pinging 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. Tinplate, stainless steel, and ordinary flat or corrugated aluminum sheets are efficient and long-lived. 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. 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, which involves sweeping of the space occupied by workmen and process heat sources with large quantities of outdoor air, may be used to limit the temperature rise within the space, if the outdoor air itself is not too hot. The method is particularly suitable for cases where the heat sources are spread over the entire area, and for the removal of solar heat from the space.

Dilution Ventilation

The principles of dilution ventilation furnish the basis for the design of the general ventilation system. The amount of air which must be circulated can be estimated as:

$$(\text{cfm}) = \frac{H}{1.08\Delta t} \qquad (8)$$

where

H = Heat to be removed from the space, Btu per hour.
Δt = temperature rise of the air, Fahrenheit degrees.

All heat sources such as furnaces, electric motors, ovens, and kilowatts of lighting should be tabulated to give the total heat output in Btu per hour (See Cooling Load Calculations, Chapter 13). The amount of air to be exhausted is a function of the total amount of heat and the permissible air temperature rise which, in practice, may vary from 10 up to 40 deg, depending on many factors such as roof height, nature of work being done, and magnitude of heat release.

Advantage should be taken of the chimney effect of the heated air within the space by introducing the diluting air near the floor of the space and discharging the heated air as near the top of the structure as possible, regardless of whether natural or mechanical exhaust ventilation is used. Since the workmen ordinarily operate near floor level, the entering air temperature should be within acceptable limits as outlined earlier in this section. The leaving air temperature will have its effect on workmen through the radiant heat emitted by the upper parts of the structure which are heated by the air. A higher leaving air temperature can be used with a high than with a low ceiling, since the ceiling contribution to the mean radiant temperature will be less for the taller structure.

Roof Ventilators

Roof ventilators are basically heat escape ports located in the high section of a building and properly enclosed for weather-tightness. Stack-draft effect plus some wind induction are the motive forces for several common designs of continuous ventilators and round ventilators. The latter can be equipped with fan barrel and motor, thus permitting gravity operation, or motorized high capacity operation, at will.

Two other main designs are available: one is the low-type ventilator which consists essentially of a stack fan with a rainhood; the other contains a stack fan with a split butterfly closure that is floated to open position by the discharge air stream and is self-closing. Both employ mimimum enclosures and have little or no gravity capacity.

Various types of roof ventilators may be listed in diminishing order of temperature differential and heat-removal capacity. Next to chimneys and stacks, the continuous ventilation monitor is most effective for removal of substantial and concentrated heat loads. This may be in the form of an elevated length of roof ridge with extended overhang and no rain louvers. Such structures are commonly employed over open hearth furnaces and soaking pit buildings but, in practice they give uncertain performance. A more efficient type is a streamlined, watertight monitor constructed of noncorrosive metals or protected metals. Its capacity increases with wind velocity and it can be readily closed in winter to conserve building heat. Both types have tremendous capacity and are limited only by roof area and proper relation of low-level air inlets.

Next in capacity are the (1) round gravity or windband ventilator, (2) round gravity type with fan and motor added, (3) low-hood powered ventilator, and (4) vertical upblast powered ventilator. Popular modifications of these include the rotary type and the turbine ventilator.

Minimum-capacity ventilators of the gravity type are applicable to warehouses with light heat loads, and to manufacturing areas having high roofs and light loads. Nonmechanical ventilators are desired here because the wide spacing makes electrical wiring and maintenance of fans and motors a matter of concern.

Streamlined continuous ventilators must be able to operate effectively in the absence of mechanical power. While it is difficult to predict performance accurately, it can safely be said that efficient ventilator operation is generally obtained when difference in elevation between the average air inlet level and the roof ventilation is not less than 30 ft and the exit temperature is 25 F deg above the prevailing outdoor temperature. See Chapter 11, Infiltration and Ventilation. Under these conditions and with a wind velocity of 5 mph, the ventilator throat velocity will be about 375 fpm. It will thus remove 10,000 Btu (per hr) (sq ft of throat area):

$$25 \text{ deg} \times 1.08 \times 375 \text{ cfm} = 10{,}000 \text{ Btu}$$

To insure this level of performance it is essential that sufficient low-level openings be provided for the incoming air; otherwise the gravity ventilator becomes starved for air and capacity falls off. The manufacturers recommend 250 fpm to 450 fpm inlet velocity. Lack of adequate inlet area is the most common cause of failure of gravity-type roof ventilators. A positive supply of air to insure direct ventilation around the hot equipment may be necessary within buildings of considerable area where the external wall inlets are remote from the equipment.

A decision between gravity and mechanical ventilators may be difficult to reach. The electrical power required for fan operation may be a deterring factor but this is offset by the advantage of constant ventilation capacity given by fan operation. Mechanical ventilators will also function despite inadequate fresh air inlets. In many cases there is justification for a mechanical supply (make-up air) which will positively supply air to the work zone.

LOCAL RELIEF

General

The methods required for general ventilation of industrial areas have been described. Such ventilation may have to be supplemented, or in some cases replaced by local ventilation in large industrial areas having substantial heat loads, high ceilings, and scattered work stations. Provision must be made for local relief, to provide tolerable working conditions around the several operations where the heat loads are concentrated. The methods indicated to be described for local relief are based on the assumption that exhaust ventilation, radiation shielding, equipment insulation, and possible changes in process design have been fully utilized to minimize the heat loads.

Methods of Providing Relief

Relief in local industrial work areas may be provided by any of the following three methods (or a combination of the three):

1. Provide a complete enclosure around the worker with separate ventilation in order to maintain cooler working conditions. This may be in the form of a control room, small shelter booth, or ventilated crane cab. In effect, this is "localized" general ventilation, differing only in the conditions of air temperature, humidity, and motion required.
2. Surround the worker with a relatively cool atmosphere by a direct supply of air introduced at a low level over a small area of the plant. In such cases we are not concerned with the temperature at higher levels in the space so long as adjacent structures do not become hot and thus return radiant heat into the work space.
3. Direct a high-velocity air stream at the worker to increase the evaporative cooling effect. This method, commonly called *spot cooling* will incorporate varying degrees of Method 2, depending upon the number of employees and the distribution of the work stations.

Method Number 1, in the form of a work station enclosure, is the most desirable because it permits complete control of the environment. The second method is effective in large areas with many work stations, such as machine shops and assembly lines. The last method is used to provide *spot cooling* in large spaces where scattered work stations and localized sources of heat make it highly impracticable to maintain a tolerable environment throughout the building.

Physiological Aspects of System Design

Two different situations in respect to heat load are encountered: (1) where radiant heat sources are not important, and (2) where radiant heat sources are important. These two situations must be treated differently in design.

Where Radiant Heat is Not Important. Where no important sources of radiant heat are located within or close to the work area, it is only necessary to introduce the relief air into the work space in such a way as to displace the hot air and thus surround the worker with an acceptable atmosphere, consistent with his own needs.

Where Radiant Heat is Important. Where important sources of radiant heat are present and cannot be entirely controlled by radiation shielding, the air supplied for relief must do more than simply displace the hot air. It must also provide convective cooling to offset the radiant heat load. This requires that the air be supplied at a lower temperature and with sufficient velocity. Contrariwise, if the temperature of the relief air exceeds skin temperature, a convective load is added to the radiative load and these, together with the metabolic heat must be removed by evaporative cooling. As the temperature of the air impinging on the worker rises above the skin temperature, a critical point is approached where too high an air velocity will add to the body heat load and too low a velocity will fail to evaporate the sweat, and thus fail to provide the maximum evaporative cooling effect.[3,4]

The level of air motion provided at the work station should be low, approaching normal room velocities, or about