

4, and to all four of the thermal characteristics of the environment:

$$M + 22(t_a - t_{cl}) + 2\sqrt{V}(t_a - t_{cl}) = 10V^{0.16}(P_s - P_a) \quad (6)$$

Equation 6 provides a rational basis on which to construct a heat stress index and to establish thermal standards for different industrial work situations.

Two physiological criteria are important in fixing the limit of sustained heat exposure:

1. The increase in body heat content must not exceed a certain level. Practically, this is reflected in the rise in skin temperature. This temperature may be limited to 95 F.

2. Thermal balance must be accomplished with a rate of sweating not greater than one liter per hour (equivalent to evaporative cooling of 2400 Btu per hr). Studies on young acclimatized subjects have shown that this maximum rate of sweating can be maintained over a workday without undue strain or physiological cost.

The Heat Stress Index (HSI) proposed by Belding and Hatch⁴ makes use of these criteria together with the previous biophysical equations. A so-called standard young man, in good physical condition and acclimatized to heat, can safely engage in simple physical work over a normal eight-hour day in a particular thermal environment so long as his skin temperature does not exceed 95 F and he maintains thermal balance with a sweat rate not exceeding 1 liter per hr. By definition, this degree of stress has an (HSI) value of 100 and is given by any combination of $M + R + C$ which is balanced by E_{max} within their defined limits. For other situations where E_{max} is greater or less than E_{max} (≤ 2400 Btu per hr), the value of (HSI) is proportionately different from 100:

$$(HSI) = 100 \times \frac{E_{max}}{E_{max} \approx 2400} \quad (7)$$

By using the globe thermometer temperature of the environment to represent the combined effects of mean radiant temperature and air temperature, the Heat Stress Index chart (Fig. 1) has been constructed, to permit quick determination of (HSI) when M , t_{cl} , t_{sk} , and air velocity are given. The procedure for finding (HSI) will be obvious by following the dash line in Fig. 1.

It should be noted that the globe thermometer temperature reading is made directly. A satisfactory globe thermometer can be constructed from a 4 in. diameter float ball (a toilet float will do) painted a flat black. A laboratory thermometer should be inserted through a rubber stopper and this assembly inserted in an opening in the ball so that the thermometer bulb is at the center of the sphere. For additional information on globe thermometers, see Chapter 16 in the 1961 Guide And Data Book.

The Heat Stress Index was developed from research experience with young men in good physical condition and well acclimatized to heat. Table 2 assigns suggested physiological meaning to (HSI) values above and below 100, for older men as well as the standard young man and, also, for various kinds of jobs which differ in their demands upon mental and physical effort. From these it becomes possible to select (HSI) levels appropriate to each work situation.

However, the maximum allowable index level for a specific job condition must be selected with caution. The research for the (HSI) was conducted on nude subjects.⁴ Recent studies indicate that the insulating effect of clothing may reduce the effects of radiation and convection by 40 percent.⁵ The (HSI) is being re-evaluated to allow for the effects of clothing. Provisionally it is recommended that R and C be estimated by taking 60 percent of the values indicated by Equations 3 and 4 and inserting the results in Equation 6, to determine the heat load, E_{req} , and (HSI) by Equation 7. Where possible it

Table 2.... Evaluation of Index of Heat Stress

Index of Heat Stress	Physiological and Hygienic Implications of 8-Hr Exposures to Various Heat Stresses
-20	Mild cold strain. This condition frequently exists in areas where men recover from exposure to heat.
-10	
0	No thermal strain.
+10	Mild to moderate heat strain. Where a job involves higher intellectual functions, dexterity, or alertness, subtle to substantial decrements in performance may be expected. In performance of heavy physical work, little decrement expected unless ability of individuals to perform such work under no thermal stress is marginal.
20	
30	
40	Severe heat strain, involving a threat to health unless men are physically fit. Break-in period required for men not previously acclimatized. Some decrement in performance of physical work is to be expected. Medical selection of personnel desirable because these conditions are unsuitable for those with cardiovascular or respiratory impairment or with chronic dermatitis. These working conditions are also unsuitable for activities requiring sustained mental effort.
50	
60	
70	Very severe heat strain. Only a small percentage of the population may be expected to qualify for this work. Personnel should be selected (a) by medical examination and (b) by trial on the job (after acclimatization). Special measures are needed to assure adequate water and salt intake. Amelioration of working conditions by any feasible means is highly desirable, and may be expected to decrease the health hazard while increasing efficiency on the job. Slight "indisposition" which in most jobs would be insufficient to affect performance may render workers unfit for this exposure.
80	
90	
100	The maximum strain tolerated daily by fit, acclimatized young men.

is desirable to establish the maximum allowable (HSI) value from field tests of the workers under normal conditions of work load, duration of work and clothing. Once established, this limit may then be extended to similar working conditions.

The Heat Stress Index (HSI) differs from the Effective Temperature (ET) scale in the rational rather than subjective basis of its construction. Practically, the commonly recommended ET = 80 F for heavy work at moderately high air velocity agrees very well with the (HSD) limit of 100 for acclimatized young men. In Fig. 2 are shown the combinations of dry- and wet-bulb temperature (air and wall temperature alike) for three different air velocities and three different grades of work, all of which give (HSI) = 100. Points representing ET = 80 F with an air velocity of 300 fpm are also shown for comparison.

CONTROL OF HEAT EXPOSURES

Measures for control of heat exposures will be treated under the following headings: Control at Source, Local Exhaust

Control of the Industrial Environment

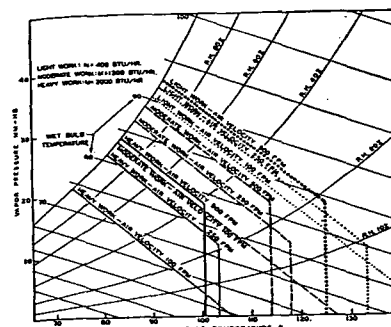


Fig. 2.... Conditions for Stress 100 at Three Grades of Work and Three Air Velocities

Ventilation, Radiation Shielding, General Ventilation, Dilution Ventilation, Local Relief Ventilation.

Control at Source

The magnitude of heat exposure can be reduced by insulating hot equipment, locating such equipment most favorably (in zones of good general ventilation within buildings or even outdoors), covering steaming water tanks, providing covered drains for direct removal of hot water, and maintaining tight joints and valves where steam may escape. This method is an obvious one and requires no particular comment other than to emphasize the benefits to be derived from elimination of heat sources wherever possible.

Local Exhaust Ventilation

The natural convection column of heated air rising from a hot process may be captured by means of ventilated enclosures or exhaust hoods and removed with a minimum of dilution by air from the surrounding space when local exhaust ventilation can be used. Chapter 21 provides detailed information on the design of exhaust hoods and duct systems for local exhaust.

Radiation Shielding

In some industries, commonly referred to as the hot industries, there are many hot objects and surfaces such as furnaces, ovens, furnace flues and stacks, boilers, molten material, and hot ingots of metal, castings, or forgings and, in consequence, the major environmental heat load is in the form of radiant heat. Since air temperature has no significant influence on the flow of radiant heat, ventilation is of no help in controlling such exposures. The only effective control is the direct one of decreasing the amount of radiant heat impinging on the exposed worker. This frequently can be accomplished by radiation shielding. Radiant heat exposures can be reduced by lowering the surface temperature of hot equipment by using insulation or water-cooled surfaces or radiation shields.

Hot surfaces emit infra-red waves which reach all objects within visible range. This is true not only if the hot surface is a primary one such as a furnace wall, a high temperature stack, or a hot ingot, but also if it is secondary in nature, that is, one which is reradiating heat after receiving it by direct radiation from a high temperature source. It may well be

that all surfaces in a shop or building are hot because of radiant heat received from a few primary sources. Under these circumstances, the ventilation air is heated rapidly as it circulates through the building. The result is a very unsatisfactory thermal environment, all stemming from the few primary heat sources. Consequently if the radiant heat load from these is reduced there will be a great improvement in the entire building.

A shield is simply a sheet of material, opaque to the infra-red waves (or essentially so), placed between the hot object such as a furnace, and the cooler surroundings. The closer it can be placed to the hot object, the greater will be the effective coverage. Essential to most shielding is the absence of physical contact and the presence of an air space between the hot object and the shield to avoid heating of the shield by conduction. This is not a vital matter if the shielding material has a low coefficient of emission for infra-red rays as does aluminum, for example. Under such circumstances, very little heat is radiated even if the shield becomes very hot.

Radiation shields in the following 5 forms are very effective:

1. Sheets of reflective metal or insulating board, semi-permanently attached to the hot equipment (such as furnace buck stays) or arranged as semi-portable floorstands.
2. Aluminum foil-faced cloth curtains raised or lowered on spring rolls.
3. Transparent shields, including heat reflective tempered plate glass, reflective metal chain curtains, and close mesh wire screens. These have lower efficiency than opaque shields in items 1 and 2.
4. Water-cooled shields for absorbing the heat.
5. Reflective garments, such as aprons, or in the form of a sandwich in cases of continuous front and back exposures. For continuous wear the apron or sandwich width should be limited to from 14 to 18 in. in order to assure adequate continuous side openings for air circulation and body ventilation. In addition, gauntlets and face shields are particularly applicable to operations such as the pouring and casting of hot metal. Supply houses dealing in safety clothing for industry offer suitable light-weight flame proofed foil-faced cotton drill or denim of excellent reflectivity. For repairs inside hot coke ovens and industrial furnaces, a complete suit is available using forced ventilation from a small blower or a compressed air source. These suits may be made of asbestos cloth faced with a reflective metal in atomized form.

If the shield is a good reflector, it will remain relatively cool in the presence of severe radiant heat. This reflectivity is a surface characteristic and is not dependent on thickness. A thin foil is effective. Bright or highly polished tinplate, stainless steel, and ordinary flat or corrugated aluminum sheets are efficient and long-lived. See Chapter 4 of the 1961 GUIDE AND DATA BOOK. Foil-faced plaster board, though less durable, gives good reflectivity on one side. Since the best radiation shields are effective reflectors of infra-red rays, they must be used intelligently lest a radiant heat load merely be transferred from one place to another. To be efficient, the reflective type shield must be maintained in the bright condition. The objective is to have the shield reflect the radiant heat back to the primary source where it may be removed by local exhaust. However, unless the shield completely surrounds the primary source, some of the infra-red energy will be reflected into the cooler surroundings and possibly into an occupied area. It is imperative, therefore, to study well where the reflected heat will go before shielding is installed, to avoid merely getting rid of the problem in one area by transferring it to another.

GENERAL VENTILATION

General ventilation involves sweeping a building area with relatively large quantities of air in order to provide an im-