higher. These diffusers have found favor in high velocity systems operating at substantially higher static pressures.

Perforated ceiling outlets have proven exceptionally satisfactory in preventing drafts, particularly where air changes are high and ceiling heights are low.

Exhaust and Return Air Outlets

Exhaust and return air terminals are usually either registers, grilles, louver or mesh screens. Registers have the advantage that balancing provisions are built within the terminal, particularly where ducts are concealed. With mesh screen, commonly found in toilet and shower spaces, a separate balancing damper must be located in the exhaust ductwork. This offers no disadvantage where ducts are exposed.

Exhaust terminals are selected for a face velocity consistent with noise levels acceptable in the space served, and to provide reasonable pressure drop when clogged with lint and dirt.

Decorative grilles frequently are provided in public spaces. Return air from individual small spaces like staterooms is usually accomplished by either a sight-tight louver mounted in the door or by *undercutting* the door leading to the passageway, the latter being confined to small air quantities (75 cfm or less). Louvers are most commonly sized for a velocity of 400 fpm based on net area.

CONTROLS

A ship, on a single voyage, may encounter extremes of climate—sometimes even within an hour. As a result, the air conditioning load on a ship varies over a wide range in a short period of time. Therefore. not only must the refrigeration plant successfully meet these variations in load, but the automatic controls must also be designed to readily adjust the system to sudden climatic changes. Accordingly, it is the general practice to equip the plant with the necessary auto matic controls. Inasmuch as body comfort is a matter of individual taste, it is necessary to provide room thermostats in living spaces such as staterooms, which can be adjusted by the occupant to suit personal requirements.

Controls used can be divided into four basic types: self contained, pneumatic, electric and manual.

On merchant ships pneumatic controls are used most extensively, particularly where accurate modulation and sequenced operation are essential. The self-contained control has the advantage of simplicity. They are used to control steam flow where accurate control is not particularly essential.

Except for special cases, electric controls are used only on naval vessels. In most cases these applications require only two position operation.

Manual volume control has been used to regulate temperatures in cabins and staterooms with varying results. On low velocity air distribution systems manual volume control has a tendency to disturb the air balance of the remainder of the spaces served. Manual controls used on high velocity dual-duct systems have been successfully applied where a constant volume regulator is employed in the mixing box.

The control of design conditions in staterooms and public spaces can be obtained by any one or combination of:

1. *Volume control* (used in *Type C* systems). This is the least expensive and simplest type of control. However, there are many disadvantages such as lack of flexibility in meeting simultaneous heating and cooling demands in adjacent spaces, unsatisfactory air distribution (lack of air motion where volume is reduced or excessive air motion in other spaces on the same system due to changes in static pressure), objectionable noise increase and fluctuations in adequate ventilation due to reduction in air delivery.

2. *Reheat Control* (used with *Types D* and *F* systems room units). Room thermostats provide individual temperature control over a wide range to compensate for space load changes and occupant preference. The room thermostat regulates precisely the amount of heating medium; usually hot water, delivered to each room reheater.

Similar control is used for Class *A* systems, except heating medium is usually steam. Where system serves only one space, humidistats are used to override room thermostat when humidity exceeds set point. In such cases room thermostat supplies heat when over cooling occurs.

3. *Local Cooling and Heating Control* (used with the *Type E* System). Heating-cooling thermostats control flow of water (hot or cold) through induction unit coils to suit demand of room thermostats (pneumatic).

Although most design conditions in spaces can be achieved with this arrangement, range of temperature control is rather limited during intermediate seasons (about 35 to 50 F). This is due to the fact that the heating effect (temperature) of the primary air must be limited to prevent exceeding the available cooling effect of the secondary water circulating through the induction unit coils. The flexibility of control therefore is reduced.

4. *Air Mixture Control* (used with *Type G* system).

Individual temperature control is accomplished by the positioning of an air valve either automatically utilizing a room thermostat or manually by remote control, which mixes the hot and cold air to suit space load demands.

5. The control required for zone reheaters of *Type C* Systems is achieved by regulating the amount of steam to the zone coils by one of two methods. One method utilizes a room thermostat in a *representative* space set and locked for an *average* zone temperature. Obviously, such an average seldom exists, and spaces served by this type control will not always achieve the desired comfort conditions.

A second method utilizes a master-submaster control which adjusts the reheater discharge temperature according to a predetermined schedule so that full heat is applied at the design outside heating temperature and less as this temperature rises. This control also does not adjust to meet variations in individual room loads. However, it is considered superior to the *representative room thermostat* method because it is more foolproof. With the first method occupants of the representative room may restrict air flow, thus disturbing the control of the entire zone.

Preheaters are controlled by a duct thermostat which modulates steam through the valve. The set point usually is a few degrees below the design cooling off coil setting to prevent *bucking*.

Except for *Type A* systems with humidity control and *Type E* system primary air coils, cooling coils (water) are controlled by a *dewpoint* thermostat to give a constant off-coil temperature during the entire cooling cycle. No control is provided for coils of *Type E* systems, because they are hooked up in series with the flow through induction units and it is essential that maximum dehumidification be accomplished by the primary coil to provide dry coil operation in room units.

Outdoor, return, and exhaust dampers are either manually (as a group) or automatically controlled. If automatic, one of two methods are used. One controls the damper settings by means of thermostats exposed to weather air. A second method uses a duct thermostat which restricts the outdoor air flow only when the design temperature leaving the coil cannot be achieved with full water flow through the cooling coil.

REGULATORY AGENCIES

Vessels which operate under the United States flag come under the jurisdiction of the United States Coast Guard. Accordingly, the installation and components must conform to the Marine Engineering Rules and Marine Standards of the United States Goast Guard. The design of the equipment and the installation must also comply with the requirements of the United States Public Health Service. This involves principally rat-proofing. Although comfort air conditioning installations do not ordinarily come under the cognizance of the American Bureau of Shipping, equipment should be manufactured wherever possible to comply with the American Bureau of Shipping Rules and Regulations. ASA B59.1-1958, *Recommended Practice for Mechanical Refrigeration Installation on Shipboard*, provides a guide for the installation of air conditioning and refrigerating equipment. Refrigerated cargo space installation must comply with A.B.S. requirements, if they are to be so certified.

CHAPTER 20

CONTROL OF THE INDUSTRIAL ENVIRONMENT

Heat Control of Industrial Work Areas, Thermal Standards, Control of Heat Exposures, Radiation Shielding, Roof Ventilators, Local Relief Methods, Physiological Aspects of System Design, Types and Requirements of Systems, Outlet Types and Design, Control of Contaminants

CONTROL of the industrial environment is concerned with the design and application of equipment for providing the necessary conditions within industrial areas for maintaining the efficiency, health, and safety of workers. This chapter includes a comprehensive list of the requirements for heat control and for control of gases and vapors, and dust and fumes.

General ventilation may be relied upon in some cases to control the industrial environment, as outlined in this chapter. Additional information on methods of ventilation may be found in the following chapters of the 1961 GUIDE AND DATA BOOK: natural ventilation, Chapter 24, mechanical ventilation, Chapters 11, 12, 13, 37, 38, 40, 47, and 48.

Information on heating and cooling loads and equipment will be found in Chapters 25, 26, 27, 28, 32, 33, 34, and 39 of the 1961 GUIDE AND DATA BOOK.

In this volume, reference should be made to Chapter 21 for design of hoods and exhaust systems for fumes and dusts. Chapters 23, 24, 25, 26, 27, 28, 29, 30, 33, 34, and 35 include information on process requirements for specific industrial applications.

For further information on estimating radiant heat conditions, see Chapter 4 of the 1961 GUIDE AND DATA BOOK and Chapter 10 in this volume.

Information on globe thermometers and other instruments used to measure the industrial environment may be found in Chapter 16 of the 1961 GUIDE AND DATA BOOK. More complete information will be found in References 1–4.

Specialists in the field of industrial hygiene should be consulted in case of doubt concerning the presence of airborne industrial hasards to health. Chapters 8 and 10 of the 1961 GUIDE AND DATA BOOK will be of help in establishing the atmospheric conditions that should be maintained around the worker. Local codes, ordinances, or state labor laws must likewise be observed, particularly with regard to ventilation requirements for hazardous trades. Comfortable conditions, if possible, or tolerable conditions at least, are desirable because they are likely to increase the efficiency and, hence, the output of workers. The majority of air-conditioning and ventilation installations in a typical industrial plant are concerned with the control of sensible, latent, or radiant heat.

HEAT CONTROL IN INDUSTRIAL WORK AREAS

In certain industrial work situations there is considerable release of heat from the process equipment to the environment. It is not economically feasible to stop the escape of all of this process heat or to offset it completely by the usual methods of *comfort* ventilation and air conditioning. In the design and operation of control measures it is frequently necessary to accept some heat exposure in excess of simple comfort requirements.

The engineer must distinguish between the control needs for *hot-dry* industrial areas and *warm-moist* conditions. In the first case, the process gives off only sensible and radiant heat without adding moisture to the air. The heat load on exposed workers is thereby increased but the rate of cooling by evaporation of sweat is not reduced. Heat balance may be maintained although this will be at the expense, perhaps, of excessive sweating. In the warm-moisture situation, the wet process gives off principally latent heat. There may be no significant rise in the heat load on the worker but the increase in moisture content of the air will seriously reduce the heat loss by evaporation of sweat. The warm-moist situation is potentially more hazardous than the hot-dry.

Examples of hot-dry work situations are seen around hot furnaces, forges, metal-extruding and rolling mills, glass-forming machines, and the like. Typical of warm-moist operations are many textile mills, laundries, dye houses, and deep mines where water is extensively used for dust control.

The industrial heat problem varies in magnitude with local climatic conditions. Solar heat gain and an elevated outdoor temperature will increase the heat load at the work place but these contributions may not be very important compared with the locally generated heat of the process itself. The moisture content of the outdoor air, on the other hand, is a most important climatic factor affecting hot-dry work situations and on a moist summer day will seriously restrict evaporative cooling. For the warm-moist job, in contrast, solar heat gain and elevated outdoor temperature are the more important, since, compared with the moisture release on the job, that contributed by the outdoor air will be of little significance.

Thermal Standards for Industrial Work Areas

The work situations considered here are those in which the attainment of simple thermal comfort is not always practicable. The heat stress must be kept below the level of outright hazard, but how much below? On what criteria should the specifications for control be based? How should the standards be varied in recognition of the differing demands and work rates from one kind of job to another? What differences exist between older and younger workers or between workers with differing degrees of physical fitness? To what extent can periods of heat exposure be offset by alternating periods of recovery? How is this expressed in terms of design of the control measures? These and other questions arise in the analysis of an industrial heat problem and must be considered by the design engineer and others before specifications are fixed. As there is no single set of thermal standards applicable to all work situations, failure to give proper recognition to the many facets of the problem can result in inadequate control measures.

Biophysical Basis for Fixing Thermal Standards

Under conditions of thermal comfort, the rate of internal heat production (metabolism) is just balanced by the rate of heat loss to the environment. This comfortable balance is maintained without active sweating, with optimum skin and