REPORT No. 1491—Further studies of the thermal characteristics of plaster panels (ASHVE TRANSACTIONS, Vol. 59, 1953, p. 511).

H. B. Nottage, C. V. Franks, L. E. Hulbert, and L. F. Schutrum: ASHVE RESEARCH REPORT No. 1492—Heat flow analysis in panel heating or cooling sections, case II—Floor slab on earth with uniformly spaced pipes or tubes at the slab-earth interface (ASHVE TRANSACTIONS, Vol. 59, 1953, p. 527).

W. S. Harris and E. L. Sartain: *Performance of Hot Water Panel Heating Systems* (University of Illinois *Engineering Experiment Station Bulletin* No. 453, 1959).

C. M. Humphreys, H. B. Nottage, C. V. Franks, R. G. Huebscher, L. F. Schutrum, and D. W. Locklin: ASHVE RESEARCH REPORT No. 1337—Laboratory studies on heat flow within a concrete panel (ASHVE TRANSACTIONS, Vol. 56, 1950, p. 175).

L. F. Schutrum and T. C. Min: ASHAE RESEARCH REPORT No. 1598—Cold wall effects in a ceiling-panel-heated room (ASHAE TRANSACTIONS, Vol. 63, 1957, p. 187).

E. L. Sartain and W. S. Harris: Performance of covered hot water floor panels, Part II—Room conditions (ASHAE TRANSACTIONS, Vol. 63, 1957, p. 209)

CHAPTER 11

ELECTRIC HEATING

Resistors, Heating Elements, Electric Heating Units, Electric Space Heating Applications, Types of Electric Heating Systems, Equipment and Installation Methods, Calculating Capacities, Power Considerations

ELECTRICITY as a source of heat represents thermal energy in a refined form, easily applied to space heating, and readily distributed and controlled. For many applications, including use to supplement heating systems of other types, the compactness, simplicity, responsiveness, accuracy of control, safety, and cleanliness of electric heating may carry greater weight in choice of method than operating cost and initial investment. Electric heat often is more expensive on a direct-heat-equivalent basis than heat from conventional fuels. Economical service requires careful application in the design of system, adaptation of building structure, choice of control devices, and in method of operation by the user.

Using the power-to-heat conversion constant, 1 kilowatt equals 3,413 Btuh, resistance heating calculations are expressed directly in terms of kilowatt power requirements.

Definitions of *Resistor*, *Heating Element*, and other terms for electric heating practice are given in Chapter 63 of the 1961 GUIDE AND DATA BOOK.

All equipment, materials, and construction used in electric heating systems should comply with the requirements of the *National Electrical Code* and with local codes.

ELECTRIC HEATING UNITS

An electric heating unit is a frame, casing, or other supporting means containing one or more heating elements, electric terminal connections or leads, and electrical wiring and insulation, all assembled into a unit. There are many varieties of housing, material, and arrangement of heating elements, operating temperatures, ratio of radiant to convective heat delivery, directional control for radiation, natural or forced convection, automatic or manual control, and electric load limiting features. Many specific types of units are discussed in the section Equipment and Installation Methods.

RESISTORS AND HEATING ELEMENTS

Electric resistors usually are composed of metal-alloy wire or ribbons, non-metallic carbon compounds in rod or other shapes, or printed circuits. Heating elements may have exposed resistor coils mounted on insulators, metallic resistors embedded within refractory insulation encased in a protective metal sheath, or a printed circuit encased in glass sheets. Fins or extended surfaces may be used to add heat-dissipating area. Elements are made in many forms. Strip elements are used for clamping to surfaces for heat transfer by conduction in some convection air heaters and some low temperature radiant heaters. Ring and plate elements are common in electric ranges and many small air heaters. Metal or oxide conductive films on glass and ceramics have been used usually in panel form. Tubular elements may be immersed in liquids, may be used bare, may be formed into coils, or may be cast into metal or plastic, and used in water heaters, ranges, and air heaters.

Cloth fabrics, incorporating flexible resistor wires, are employed for many low temperature purposes such as heating pads, sheets, blankets, aviators' clothing, and some radiant panel heating installations.

Paper or fabric incorporating a surface resistor on the back side is being applied for ceiling or wall panel heating installations.

Coiled resistors in quarts tubes, metal sheath elements, or special incandescent lamps with tungsten or carbon filaments and glass or quarts envelopes are designed to produce maximum energy in the infra-red portion of the spectrum. They are applied as radiant heaters.

ELECTRIC SPACE HEATING APPLICATIONS

Complete electric heating systems are now finding wide application not only in residences but also in many commercial and industrial establishments. Auxiliary electric space heating is often used where minimum initial cost is the dominant factor, or for convenience, for instance: (*a*) for local use when the main heating system is shut down, (*b*) for local use where the main heating system is inadequate, (*c*) for temporary heating, (*d*) for special conditions involving separate or remote control, (*e*) for isolated locations. Portable units readily satisfy some of these requirements.

Compact electric heating units are sometimes installed in main supply or branch ducts of central-fan steam and water systems to provide the final temperatures and relative humidities required for comfort or process air conditioning. Electric heaters installed for use primarily in the heating cycle can also be utilized for reheat in the cooling cycle. (See later section Central Warm Air Systems.)

In control of systems, the flow of air over the electric heaters should be constant while the input to the heaters should be varied. This is necessary because of the basic difference between electric heating and other methods such as steam heating. Steam is approximately a constant temperature source of heat at any given pressure, and, consequently, a change in air flow over a steam coil does not greatly alter the coil surface temperature. Hence, the heat output of a steam coil varies in proportion to the air volume, but the surface temperature of the coil remains about the same. With electric heat the energy input and output are constant, and if the electrical energy input remains constant, the temperature of the heating elements will vary inversely with the air flow. Therefore, face and bypass dampers should not be used in electric heating, because the reduction in air flow and the corresponding rise in heater temperature would endanger the operating life of an electric heating element.

The majority of electric heaters are controlled directly by line voltage thermostats (or low voltage thermostats operating contactors) to provide on-off control. Where a more refined control is required a proportional-type step controller may be used to energize or de-energize heaters in increments small enough to achieve a balance with little cycling. The electrical input per step is normally determined by the permissible change in supply air temperature per step. High-limit thermo-