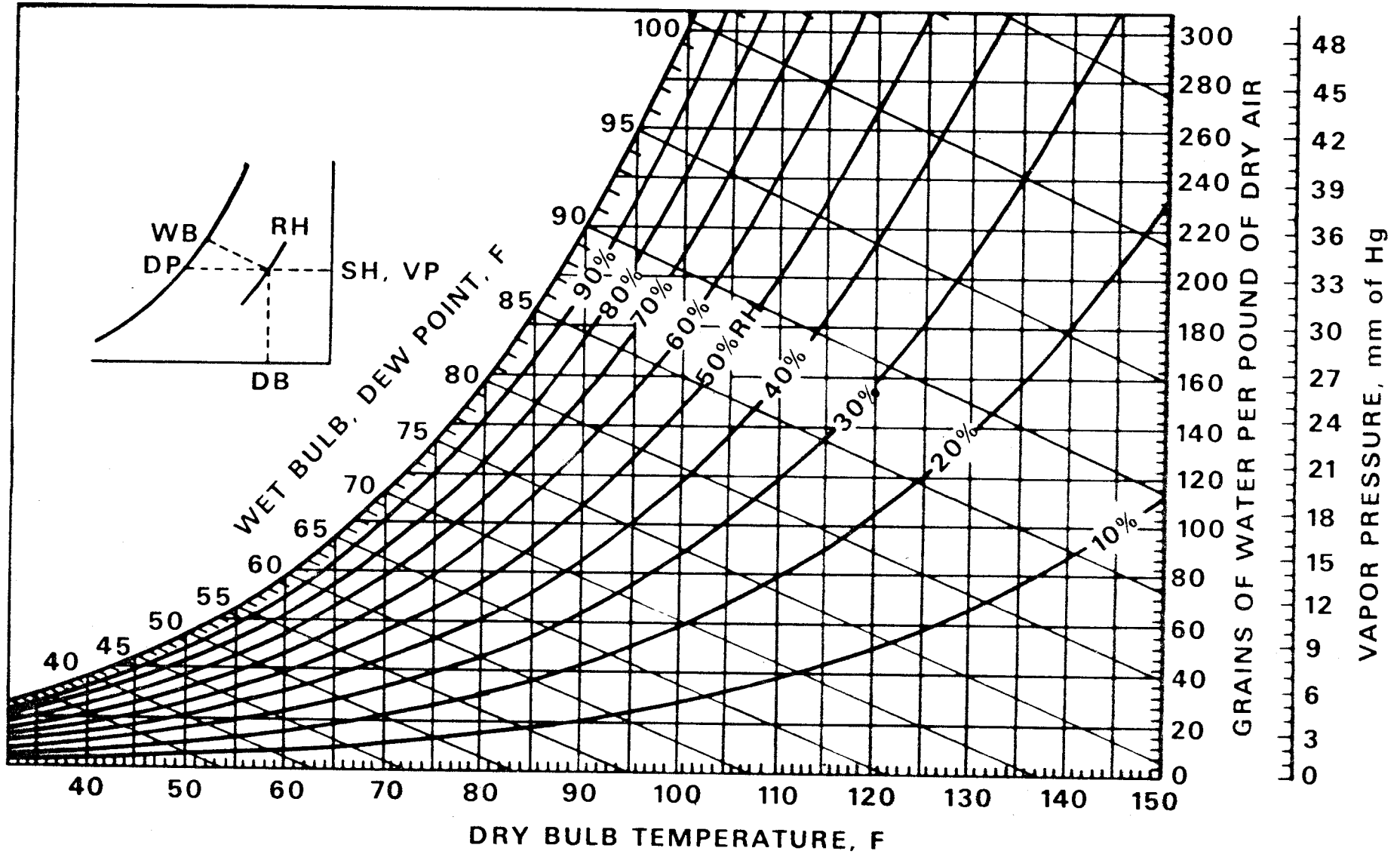
The basic information that is present on a psychrometric chart is presented in Figure 3.2.5. Note that dry bulb temperature in degrees Fahrenheit is presented on the abscissa while pounds of water or vapor pressure in millimeters mercury is presented on the ordinant. The wet bulb temperature can be found by consulting the left-hand margin of the graph section.

To use the psychrometric chart, it is necessary to have a wet bulb and a dry bulb temperature reading. These readings are found on the chart, and the intersection of the two lines provides the additional data concerning the relative humidity, vapor pressure, and dew point.

An example is presented here to illustrate the use of the psychrometric chart. Assume a wet bulb reading of 75°F and a dry bulb reading of 100°F are obtained. Consulting the psychrometric chart in Figure 3.2.5, the intersection of the vertical line from 100°F and the diagonal from a wet bulb temperature of 75°F is found. At this point, it is determined that a relative humidity of 30% exists with a dew point of 64.5°F. The vapor pressure exerted by the water vapor in the air in this situation is 15 mm Hg, which corresponds to approximately 90 grains of water per pound of dry air. Other types of psychrometric charts list additional information such as enthalpy at saturation and pounds of water per pound of dry air.

Figure 3.2.5

PSYCHROMETRIC CHART



Summary

As has been discussed in this chapter, a measurement of dry bulb temperature alone is not sufficient to determine the level of heat stress that is present. Other factors that are important are the movement of the air in the environment, the relative humidity present within the air, and the radiant heat load that exists. These factors can be measured using the equipment discussed in this chapter. One other factor that is important in determining the thermal stress that is present is the individual differences of the workers. Methods for measuring such individual differences do not exist. Only experience and past history can be used to estimate the effects of such individual differences.

Measurement alone does not determine the level at which a thermal stress will exert a strain on the human body. It is necessary that the measurements obtained be converted in some manner to a stress level that indicates the point at which a physiological strain will be encountered for most individuals. Various attempts have been made to develop such a method. These attempts will be discussed in the next chapter.

Practice Exercises

1. If the following values are present in a work environment, calculate the mean radiant temperature for that area:

Globe reading = 180°F

Dry bulb reading = 88°F

Velocity of air = 40 fpm

2. A dry bulb temperature of 88°F is obtained. At the same time, a wet bulb reading of 75°F is obtained. Determine the relative humidity, dew point temperature, and vapor pressure of water for the air involved.

Note: English units are used to ease looking up on charts.

3. Air at 85° dry bulb and with a relative humidity of 50% is passed through an evaporative cooler in which water is sprayed into the air. Assuming the cooler is 100% efficient and fully saturates the air, what will the dry bulb and wet bulb temperatures be after cooling? If 20 pounds/minute of air are cooled by this process, how many BTU's of heat will be removed per minute?
4. Explain the basis for the saying, "It's not the heat, it's the humidity."

CHAPTER 3

THERMAL STRESS INDICES

Introduction

Excessive thermal stress can result in a physiological and psychological strain on the exposed worker. The amount of thermal stress that is present in a work environment is a function of certain environmental measures, such as the temperature of the air, the humidity of the air, the radiant heat load, and the air movement present. These measures have been discussed in the previous chapter.

In addition, stress is a function of certain physiological conditions involving the worker. The amount of acclimatization to which the worker has been exposed affects the stress to which a specific worker is being subjected. The worker's metabolic rate as well as his work rate is also important. In addition, the body surface area to weight ratio, as previously discussed, can have an effect upon the stress to which the worker is being exposed.

Other factors that are important and that have been discussed previously include the clothing that the worker wears, the worker's age, sex, and physical condition. It has been shown that older workers are more subjected to strain resulting from thermal stress than younger workers. The worker's sex is also a factor since experiments have shown that tolerance to heat is higher among males than females. The worker's general health and physical condition are also factors that affect the stress that is placed on an individual worker. Since each worker represents a different mixture of the various factors, there are individual variations in the ability to withstand heat stress. This alone presents some difficulties when attempting to determine how much heat will be hazardous to a given group of workers.

On the other hand, the physiological strain that results from thermal stress is a function of the circulatory capacity of the individual, his capacity for sweating, and tolerance to elevated body temperature. In addition, the exposure time is an important factor in determining the strain that is felt by an individual. The human body can withstand high temperatures for short periods of time without causing harmful effects to the health of the exposed individual.

In order to determine the amount of thermal stress above which workers should not be exposed, it is necessary to develop a method that relates stress to strain. That is, it is necessary to state in some manner strain as a function of the stress variables:

$$\text{Strain} = f(\text{Stress})$$

Attempts have been made to develop such a thermal stress index for this relationship. Although many indices have been developed, none are entirely satisfactory. In developing criteria for a thermal stress index, it is important that the following factors be considered:

1. The index that is developed should be quantitative and yield scalar values relating to stress and strain.
2. The index should be calculated from available data concerning the conditions that are present in the environment.
3. The index should be tested and proved applicable through use.
4. All important factors should be included in the index.
5. The method should be simple to use and not lead to rigorous calculation or difficult measurements.
6. All factors included should be related to physiological strain in some weighted manner.
7. The method should be applicable and feasible for determining regulatory limits or threshold limit values for heat stress.

In the following discussion, various heat stress indices will be presented. None of these indices totally meets the criteria outlined above. In some cases, the calculations and measurements are difficult to obtain. In other cases, not all factors are included. However, these indices are the best that are available at the present time and, as a result, are the tools that the industrial hygienist has at his or her disposal to determine if a thermal stress is present in the work environment.

Effective Temperature

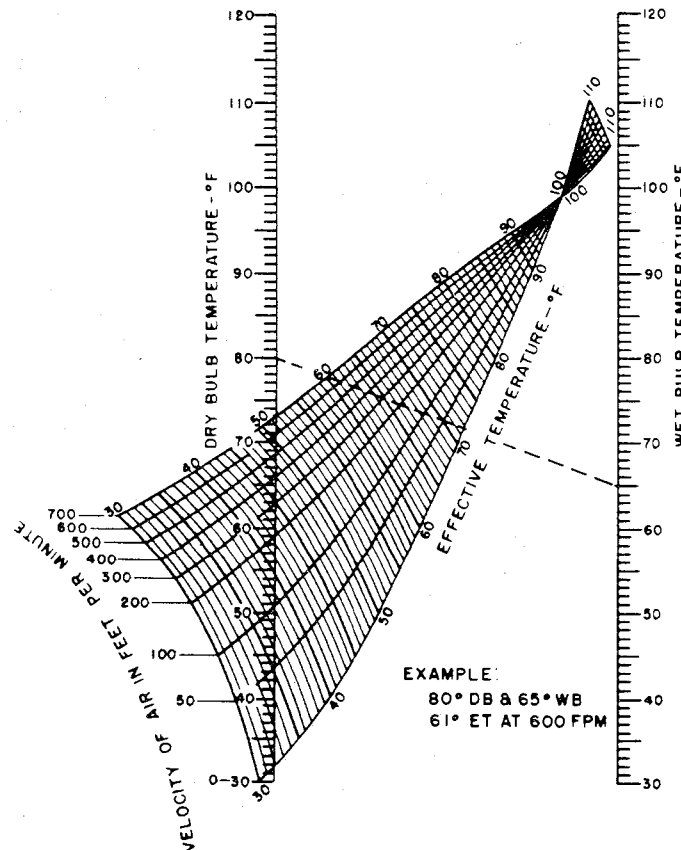
The Effective Temperature (ET) is a widely used index that is related to the comfort that is felt in a given atmosphere by individuals subjected to this environment. The Effective Temperature was developed by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) in 1924 and was revised in 1950.

The Effective Temperature combines into a single value the temperature of the environment, the humidity of the air, and the air movement. The Effective Temperature scale was developed from empirical data gathered from individuals who indicated the degree of warmth that they felt upon entering a given atmosphere. The individuals involved in responding to the environment were either sedentary and normally clothed or stripped to the waist doing light work. The Effective Temperature scale has been used extensively in the field of comfort ventilation and air conditioning work.

The relationship of Effective Temperature to the wet bulb temperature, the dry bulb temperature, and the velocity of the air has been graphed for both sedentary individuals and those doing light work. The accompanying graph (Figure 3.3.1) illustrates the relationship of Effective Temperature to the factors listed for individuals doing light work.

Figure 3.3.1

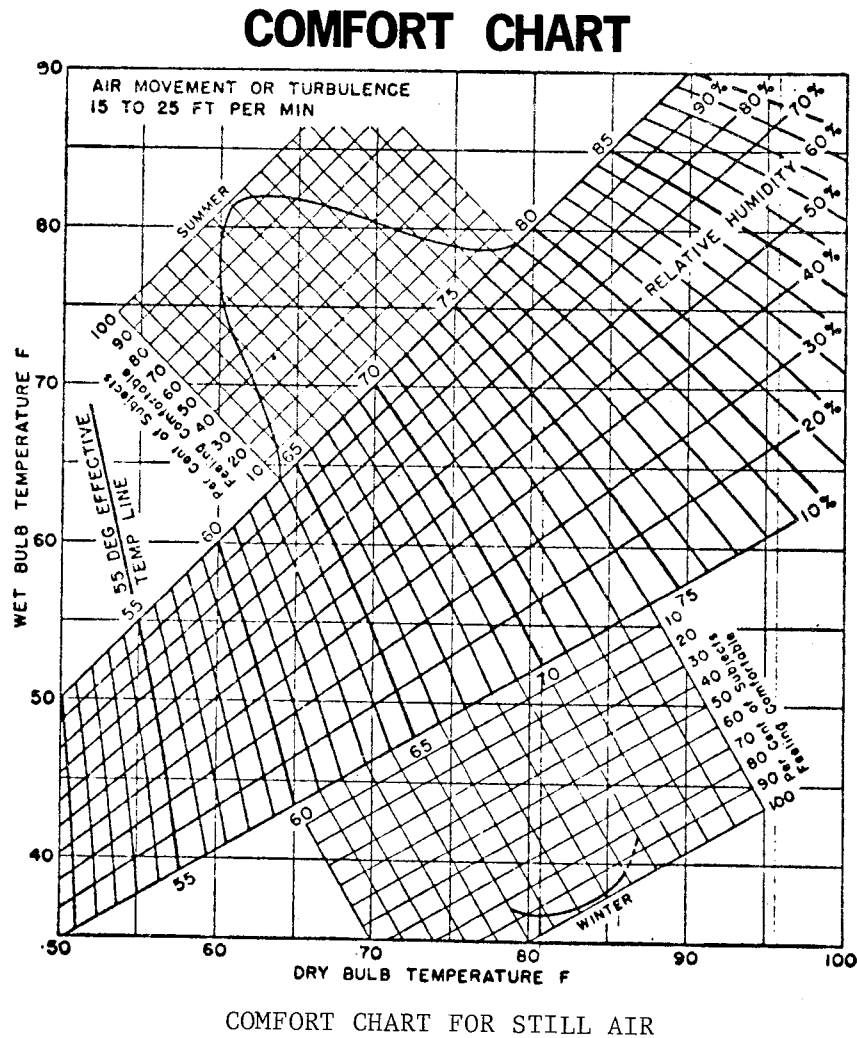
EFFECTIVE TEMPERATURE



As an example of how to use the graph, consider a dry bulb temperature of 80°F and a wet bulb temperature of 65°F in an atmosphere in which the air is moving at 100 feet per minute. Drawing a line between the dry bulb temperature and the wet bulb temperature on the vertical graphs, one can determine the point at which this line intersects with the diagonal lines indicating air velocity. Reading diagonally down the Effective Temperature scale, a value of 68.5 is obtained. If a graph for sedentary individuals is consulted, the equivalent Effective Temperature would be 72°F. These values indicate the degree of warmth felt by individuals in an environment with the conditions listed.

Somewhat akin to the Effective Temperature is the ASHRAE comfort chart (Figure 3.3.2). This index presents the subjective feeling of warmth of an individual after being in an environment for three hours. It is based upon sedentary individuals in light clothing and includes both summer and winter responses. This index is quite often used for comfort ventilation determinations.

Figure 3.3.2



The Effective Temperature has certain problems when one considers its use as a measure of thermal stress. In the first place, the Effective Temperature requires a radiation correction. The accuracy of this correction has been questioned. In addition, the Effective Temperature does not consider varying work rates and the resulting varying metabolic heat generation rates. Experience has shown that Effective Temperature exaggerates stress in hot, dry conditions at air velocities of 100-300 fpm. On the other hand, the Effective Temperature underestimates stress at low air movement with hot, wet conditions. As a result, the Effective Temperature has not proved of significant value in determining the level of heat stress that is present in a work environment.

Heat Stress Index

The Heat Stress Index (HSI) was developed by Belding and Hatch in 1965. The Heat Stress Index considers the radiant heat load, convective heat load, and metabolic heat generated by the worker. The heat stress relationship is stated below.

$$(3.3.1) \quad E_{\text{req}} = M \pm R \pm C$$

where

E_{req} = the required sweat evaporation rate to dissipate the heat load in BTU/hr

M = the metabolic heat produced in BTU/hr

R = the radiant heat load in BTU/hr

C = the convective heat load in BTU/hr

Using this relationship, a Heat Stress Index is developed. The strain relationship is stated as

$$(3.3.2) \quad \text{HSI} = \frac{E_{\text{req}}}{E_{\text{max}}} \times 100$$

where

HSI = the Heat Stress Index

E_{max} = the maximum evaporative capacity of the environment in BTU/hr

From the relationship for the Heat Stress Index stated above, it can be seen that if the ratio $E_{\text{req}} \div E_{\text{max}}$ is = 1, the environment will not provide relief from heat stress.

$E_{\max}$, or the maximum evaporative cooling that is possible in the environment, can be determined by making measurements of environmental conditions such as the air velocity and vapor pressure. On the other hand, under hot, dry conditions $E_{\max}$ is confined to man's ability to sweat which is never more than 2400 BTU's per hour or one liter per hour.

Formulas have been empirically developed for calculating the variables in the heat stress relationship. These formulas are presented below.

Radiant Heat Load

$$(3.3.3) \quad R = 17.5(T_w - 95)$$

Convective Heat Load

$$(3.3.4) \quad C = 0.756V^{0.6}(T_a - 95)$$

Maximum Evaporative Capacity

$$(3.3.5) \quad E_{\max} = 2.8V^{0.6}(42 - PW_a)$$

where

T_w = the mean radiant temperature °F

T_a = the dry bulb temperature of the ambient air °F

V = the air velocity ft/min

PW_a = the vapor pressure of water in the air measured
in mm Hg

In order to evaluate the various levels of the Heat Stress Index, Belding and Hatch also presented an interpretation of these levels to the physiological implications of an 8-hour exposure to various levels of the Heat Stress Index. A summary of the Belding Hatch information is presented in Table 3.1.

Table 3.3.1

Heat Stress Index Implications of 8-Hour Exposure

-20 to -10	Mild cold strain. Frequently exists in heat recovery areas.
0	No thermal strain.
+10 to +30	Mild to moderate heat strain. Subtle to substantial decrements in performance may be expected where intellectual forms of work are performed. In heavy work, little decrement is to be expected. Unless worker is normally marginal.
40 - 60	Severe heat strain, involving threat to health unless men are physically fit. Climatization required. Not suitable for those with cardiovascular or respiratory impairment. Also not suitable where sustained mental effort required.
70 - 90	Very severe heat strain. Personnel should be selected by (1) medical examination and (2) trial on the job after acclimatization. Slight indisposition may render worker unfit for this exposure.
100	The maximum strain tolerated by fit, acclimatized young men.

Though the Heat Stress Index considers all the environmental factors and the work rate, it is not totally satisfactory as an index for determining the heat stress on an individual worker. The heat stress index requires that a measurement of the air velocity in the workplace be made. In actual practice, such measurements are difficult to obtain with accuracy since workers move around and the turbulence of the workplace atmosphere is such that differing velocities exist in different areas. In addition, the procedure is relatively complicated and requires that the metabolic rate of the worker be estimated. This estimate can be determined using tables of the metabolic rate for given types of activities.

In 1966, McKarns and Brief developed nomographs that can be used to estimate the Heat Stress Index. These nomographs give an allowable exposure time. The allowable exposure time (AET) is defined as the time necessary to raise the body temperature 2°F. The formula from which this allowable exposure time is developed is as follows:

$$(3.3.6) \quad AET = \frac{250 \times 60}{E_{\text{req}} - E_{\text{max}}}$$

In addition, the minimum recovery time (MRT) from exposure to heat stress can be calculated using the formula

$$(3.3.7) \quad \text{MRT} = \frac{250 \times 60}{E_{\text{max}} - E_{\text{req}}}$$

In order to illustrate the McKarns and Brief nomograph, consider the following example and the accompanying charts:

Given

$$T_g = 120^{\circ}\text{F}$$

$$T_a = 100^{\circ}\text{F}$$

$$T_{\text{wb}} = 78^{\circ}\text{F}$$

$$V = 40 \text{ feet per minute}$$

$$M = 1500 \text{ BTU's per hour}$$

HEAT STRESS NOMOGRAPH

Chart 1

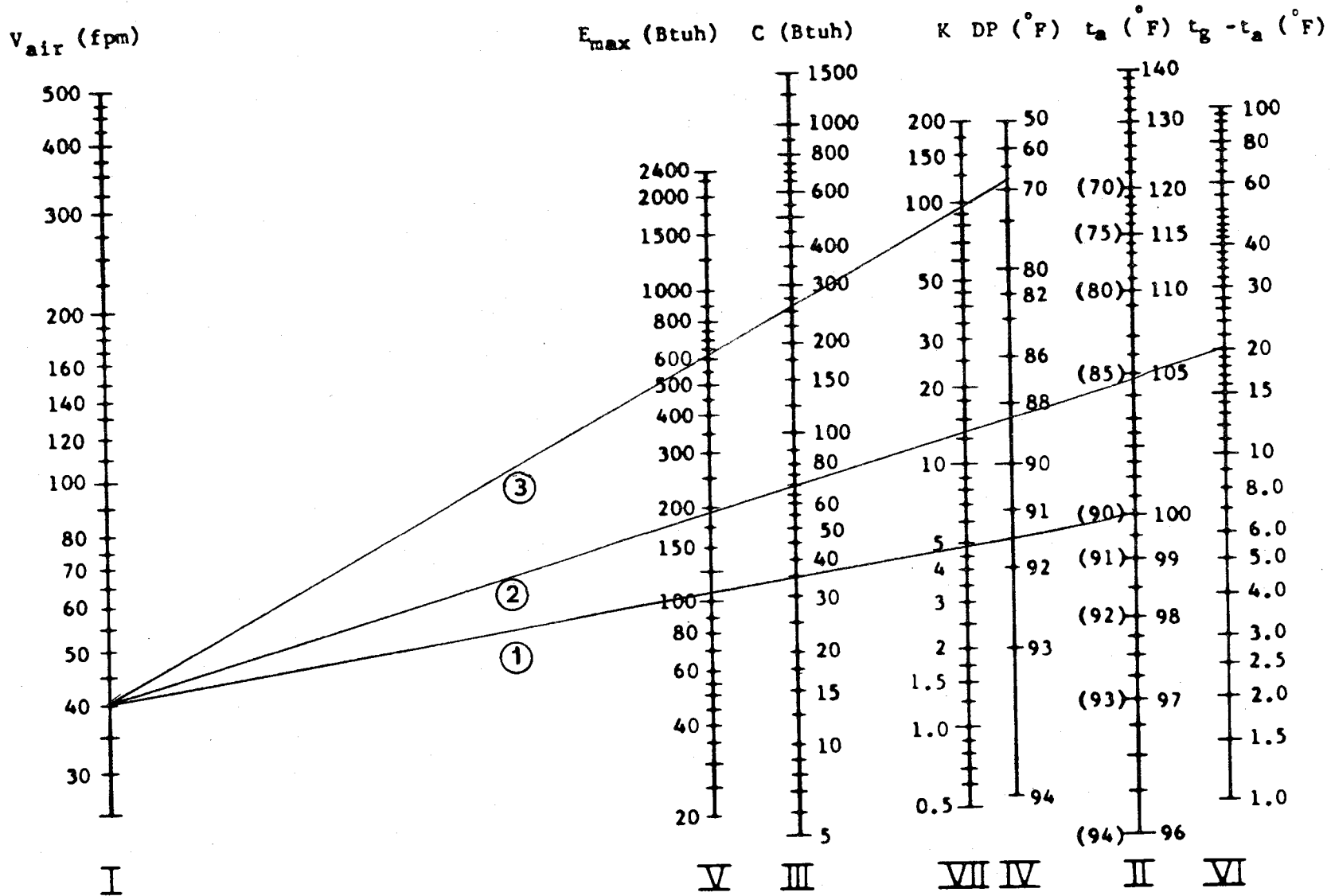
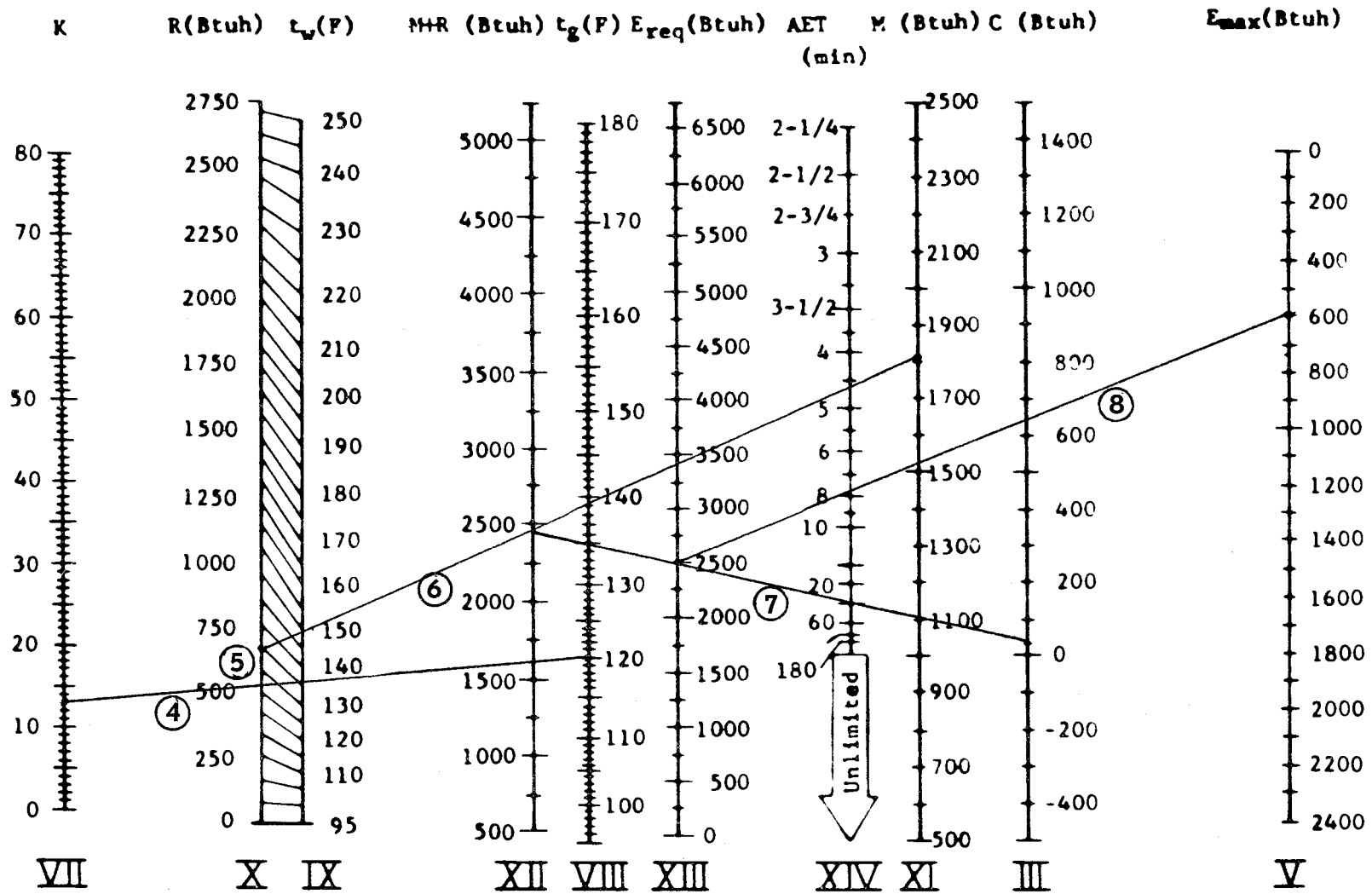


Figure 3.3.3

HEAT STRESS NOMOGRAPH

Chart 2



Procedure

- Step 1. Determine the convective heat load (C). Connect Column I or air velocity with Column II or air temperature. Read convection or C in BTU's per hour in Column III. C then has a value of 35 BTUh. It should be noted that since the air temperature is above 95°, this is a positive value. Below 95° the left-hand side of Column II is read and indicates a negative value.
- Step 2. Determine the maximum evaporative cooling ($E_{\max}$). The dew point temperature must be calculated from a psychrometric chart. Given the values stated, the dew point temperature determined is 68°F. Connecting the air velocity with the dew point temperature in Column IV, the intersection of Column V for $E_{\max}$ is read. The $E_{\max}$ value obtained is 610 BTUh.
- Step 3. Determine the constant value, K. Connecting Column I or air velocity with the temperature difference between the globe thermometer and the ambient air in Column VI and reading Column VII for the constant value K, the value obtained for $K = 13$.
- Step 4. Determine the mean radiant temperature. Locate the value for K in Column VII of the second chart. Connect this value with the globe thermometer reading in Column VIII. Read IX for the mean radiant temperature. In this case, $T_w = 135^\circ\text{F}$.
- Step 5. Determine the radiant heat load (R). Following the diagonal line upward from 140° to Column X, a radiant heat load of approximately 700 BTUh is obtained.
- Step 6. Determine the sum of the radiant heat load and the metabolic head load. An estimate of the metabolic heat rate must be made. Assume in this case that the metabolic heat rate is estimated to be 1800 BTUh. Connecting Column X for R and Column XI for the metabolic heat load and reading Column XII for $M + R$, a value of approximately 2400 BTUh is obtained for $M + R$.

- Step 7. Determine the required evaporative rate (E_{req}). Using the value obtained in Chart 1 for C, or 35 BTUh, connect Column XII for the value of M + R to Column III on Chart 2 for C = 35 BTUh. Read Column III for E_{req} . The value obtained is approximately 2500 BTUh.
- Step 8. Determine the allowable exposure time (AET). The allowable exposure time is calculated by connecting the value for E_{req} in Column XIII with the value obtained in Chart 1, Column V, for E_{max} on Column V of Chart 2. Reading Column XIV for the allowable exposure time, the value obtained is approximately 8 minutes.

The minimum recovery time can then be calculated using the formula previously stated. The values of E_{max} and E_{req} in calculating MRT are based upon that which the worker would experience in the rest area.

The Predicted Four-Hour Sweat Rate

The Predicted Four-Hour Sweat Rate, commonly denoted as P_4SR , is based upon the sweat loss in liters for various environments. A graph is used to calculate the four-hour sweat rate. Using the graph on the next page, determine the value for P_4SR in the following example. The example is based upon sedentary individuals.

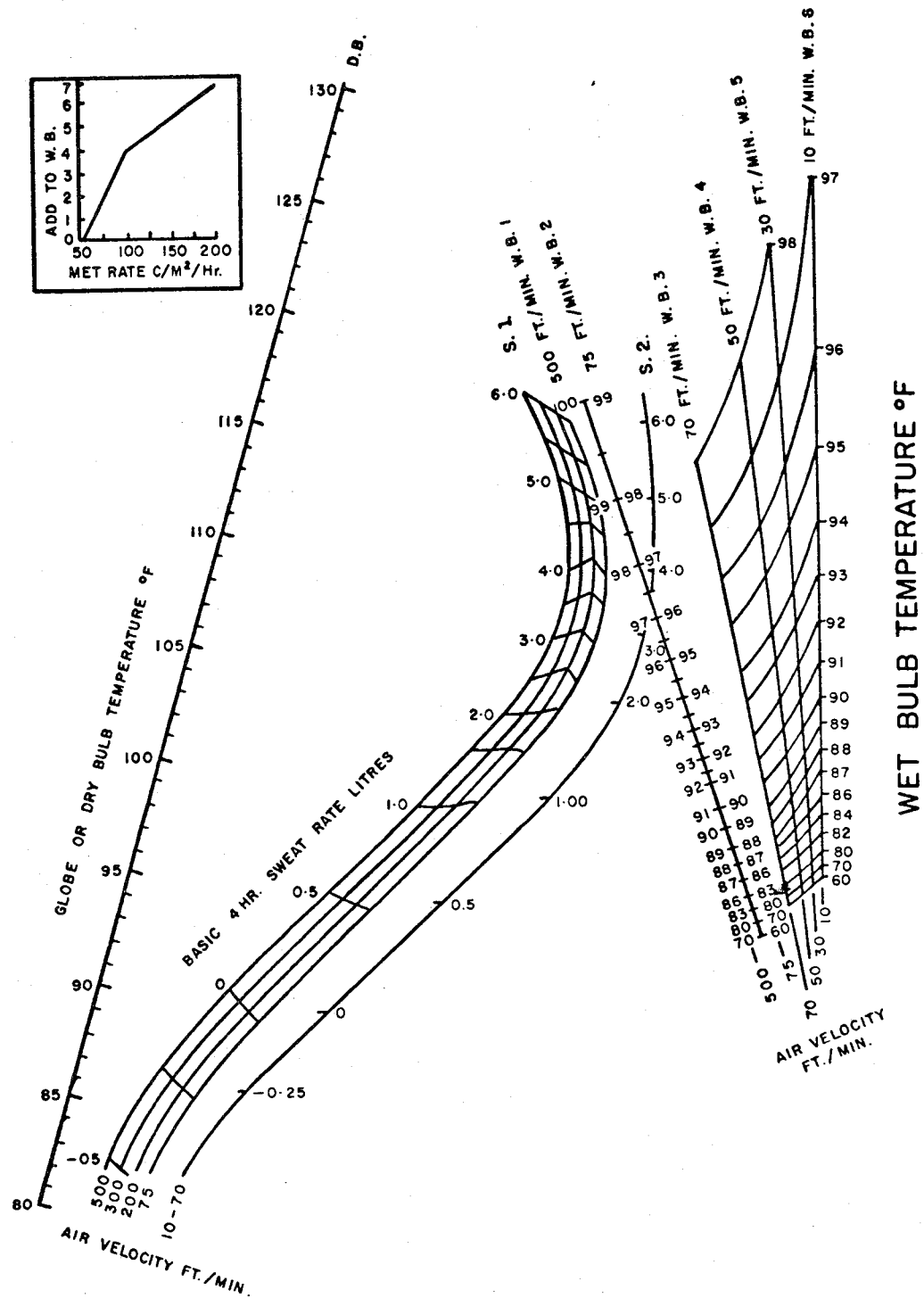
$$T_{wb} = 80^{\circ}\text{F}$$

$$T_g = 95^{\circ}\text{F}$$

$$V = 50 \text{ feet per minute}$$

$$M = 150 \text{ K calories per meter}^2 \text{ per hour}$$

PREDICTED FOUR - HOUR SWEAT RATE



To obtain the P_4SR , follow the line intersecting the T_{wb} to the velocity line. This point is then connected to the T_g , and the intersection of the connecting line with the P_4SR for the appropriate velocity yields the resulting P_4SR . In the example, $T_{wb} = 80^\circ F$, and the intersection of the T_{wb} and $V = 50$ ft/min is connected to a value of $T_g = 95^\circ F$. The connecting line intersects the P_4SR line for $V = 50$ ft/min ($V = 10 - 70$ ft/min) at .6 liters. If the workers are involved in a work activity in which a metabolic rate is estimated, the small chart in the upper left-hand quadrant is used, and a correction for T_{wb} is made for the appropriate estimated metabolic rate.

The P_4SR index is based upon young men working in shorts and, as such, has limitations when applied in the industrial environment. The index also requires an estimate of the metabolic rate and a measurement of air velocity.

The Wet Bulb Globe Thermometer Index

The wet bulb globe thermometer index, commonly designated as WBGT, is based upon a measurement of the globe thermometer reading, a dry bulb thermometer reading, and a natural wet bulb thermometer reading. The natural wet bulb thermometer (T_{nwb}) reading is obtained using no artificial air movement with only evaporation in the ambient air occurring.

Two formulas have been developed, one for outdoor use and the other for indoor use. The formula for indoor use does not involve a dry bulb reading. These formulas are presented below:

Outdoor Use

$$(3.3.8) \quad WBGT = 0.7T_{nwb} + 0.2T_g + 0.1T_a$$

Indoor Use

$$(3.3.9) \quad WBGT = 0.7T_{nwb} + 0.3T_g$$

The WBGT formula is easy and simple to use. It is the basis for the ACGIH guide for a heat stress TLV. It is also the basis for the NIOSH recommended standard.

Although the WBGT is easy and simple to use, it does not in itself include a factor for the rate in which the individual is working. In addition, it is not

possible to determine an allowable exposure time directly from the WBGT. However, in the following section discussing the ACGIH TLV guideline, certain steps have been taken to eliminate these difficulties.

Whenever a worker is exposed to different heat loads for various time periods during his work schedule, a time-weighted WBGT must be used. A formula for calculation of this time-weighted WBGT is presented below.

$$(3.3.10) \quad \text{WBGT}_{\text{ave}} = \frac{\text{WBGT}_1(t_1) + \text{WBGT}_2(t_2) + \dots + \text{WBGT}_n(t_n)}{t_1 + t_2 + \dots + t_n}$$

The ACGIH Guide for Assessing Heat Stress

The ACGIH has developed a guide for determining heat stress and has set forth a TLV based upon the work rate of the worker exposed to this heat stress.

The basis for measurement of this index is the WBGT temperature. The procedure required for such a measurement is as follows:

- A. Dry and wet bulb thermometer in the range of -50°C to $+50^{\circ}\text{C}$ with an accuracy of $\pm 0.5^{\circ}\text{C}$.
- B. The dry bulb is to be shielded from the sun when outdoor measurements are being made.
- C. Allow 1/2 hour for the wet bulb to reach equilibrium.
- D. The wick should be entirely wetted 1/2 hour before reading.
- E. The globe is to be a 15 centimeter (6 inches) diameter hollow copper sphere painted matte black.
- F. The globe thermometer range should be -5°C to 100°C with an accuracy of $\pm 0.5^{\circ}\text{C}$.
- G. Allow 25 minutes for the globe thermometer to reach equilibrium.

Table 3.2 sets forth the criteria for determining the work load of the exposed worker. This table can be used to estimate the metabolic rate of the worker. Another method that is much more time consuming is to measure the worker while he is performing the job.

Table 3.3.2
Assessment of Work Load

Average values of metabolic rate during different activities.

A. Body Position and Movement		Kcal./min
Sitting		0.3
Standing		0.6
Walking		2.0-3.0
Walking up hill		add 0.8
		per meter (yard) rise
B. Type of Work		Average Kcal./min Range Kcal./min
Hand work		
light	0.4	0.2-1.2
heavy	0.9	
Work with one arm		
light	1.5	0.7-2.5
heavy	1.8	
Work with both arms		
light	1.5	1.0-3.5
heavy	2.5	
Work with body		
light	3.5	2.5-15.0
moderate	5.0	
heavy	7.0	
very heavy	9.0	
Light hand work: writing, hand knitting		
Heavy hand work: typewriting		
Heavy work with one arm: hammering in nails (shoemaker, upholsterer)		
Light work with two arms: filing metal, planing wood, raking a garden		
Moderate work with the body: cleaning a floor, beating a carpet		
Heavy work with the body: railroad track laying, digging, barking trees		
Sample Calculation: Using a heavy hand tool on an assembly line		
A. Walking along		2.0 Kcal./min
B. Intermediate value between heavy work with two arms and light work with the body		<u>3.0 Kcal./min</u> 5.0 Kcal./min
C. Add for basal metabolism		<u>1.0 Kcal./min</u>
Total		6.0 Kcal./min

Adapted from Lehmann, G. E., A. Muller and H. Spitzer: Der Kalorienbedarf bei gewerblicher Arbeit. Arbeitsphysiol. 14: 166, 1950.

A permissible heat exposure threshold limit value has been presented based on the amount of time the worker is involved in continuous work and the level of work that the worker is performing. This TLV is presented in Table 3.3. It should be mentioned that the TLV is applicable only for acclimatized workers and assumes that the workers are using light summer clothing. If the rest area is maintained at a temperature below 24°C WBGT, then the amount of rest that is required may be reduced by 25%.

Table 3.3.3

Permissible Heat Exposure Threshold Limit Values
(Values given are in °C WBGT)

Work-Rest Regimen	Work Load		
	Light	Moderate	Heavy
Continuous Work	30.0	26.7	25.0
75% Work-- 25% Rest, Each hour	30.6	28.0	25.9
50% Work-- 40% Rest, Each hour	31.4	29.4	27.9
25% Work-- 75% Rest, Each hour	32.2	31.1	30.0

The Wind Chill Index

On the opposite side of the coin, many workers are exposed to extremely cold temperatures. In general, the strain produced in the worker by the stress of the cold environment is based on many factors. Little work has been done in this area. However, a wind chill index has been developed that indicates where danger areas may be present.

Since convection causes heat loss and helps to reduce thermal stress, it stands to reason that as the wind increases additional heat is lost from the body. Thus, when the temperature is cold, this additional heat loss can present a problem to the workers. A wind chill index has been developed that equalizes the temperature and wind factors for these two conditions. The table on the next page illustrates values for the wind chill index.

Table 3.3.4
Equivalent Temperatures on Exposed Flesh
at Varying Wind Velocities¹

Temperature, °F	Wind Velocity, mph								
	0	1	2	3	5	10	15	20	25
	23	47.5	53.5	57	60	65	67	68	69.5
	-11	20	34.5	39	44.5	52	55	57	59
	-27	0	11	18.5	28	38	42.5	45	47
	-38	-23.5	- 9	0	11	25	30.5	34	36
	-40*	-40*	-40	-16.5	- 5	11	18	23	25
			-40*	-40	-19	- 2	6	11	14
				-40*	-35	-15	- 6	0	3
					-40	-29	-18	-12	- 8
				-40*	-40	-30	-23	-18	
					-40*	-40	-35	-30	
						-40*	-40*	-40*	

¹Adapted from Consolazio, Johnson, and Pecora, Physiologic Measurements of Metabolic Functions in Man, McGraw-Hill Book Company, New York, 1963.

* Less than value

Summary

Significant work has been done to develop a relationship between thermal stress and physiological strain. Among the indices that have been developed are the Effective Temperature, the Heat Stress Index, the P_4SR , and the WBGT. None of these indices are perfect and at best provide only an estimate of the relationship between thermal stress and physiological strain. However, until such time as a better method is developed, the industrial hygienist has the indices that have been developed to evaluate thermal stress in the industrial environment.

Practice Exercises

1. Given a $T_{db} = 80^{\circ}\text{F}$, $T_{wb} = 68^{\circ}\text{F}$, and an air velocity of 100 fpm, determine the Effective Temperature for men doing light physical work.
2. If the following readings are obtained in an area where lightly clothed men are performing light physical work and provided a rest area away from the hot work area

	<u>Work Area</u>	<u>Rest Area</u>
T_{db}	105°F	80°F
T_{wb}	77°F	65°F
T_g	130°F	85°F
V	150 fpm	100 fpm
M	700 BTUh	400 BTUh

determine the following:

- a. the Allowable Exposure Time (2°F rise in body temperature)
- b. the Minimum Recovery Time
- c. the WBGT for the work site and rest area (assume indoors)
- d. if the ACGIH TLV is being exceeded when a 3/4-hour work period is scheduled with a 1/4-hour rest period.

CHAPTER 4

METHODS FOR CONTROLLING THERMAL EXPOSURES

Introduction

In the preceding chapters, the discussion centered about the fact that man at work in an industrial environment can be exposed to thermal stress. The industrial process generates heat by convection and radiation while the worker in the environment generates body heat as a result of metabolism and general physical activity. The industrial hygienist must develop methods to control the exposure to thermal stress in order to protect the worker from physical strain. There are three general methods that are available to the industrial hygienist to accomplish this task. These methods are

1. Administrative controls
2. Modifying the thermal environment
3. Personal protective equipment

Before undertaking a method for controlling thermal stress, it is important that the industrial hygienist determine the type of thermal stress that is present in the environment. Since the methods of control differ for radiant heat and convective heat, it is important to determine the relative heat load from each of these sources. In addition, it is important to identify the source of heat and measure its intensity. As discussed in the previous chapter, in most cases, the WBGT method is the simplest method for such measurement while the HSI method takes into account the total heat load on the worker. The industrial hygienist should consider the work rate at which the worker accomplishes his tasks. This work rate will determine the metabolic heat generated by the worker. Incidental environmental heat such as that resulting from the operation of equipment in the area, lighting, the general climatic conditions, and heat and steam distribution lines should be considered.

After the industrial hygienist has identified the source of heat, measured its intensity, and determined the type of heat stress to which the worker is being exposed, the work of developing controls can begin. The remainder of this

chapter will discuss the various methods of control that are available to control thermal stress. It is unlikely that any single method will be totally satisfactory. In most cases, it may be necessary to combine various approaches to control the thermal environment of the worker.

General Administrative Methods for Reducing Heat Stress

Decreasing the Work Required. One obvious method that can be used to control the exposure to heat stress is to decrease the amount of work required on the part of the workers exposed to the heat. As the physical activity of the worker lessens, the metabolic rate is lower and the possibility of heat strain developing is thus lessened. Quite often this approach does not result in a significant reduction in heat stress as is evident from the discussion related to the Heat Stress Index. However, in many situations where a marginal exposure exists, this reduction may be sufficient to eliminate the possibility of heat strain occurring.

In order to determine if the physical activity of the worker can be decreased, it is necessary to observe the jobs being performed. During this observation, the amount and type of physical activity of the workers can be noted. Analysis can then be made to determine if these activities can be modified in some manner to reduce the physical exertion of the worker. Can a particular tool be modified to reduce the amount of muscular activity? Can the total procedure be automated in a manner that allows the worker to be removed from the source? Can various procedures be implemented that decrease the worker's activity?

Modifying the Worker's Exposure to Heat Stress. In addition to decreasing the work required, it may be possible to determine methods for modifying the exposure of the worker. One general method available is to provide relief to the workers on a regular schedule. By providing rest areas where the worker can escape the heat and cool down, the possibility of heat strain developing is significantly lessened. Such rest areas should preferably be air conditioned at or below 75°F (24°C). These rest areas should be located near the workplace to facilitate their regular use. A rest area located at some distance from the workplace will not likely be used by the worker because of time lost going to and from the area.

Another method for modifying the exposure is to schedule the performance of hot jobs. Where possible, hot jobs should be scheduled in the cooler part of the

day. Thus, the environmental heat load will be lessened. If such scheduling is not possible, it is wise to balance the work load throughout the day. It is better to have the worker intersperse hard, physical tasks with tasks of a less physical nature than to attempt to do all the difficult physical tasks at once.

A supply of cool water (50°F to 60°F) at or near the workplace is important in reducing the possibility of heat dehydration, resulting in heat stroke. The supply of water should be in close proximity to the workplace to encourage its use. By placing a 0.1% salt solution in the drinking water, the possibility of the worker developing heat cramps is significantly lessened. This method is preferred to the use of salt tablets since it assures that salt replacement occurs when the fluid is ingested.

Young workers are less subject to heat stress than older workers. Therefore, another method of reducing the exposure is to place young workers in hot jobs wherever possible.

Screening of Workers. Since it is known that certain individual characteristics of workers make these workers more susceptible to heat strain resulting from stress, it is important that a screening procedure be developed. Such screening can occur prior to employment or placement in a hot area. Such things as illness, particularly that involving the cardiovascular system, and general physical condition are important.

After the workers have been placed in a hot job, it is desirable that periodic examinations of the exposed workers be scheduled. The purpose of this examination is to determine if the worker's physical condition has changed in such a manner that exposure to heat stress will be harmful.

Education and Training of Workers. Before a worker is placed in a heat stress environment, education and training should be provided to assure that the employee is aware of the thermal hazards involved in the job. This training should include such items as:

1. The effects of acclimatization.
2. Need for liquid replacement.
3. Need for salt replacement.
4. Recognition of the symptoms and treatment of heat disorders.
5. The effects of alcohol, lack of sleep, illness, etc., on heat tolerance.
6. The appropriate clothing to wear on the job.
7. The need for rest away from the workplace.

By providing such training and education, the worker can become more aware of the dangers involved in exposure to thermal stress. In this way the worker will act to police his own activities in such a manner to reduce the possibility of strain occurring.

Acclimatization of Workers. Whenever a worker is being placed in a hot environment for the first time, it is important that an acclimatization procedure be used. Data from experimental studies indicate that a properly designed acclimatization program will reduce the possibility of strain developing in workers exposed to heat stress. Generally, a two-week program of acclimatization is required. During this period, the worker is progressively exposed to the hot environment and physiological adjustments occur in the body to reduce the strain experienced. The NIOSH recommendations for a standard for work in hot environments suggest that the unacclimatized employee be acclimatized over a period of six days, with 50% of the anticipated total work load and time exposure on the first day. Each day following the first day, a 10% increase in exposure is scheduled, building up to a 100% total exposure on the sixth day. In addition, the recommended standard recognizes the fact that acclimatized employees tend to lose the effects of acclimatization after a layoff. The recommended standard states that after nine or more consecutive days' leave, the employees should undergo a four-day acclimatization period with daily increments of 20%, beginning with a 50% exposure on the first day. In addition, if the employee has been away from work four days or more because of illness, the same four-day reacclimatization period should be instituted. (Criteria for a Recommended Standard . . . Occupational Exposure to Hot Environments. USDHEW, HSMHA, NIOSH, U. S. Government Printing Office-HSM-72-102-69. Washington, DC, 1972.)

Other Administrative Controls. Other administrative controls that can be used to reduce the exposure to thermal stress include the monitoring of the hot workplace to determine the level of thermal stress present. This is basically an identification task that determines where further controls are necessary. However, before a control can be instituted, it is necessary to determine where such a control is required.

An additional method for helping to identify where heat exposure exists is to keep historical records of heat illnesses as they occur. These records can

point out workers who seem to have, for some reason, a low tolerance to heat exposure. Also, these records can point out areas of extreme thermal stress that can then be the subject of further investigation.

Table 4.1

Summary of Administrative Controls
for Control of Heat Exposure

Decrease the Work Required

Modify the Worker's Exposure

--rest

--scheduling

Screen Workers

Education and Training

Acclimatization

Record Keeping

Modifying the Thermal Environment for Radiant Heat

One of the major sources of heat stress in the industrial environment is radiant heat. The reduction of the radiant heat load in a work area can make a significant contribution to the control of thermal exposures. There are three general methods that are available to reduce the radiant heat load. These methods are:

1. Lower the radiation level
2. Shield or isolate the worker
3. Provide the worker with protective clothing

Lower the Radiant Heat Level. The surface of a hot body often radiates significant amounts of heat. If the surface can be treated with a material of low emissivity, the amount of radiant heat can be significantly reduced. In order to accomplish this, the surface can be painted with a reflective or shiny paint, preferably an aluminum-type paint. In addition to reducing the radiant heat level exterior to a hot source, this approach conserves the heat inside the body where the process requires this heat.

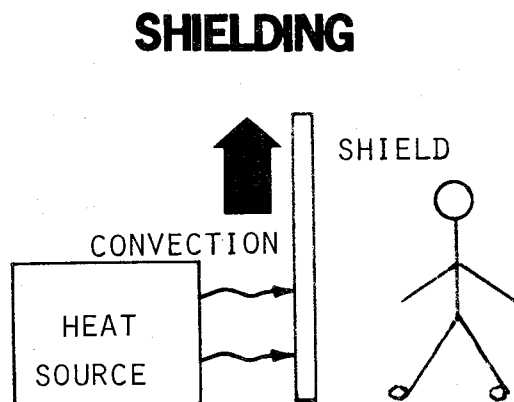
A second method for reducing the radiant heat load is to insulate the radiant source. A thermally conductive material can be placed on the outside of a hot body

that will in turn reduce the radiant heat load and cause it to be converted to heat that can be carried away by convection. An alternate method of insulating the outside of the radiant source is to provide a water jacket through which water is circulated. The water absorbs the heat energy and carries it away before entry to the workroom environment.

Shielding for Control of Radiant Heat. One of the most effective ways to reduce the level of radiant heat to which the worker is exposed is to use shielding. By applying shielding between the worker and the source, infrared radiation is intercepted. Since radiant heat travels in a straight line, it is important that the shield be located between the worker and the source and extend in such a manner that the entire worker is protected from any straight line infrared radiation.

There are basically three types of shielding methods available. These are the reflective shielding, absorbing shielding, and heat exchange shielding. Reflective shielding is made of a material that does not absorb or emit radiant heat well. Generally, a shiny material can be used for such shielding. Examples of reflective shielding include aluminum sheet, aluminum foil, aluminum paint on the surface of another metal, special reflective glass, wire or chain mesh, or flexible material. Depending upon the application, one type of material will have an advantage over the other. For example, aluminum foil is relatively inexpensive but does not hold up well over time and is easily torn. Reflective glass, wire, or chain mesh provides the operator with the ability to observe the process while limiting the exposure to radiant heat. However, neither material is as effective in reflecting radiant heat as aluminum sheeting.

Figure 3.4.1



The shield should be located with space between the shield and the source of heat. This space will act as a chimney that will carry away heat that is reflected back towards the source. Otherwise, the possibility of overheating of the structure of the source is possible. Whatever surface is used must be kept clean in order that it acts effectively as a reflector. A thin film of dirt can substantially reduce the reflective ability of aluminum sheeting.

A second method of shielding is to place an absorbing surface between the worker and the source of infrared radiation. A flat, black surface will absorb the infrared radiation. The radiant heat is then converted to convective heat by air passing over the surface. However, in these situations some reradiation occurs, and this method is not so satisfactory as using reflective shielding.

The absorptive shield may be combined with a water-cooled jacket. Water is circulated inside the shield and carries away the heat buildup in the shield. This approach, though effective, tends to be relatively expensive for installation as compared to reflective shielding.

Personal Protective Equipment. In certain situations it is desirable that the worker enter a hot environment with a high radiant heat load to perform maintenance functions. In these situations the fixed shield is not feasible. It is necessary to provide protection to the worker from the radiant heat load during exposure. Personal protective clothing provides a solution to this type of situation. Though this clothing is somewhat restrictive to motion and does not breathe, thus prohibiting evaporative cooling, it does provide the worker with a short protection against the radiant heat load.

Where it is necessary that longer exposures occur or where additional convective heat loss is required, refrigerated suits can be used. These suits can be either self-supplied or supplied from an external source. Generally the refrigeration involves either water cooling, compressed air passing through a vortex and thus expanding, or refrigerated air. Though these units are very restrictive to activity, they are useful for emergency entry into extremely hot areas.

In situations where only one portion of the worker's body is exposed to radiant heat, experiments have shown that partial protection using reflective clothing can be effective. Such items as aprons, gloves, hats, and face shields can be used where the worker must be exposed to radiant heat for short periods of time. However, again these methods do not replace the more long-term situations such as shielding.

Modifying the Thermal Environment for Convective Heat

Where the worker is exposed to convective heat stress, the industrial hygienist should consider the methods of substitution and isolation as possible controls. An investigation should be made to determine if it is possible that the process can be changed to eliminate the heat requirements. Can another process be substituted that generates less heat? Can the worker be isolated from the heat source and thus protected? An example of isolation is the provision of a separate air-conditioned control room for the workers. Another method is to isolate the hot processes in an area away from other activities, thus centralizing the source of heat in an area where control can be implemented.

One other method for controlling convective heat is to determine if the heat itself can be removed from the work area. This can be accomplished by insulating the source of heat as was discussed in the section on radiant heat. In addition, venting of the process and the use of local exhaust hoods can carry away significant portions of the convective heat generated.

General Dilution Ventilation. In many situations involving convective heat loads, general dilution ventilation can be used to reduce the thermal stress encountered. Recirculation of air from man-cooling fans can increase the convective heat loss of the workers. However, it should be remembered that such a recirculation of ambient air does not reduce the temperature. Thus, if the temperature is above 95°, recirculation will only increase the heat gain of the workers rather than accomplishing the desired result of reducing this heat gain.

Where the general heat load of a work area is high, thermal draft may assist in providing protection to the workers. Since hot air rises and escapes through ventilators in the roof or is drawn out by fans, effective cooling can be accomplished by supplying air at the outside temperature. Again, this air must be of significantly lower temperature in order to be effective in lessening the heat load. This air supply can be distributed throughout the entire work zone. Where spot cooling is required in specific hot areas, the supply then can be directed to these areas.

Removing Heat from the Air

In certain situations, the outside air is not sufficiently cool to provide relief from the hot environment. Thus, it is necessary to cool the outside supply air. This can be done either through evaporative cooling or through refrigeration of the air.

Evaporative cooling involves passing the air through a water spray. As the water evaporates into the air from the spray, heat is removed from the air because of the required BTU's necessary to accomplish this evaporation. The air thus becomes cooler as it is supplied to the worker. A totally efficient unit will reduce the dry bulb temperature of the air to that of the incoming wet bulb temperature. To further increase the cooling capacity of the evaporative cooler, water below the wet bulb temperature can be utilized in the spray system.

The second method available is to refrigerate the air. Direct expansion refrigeration units can be used to supply a general area or for spot cooling of a local enclosure or area. When a large industrial area must be cooled, this method tends to be expensive for installation and operation.

Protection from Climatic Conditions. The climatic conditions of the plant location can add an additional heat load to the interior environment. Radiation from the sun as well as hot and humid air in the environment can materially increase the potential for heat stress. Reflective glass can be placed in the windows that will reduce the radiation level passing through into the work environment. Water sprays can be placed on the roof that remove heat during evaporation. In addition, adequate insulation in the walls and below the roof can result in savings when the interior plant requires that cool air be supplied.

Modifying the Environment for Moisture

In some cases it is necessary to change the water vapor pressure in the air. A reduction in humidity allows for evaporative cooling in the worker's body to take place. On the other hand, an increase in humidity may be necessary to reduce the potential for static electricity buildup. In an explosive atmosphere, such static electricity buildup can result in the existence of a potential hazard.

The moisture content in the air can be increased by applying steam jet humidifiers and air washers to the incoming air. In these cases, a water vapor is introduced to the incoming air that increases the vapor content of the plant atmosphere.

Lowering the moisture content can be accomplished in a number of ways. Direct expansion refrigeration results in a lowering of moisture content since the air is cooled and reaches its dew point. In addition to cooling the air, the water vapor contained in the air condenses, thus lowering the humidity.

Chilled water can be sprayed into the incoming air. By lowering the temperature of the air, water vapor within the air condenses. A second method for introducing chilled water is through coils. As the air passes over the chilled water coils, it is cooled, thus lowering the dew point temperature and causing water vapor to condense.

Absorption of water vapor as the air is passed through certain solids and liquids can result in lowering the humidity. Certain problems exist when using solid absorption materials since once the solids have absorbed the water vapor, the process cannot be reversed. Liquids can be heated to release the water vapor, and thus recycling of the liquid can occur. In general the liquids are sprayed through the incoming air, gathered, heated, and then cooled and recycled back to the incoming air. One problem with such a system, however, is that there is a slight increase in the temperature of the air as a result of the dehumidification process.

Solid adsorption is another method for removing moisture from the air. Solids such as silica gel are often used as an adsorption medium. Heating of the adsorption material regenerates its adsorption properties. As in the case with absorption, heat is generated during the adsorption process, thus raising the heat of the incoming air. In many cases it is advantageous to include a refrigeration of the air prior to the adsorption process. This not only maintains the air at a comfortable incoming temperature but also removes some of the moisture prior to the adsorption process.

Modifying the Environment for Cold

During the winter months in cold climates, it is necessary to add heat to the air within an industrial facility. Heating the air can be accomplished through general heating of the make-up air or, in cases where general heating is not feasible, through the use of local heating with unit heaters and radiation panels. A further discussion of this topic is beyond the scope of this book. The interested reader is referred to the ASHRAE Engineers Guide and Data Book or the AIHA publication, "Heating and Cooling for Man in Industry."

Personal Protective Clothing. Workers are often subjected to extreme cold temperatures when working out of doors or in refrigerated areas. General heating cannot provide protection in these cases. Thus, the best approach is to provide personal protective clothing for the workers.

In general, individuals do not become acclimatized to cold. In fact, man's tolerance to cold is somewhat less than one might expect. Particularly dangerous is the exposure of the extremities and respiratory passages. Thus, there is a need to protect the worker from exposure to extreme colds that can result in frostbite and even death if the exposure lasts over a long period of time.

Figure 4.2



Where heavy work is required, there is an additional problem of evaporation of sweat that is present. The body can become overheated as the sweat collects on the skin and cannot evaporate. During rest periods after heavy activity, the sweat that is collected evaporates and exposes the body to excessive cooling. Therefore, it is important that the worker dress for the activity in which he is involved. Air that is held between layers of clothing provides additional insulation against heat loss and, as a result, multi-layered clothing is preferable. The outer layer should be wind resistant to protect the worker against convective

heat loss. Layers should be such that they can be removed during heavy work periods and added during rest periods or periods of lighter physical activity. Protection of the hands and feet can be accomplished by using mittens and insulated boots. Mittens are preferred over gloves since they provide better protection of the hands. Boots should be waterproof leather as opposed to rubber since the leather will breathe and allow for evaporation of moisture on the feet.

Summary

When controlling the work environment for thermal stress, the industrial hygienist must consider both radiation and convection heat loads. The general control methods available include decreasing the work load, modifying the exposure, screening the workers, education and training of the workers, acclimatization, monitoring the workplace, and maintenance of historical records of heat illness. For control of radiant heat, action can be taken to lower the radiation level by insulation or surface treatment by placing shields between the source and the worker and by providing personal protective equipment to the worker. For control of convective heat, the process may be modified, the source can be isolated from the work area, local exhaust can be used to remove the heat, general dilution can be used, or the workroom can be air conditioned. The industrial hygienist must also take action to control exposure to high humidity and cold.

Practice Exercises

1. A grinding operation is located in the vicinity of a series of autoclaves. The various temperature readings are as follows:

$$\begin{aligned} T_g &= 120^{\circ}\text{F} \\ T_{wb} &= 80^{\circ}\text{F} \\ T_{db} &= 85^{\circ}\text{F} \end{aligned}$$

What methods of control might be instituted to lower the level of heat stress?

2. The autoclave operator must periodically check dials on the outside of the unit to determine the internal temperature. How might this worker be protected?
3. It is necessary that workers be exposed to a hot area to perform work. No changes can be made to modify the environmental conditions. What methods of control might be used to alleviate hazards from heat stress in this situation?

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1. Explain the difference between heat and temperature.

2. Define the following terms:

BTU _____

Calorie _____

Specific Heat _____

Heat of Vaporization _____

Heat of Fusion _____

Enthalpy _____

Exothermic Process _____

Endothermic Process _____

Kirchoff's Law of Radiation _____

3. List the symptoms and treatment for each of the following heat-related illnesses:

Heat Cramps _____

Heat Exhaustion _____

Heat Stroke _____

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4. List the three methods of heat transfer. 1. _____ 2. _____ 3. _____ 5. Describe the physiological response of the human body to heat stress. _____ _____ 6. List 3 environmental and 6 individual factors that affect the level of strain from heat stress. <table style="width: 100%; border: none;"> <thead> <tr> <th style="text-align: center; width: 50%;"><u>Environmental</u></th> <th style="text-align: center; width: 50%;"><u>Individual</u></th> </tr> </thead> <tbody> <tr><td>_____</td><td>_____</td></tr> <tr><td>_____</td><td>_____</td></tr> <tr><td>_____</td><td>_____</td></tr> <tr><td>_____</td><td>_____</td></tr> <tr><td>_____</td><td>_____</td></tr> <tr><td>_____</td><td>_____</td></tr> </tbody> </table> 7. List the 4 required measurements for determining the level of heat stress and the equipment used for each. <table style="width: 100%; border: none;"> <thead> <tr> <th style="text-align: center; width: 50%;"><u>Measurement</u></th> <th style="text-align: center; width: 50%;"><u>Equipment</u></th> </tr> </thead> <tbody> <tr><td>_____</td><td>_____</td></tr> <tr><td>_____</td><td>_____</td></tr> <tr><td>_____</td><td>_____</td></tr> </tbody> </table> 8. A temperature of 76°F WB and 86°F DB is obtained. Determine the following using a Psychrometric Chart: Relative Humidity _____ Dew Point _____ Vapor Pressure _____		<u>Environmental</u>	<u>Individual</u>	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	<u>Measurement</u>	<u>Equipment</u>	_____	_____	_____	_____	_____	_____
<u>Environmental</u>	<u>Individual</u>																						
_____	_____																						
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_____	_____																						
<u>Measurement</u>	<u>Equipment</u>																						
_____	_____																						
_____	_____																						
_____	_____																						

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9. Given the following data for an indoor work area in which a man is standing and operating a series of controls:

Wet Bulb = 78°F
 Dry Bulb = 96°F
 Globe = 120°F
 Velocity of Air = 60 fpm
 Metabolic Rate = 600 BTU/hr

calculate

HSI _____

AET _____

WBGT _____

10. If a worker in the above situation has 3 rest periods during his 4-hour shift, 2 for 15 minutes and 1 for 30 minutes, in an air-conditioned room at 72°F DB, 68°F WB, and 75°F_g, calculate the time weighted WBGT exposure to the worker.
- _____
11. A workplace is exposed to a high radiant heat load. List methods of control that you would consider for reducing the thermal stress exposure of the workers.
- _____
- _____
- _____
- _____
12. If the above situation involved a convective heat load rather than a radiant load, what potential methods of control might be considered?
- _____
- _____
- _____
- _____
- _____
13. List 4 methods of reducing the humidity in the air.
- _____
- _____
14. Explain how evaporative cooling works to lower the air temperature.
- _____
- _____

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