PANEL HEATING AND COOLING SYSTEMS

This material discusses the principles and equipment available for panel heating and cooling systems. Additional details can be found in Chapter 6, "Radiant Heating and Cooling," in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*.

1 General

Radiant heating and cooling systems combine temperature control of room surfaces with central air conditioning. Radiant surfaces may be located in the floor, walls, or ceiling, and the temperature is maintained by circulating water or air or by electric resistance. Where heating-cooling panel systems are used in commercial and institutional applications, they must be supplemented with a dedicated outdoor air system (DOAS) that must provide the ventilation, filtration, air motion, and all of the space humidity control. On the cooling cycle, the system must ensure that the room dew-point temperature is always above the lowest panel or chilled-water supply pipe temperature. A controlled-temperature surface is called a **radiant panel** if 50% or more of the heat transfer is by radiation to other surfaces.

Residential heating-only applications usually consist of pipe coils embedded in wood or masonry floors or plaster ceilings. This construction serves well where loads are relatively stable and where solar effects are minimized by building design. However, in buildings with large glass areas and rapid load changes, the slow response, lag, and override effect of concrete or masonry panels is unsatisfactory. Lightweight metal panel ceiling systems quickly respond to load changes and are used for cooling as well as heating in commercial and institutional applications.

Warm air and electric heating elements are used where local factors influence such use. In the warm air system, air is supplied to a cavity behind, under, or encapsulated in the panel surface. The air may leave the cavity through a normal diffuser and flow into the room. These systems are used as floor radiant panels in schools and in floors subject to extreme cold, such as over an overhang. Electric heating elements embedded in the floor or ceiling construction and unitized electric ceiling panels are used in residences, apartments, and various applications for local spot heating. Two factors to consider when using electric radiant panels are local electric codes and the relative difference between electric and fossil fuel heating costs.

The radiant panel is often located in the ceiling of a room. A ceiling is used because it sees all other surfaces and objects in the room; it is not subject to unpredictable coverings, as are floors; for heating, higher surface temperatures can be used; it is of smaller mass and therefore has quicker response to load changes; radiant cooling can be incorporated, and, in the case of the metal ceiling system, the piping is accessible for servicing.

Ceiling panel systems commonly used are an outgrowth of the perforated metal, suspended, acoustical ceiling. These radiant ceiling systems are usually designed into buildings where the features of the suspended acoustical ceiling can be combined with panel heating and cooling. The panels can be designed as small units to fit the building module and provide extensive flexibility for zoning and control, or, for maximum economy, the panels can be arranged as large continuous areas. Two types of metal ceiling systems are available. One type consists of lightweight aluminum panels, usually 12 by 24 in. (305 by 610 mm), that are attached in the field to 0.5 in. (15 mm) galvanized pipe coils. The second type consists of a copper coil metallurgically bonded to the aluminum face sheet forming a modular panel. Modular panels are available in sizes up to approximately 36 by 60 in. (910 by 1520 mm) and are held in position by various ceiling suspension systems.

The arrangement of components in radiant panel systems is similar to other air-water systems. Room temperature conditions are primarily maintained by a combination of direct transfer of radiant energy, and by convective heating and cooling. The room heating and cooling loads are calculated in the conventional manner. Manufacturers generally rate their equipment in the form of total performance, which can be applied directly to the calculated room load for heating and to the room sensible load for cooling.

These are the principal advantages of panel heating and cooling systems:

1. If they are properly designed; because of the low airflow quantities these systems can be very energy efficient.
2. Panel systems do not require any mechanical heat exchange equipment at the outside walls, thus simplifying the wall, floor, and structural systems.
3. All pumps, fans, filters, and so forth, are centrally located, thereby centralizing maintenance and operation.
4. Cooling or heating may be obtained during any season, without central zoning or seasonal changeover, when four-pipe systems are used.
5. Supply air quantities usually do not exceed those required for ventilation and dehumidification.
6. No mechanical equipment requiring maintenance or repair is placed within the occupied space, except possibly the control valves.
7. Draperies and curtains can be installed at the outside wall without interfering with heating and cooling systems.
8. The modular panel provides flexibility to meet changes in partitioning.
9. No space is required within the air-conditioned room for the mechanical equipment. This feature is especially valuable when compared to other conditioning methods for applications in existing buildings, hospital patient rooms, and other applications where space is at a premium and where maximum cleanliness is essential.
10. A common central air system for ventilation and dehumidification can serve both the interior and perimeter zones.
11. Wet surface cooling coils are eliminated from the occupied space, thus reducing the potential for septic contamination.

Other essential factors when considering the use of panel systems are as follows:

1. Evaluate early to plan an optimum physical arrangement of the building to take full advantage of the panel system.
2. Select recessed lighting fixtures, air diffusers, hung ceiling, and other ceiling devices to provide the maximum ceiling area possible for use as radiant panels.
3. The air-side design must maintain the room dew-point temperature below the lowest temperature of panel surface at all times to eliminate any possibility of condensation on the panels. The systems must be interlocked to shut down the chilled water to the panels if the dehumidifying system fails.
4. As with any hydronic system, design the piping system to avoid noises from entrained air, high velocity or high pressure drop devices, or from pump and pipe vibrations.
5. Anticipate thermal expansion of the ceiling and other devices in or adjacent to the ceiling.

2 Types

The most common forms of panels applied in panel heating and cooling systems are

- Metal ceiling panels
- Embedded piping in ceilings, walls, or floors (heat only)
- Air-heated floors
- Electrically heated ceilings or floors

Metal Ceiling Panels. Metal ceiling panels are often integrated into a system that both heats and cools. In such a system, a source of dehumidified ventilation air is required. This system must provide all of the ventilation air and all of the humidity control, as well as pressurize the building to avoid any significant infiltration. In such a system, various amounts of forced air are supplied year-round. (See Section 10.4 of Chapter 10 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition.)

A metal ceiling panel system using copper tubing metallurgically bonded to an aluminum panel is shown in Figure 1. This panel can be mounted into various ceiling suspension systems.

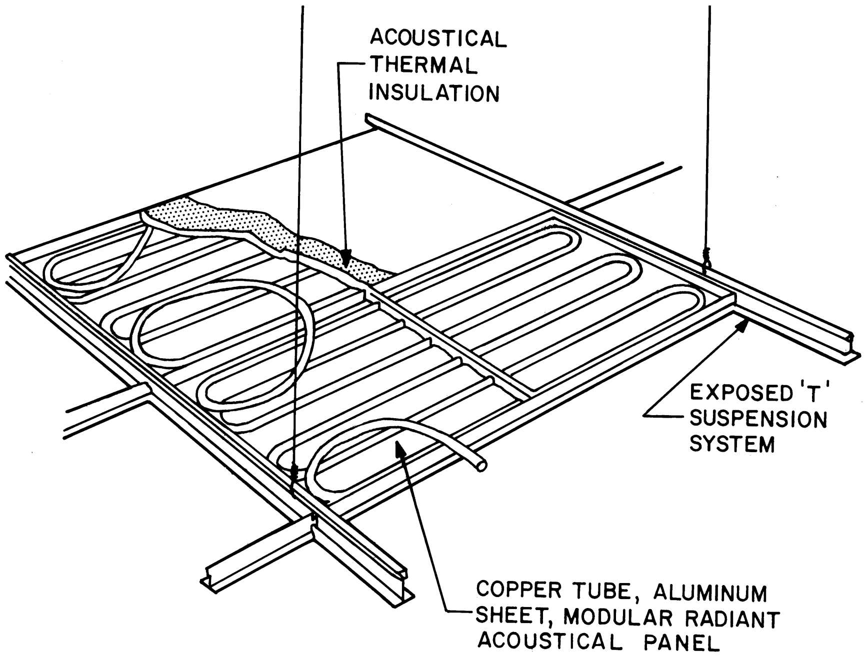

Fig. 1 Metal Ceiling Panels Metallurgically Bonded to Copper Tubing
(Figure 13, Chapter 6, 2016 *ASHRAE Handbook—HVAC Systems and Equipment*)

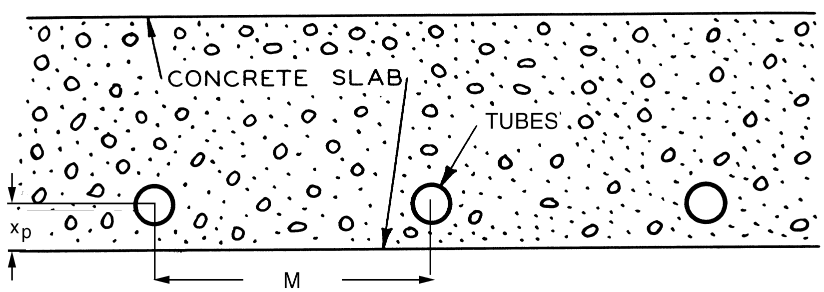

Fig. 2 Coils in Structural Concrete Slab
(Figure 16, Chapter 6, 2016 *ASHRAE Handbook—HVAC Systems and Equipment*)

Two-pipe and four-pipe distribution systems have been used successfully with metal ceiling panels. Common design practice calls for a 20°F (11°C) drop for heating across a given grid and a 5°F (3°C) rise for cooling, but higher temperature differentials may apply in some cases.

Some ceiling installations require that active grids cover only a part of the room, and consequently, compatible matching standard acoustical panels are normally used for the remaining ceiling area.

Embedded Piping in Ceilings, Walls, and Floors. When piping is embedded in ceilings, the construction used is generally one of the following:

1. Pipe or tube is embedded in the lower portion of a concrete slab, generally within an inch of its lower surface. If plaster is to be applied to the concrete, the piping may be placed directly on the wood forms. If the slab is to be used without plaster finish, then the piping should be installed not less than 0.75 in. (19 mm) above the undersurface of the slab. This method of construction is shown in Figure 2. The minimum coverage must be in compliance with the local building code requirements.
2. Pipe or tube is embedded in a metal lath and plaster ceiling. If the lath is suspended to form a hung ceiling, both the lath and the heating coils are securely wired to the supporting members in such a way that the lath is below, but in good contact with, the coils. Plaster is then applied to the metal lath, with care being taken to embed the coil.

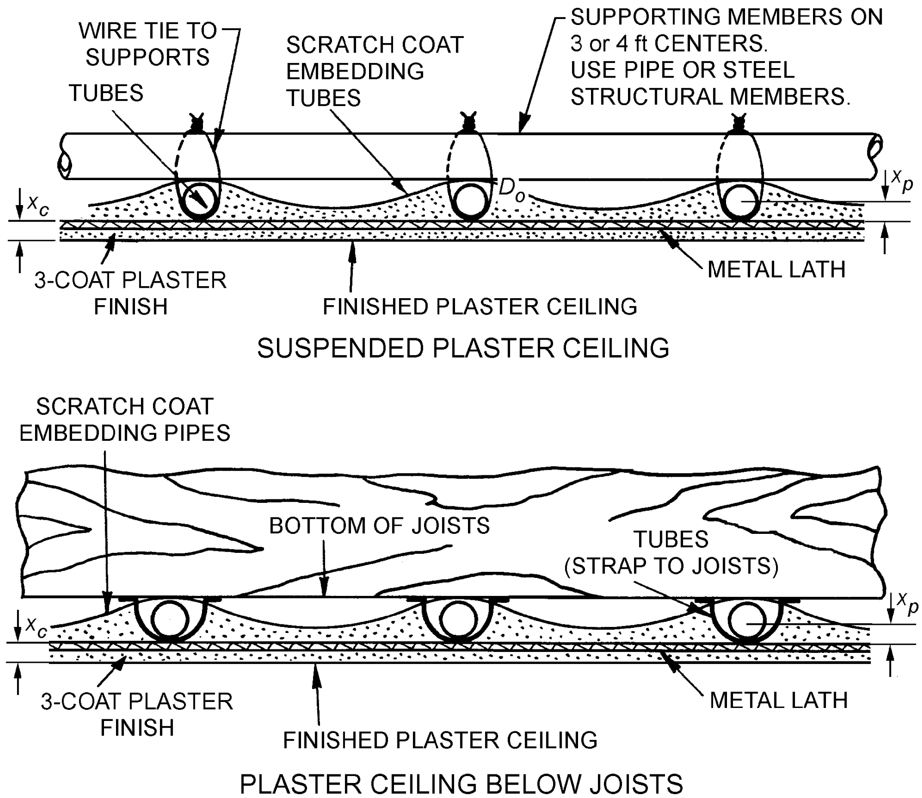

Fig. 3 Coils in Plaster Above Lath
(Figure 17, Chapter 6, 2016 *ASHRAE Handbook—HVAC Systems and Equipment*)

3. Copper tube of the smaller diameters or cross-linked polyethylene (PEX) tubing is attached to the underside of a wire lath or gypsum lath. Plaster is then applied to the lath to embed the tube (Figure 3).
4. Other forms of ceiling construction are composition board, wood paneling, etc., with warm water piping, tube, or channels built into the panel sections.

Coils are usually of the sinuous type, although some header or grid-type coils have been used in ceilings. Coils may be of plastic (PEX), ferrous, or nonferrous pipe or tube, with coil pipes spaced from 4.5 to 9 in. (115 to 230 mm) on centers, depending on the required output, pipe or tube size, and other factors.

Although not so universally used as ceiling panels, wall panels may be constructed by any of the methods described for ceilings.

The construction for piping embedded in floors depends on whether (1) the floor is laid on grade or (2) the floor is above grade.

On-Grade Floor. Plastic (PEX), ferrous, and nonferrous pipe and tube are used in floor slabs which rest on grade. The coils are constructed as either sinuous, continuous pipe coils or arranged as heater coils with the pipes spaced from 6 to 18 in. (150 to 460 mm) on centers. The coils are generally installed with 1.5 to 4 in. (40 to 100 mm) of cover above the coils. Insulation should be used to reduce the perimeter and reverse side losses. Illustrated in Figure 4 is the application of pipe coils in slabs resting on grade. Coils should be embedded completely and should not rest on an interface. Any supports used for positioning the heating coils should be nonabsorbent and inorganic.

Above-Grade Floor. Where the coils are embedded in structural load-supporting slabs above grade, construction codes may affect their position. Otherwise, the coil piping is installed in the same manner as described for slabs resting on grade. Except the pipes should be installed in the wearing (finish) concrete rather than in the structural concrete.

Air-Heated Floors. Several methods have been devised to warm interior room surfaces by circulating heated air through passages in the floor. In some cases, the heated air is recirculated in a closed system. In oth-

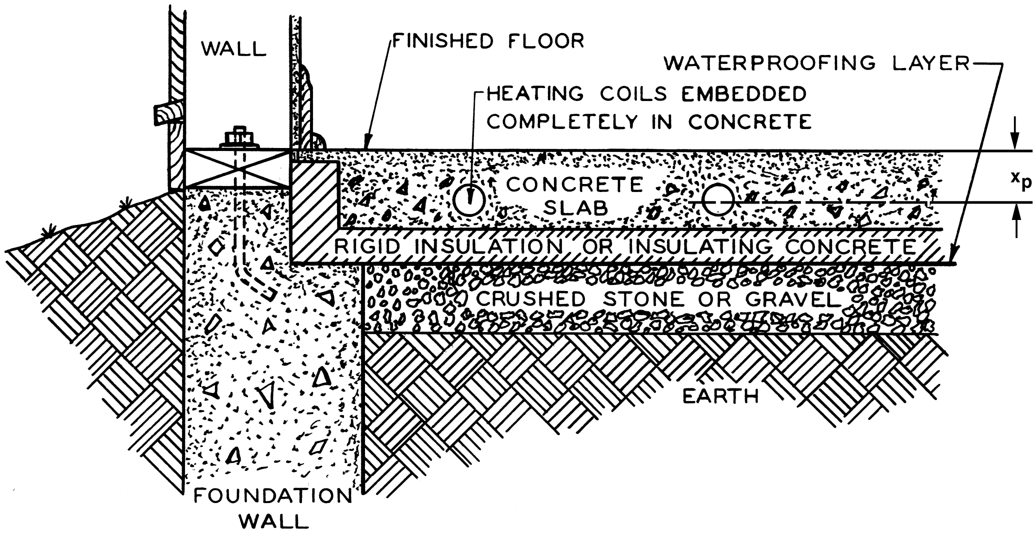

Fig. 4 Coils in Floor Slab on Grade
(Figure 19, Chapter 6, 2016 *ASHRAE Handbook—HVAC Systems and Equipment*)

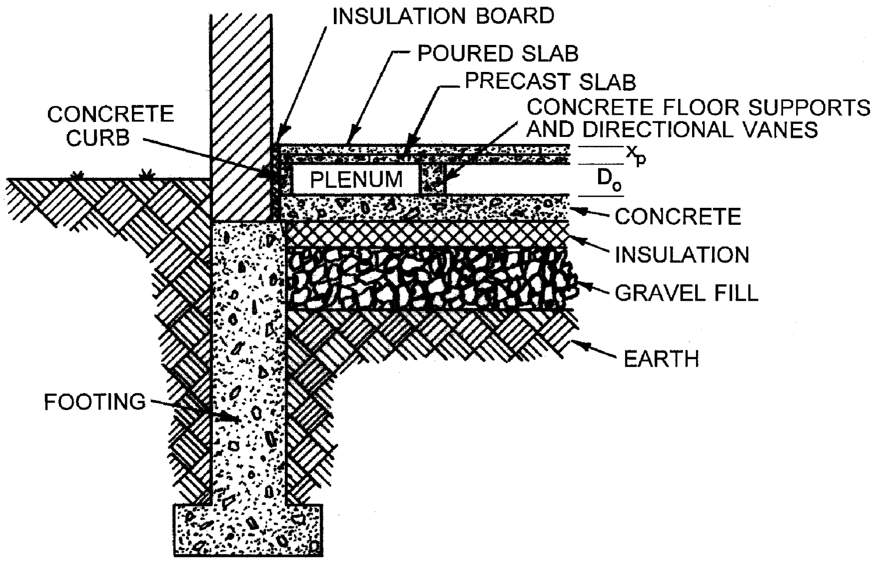

Fig. 5 Warm Air Floor Panel Construction
(Figure 27, Chapter 6, 2012 *ASHRAE Handbook—HVAC Systems and Equipment*)

ers, all or part of the air is passed through the room on its way back to the furnace or air-handling unit to provide supplementary heating and ventilation (Figure 5).

Electrically Heated Ceilings. Several types of electric resistance units are available for heating interior room surfaces. These include (1) electric heating cables that may be embedded in concrete or plaster or laminated in drywall ceiling construction; (2) prefabricated electric heating panels to be attached to room surfaces; and (3) electrically heated fabrics or other materials for application to, or incorporation into, finished room surfaces.

Ceiling Cables. The details of ceiling cable installation for plastered and drywall construction is shown in Figure 6.

Electric Heating Panels. A variety of prefabricated electric heating panels are used for either supplemental or full room heating. These panels are available in sizes from 2 by 4 ft to 6 by 12 ft (0.6 by 1.2 m to

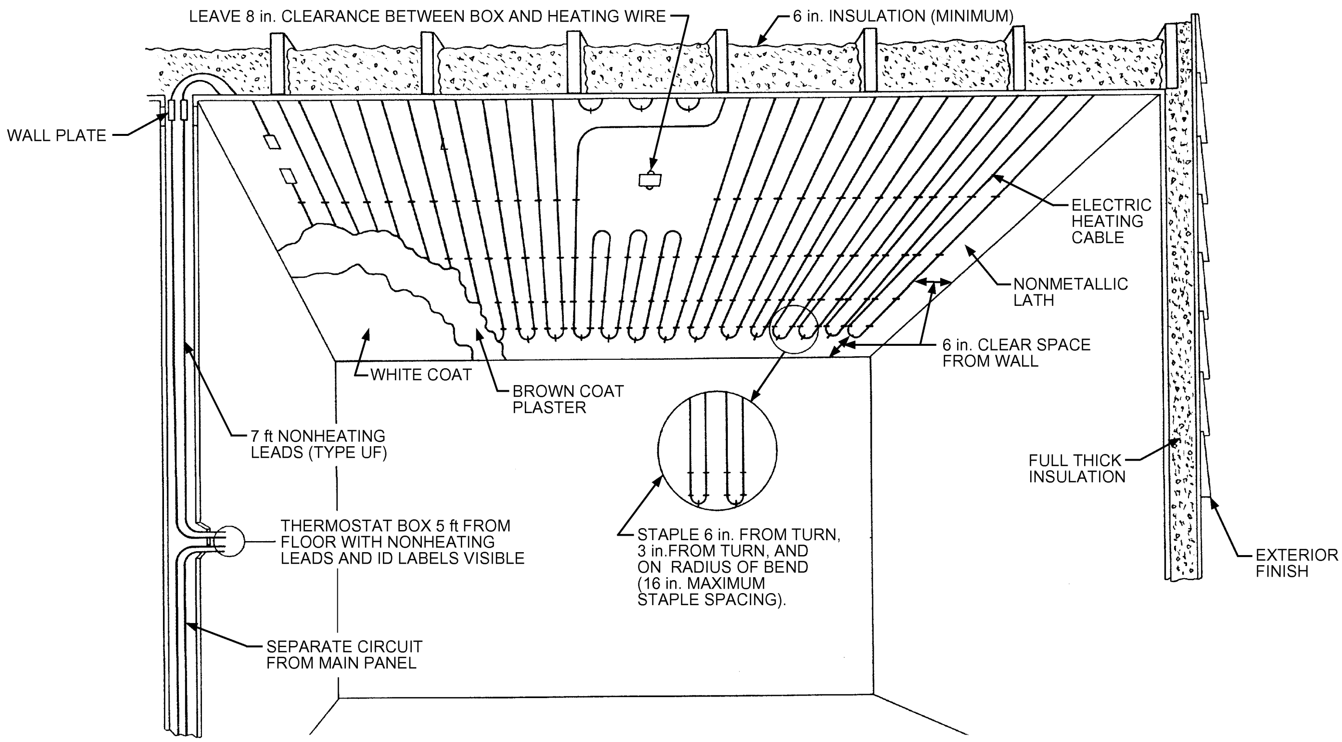

Fig. 6 Electric Heating Panel for Wet Plastered Ceiling
(Figure 24, Chapter 6, 2016 *ASHRAE Handbook—HVAC Systems and Equipment*)

1.8 by 3.6 m). They are constructed from a variety of materials such as gypsum board, glass, steel, and vinyl. Different panels have rated inputs varying from 10 to 95 W/ft^2 (108 to 1023 W/m^2) for 120, 208, and 240 V service. Maximum operating temperatures vary from about 100°F to about 300°F (38°C to 49°C) depending on watt density.

Panel heating elements may be embedded conductors, laminated conductive coatings, or printed circuits. Nonheating leads are connected and furnished as part of the panel.

Some panels may be cut to fit available space; others must be installed as received. Panels may be either flush or surface mounted. In some cases, they are finished as part of the ceiling. Rigid panels that are about 1 in. (25 mm) thick and weigh about 25 lb (11 kg) each are available to fit standard 2 by 4 ft (0.6 by 1.2 m) modular tee-bar ceilings.

Cable embedded in walls, similar to ceiling construction, is occasionally found in Europe. Because of possible damage due to nails driven for hanging pictures or because of building alteration, most codes prohibit such panels in the United States.

Some of the prefabricated panels described in the preceding section are also used for wall panel heating.

Electric heating cable assemblies, such as those used for ceiling panels, are sometimes used for concrete floor heating systems.

3 Design Steps

Panel design requires specification of the following: panel area, size and location of the heating elements in the panel, insulation on the reverse side and edge of the panel, required input to panel, and temperature of the heating elements. Specific procedures are given in Chapter 6 of the 2016 *ASHRAE Handbook—HVAC Systems and Equipment*. The procedure is summarized as follows:

1. Calculate heat loss for each room.
2. Determine the available area for panels in each room.
3. Calculate the required unit panel output.

4. Determine the required panel surface temperature.
5. Select the means of heating the panel and the size and location of the heating elements.
6. Select insulation for the reverse side and edge of panel.
7. Determine panel heat loss and required input to the panel.
8. Determine the other temperatures that are required or developed.
9. Design the system for heating the panels in accordance with conventional practice and manufacturers recommendations.

In the steps outlined for design, the effect of each assumption or choice on comfort should be considered carefully. The following general rules should be followed:

1. Place panels near cold areas where heat losses occur.
2. Do not use high-temperature ceiling panels in very low ceilings.
3. Keep floor panels temperatures at or below 85°F (30°C).

Example 1 The living room in a home is occupied by adults in light clothing and engaged in sedentary activity. The room has a net outside wall area of 275 ft^2 with a surface temperature of 54°F, 45 ft^2 of glass with a surface temperature of 20°F; 540 ft^2 of ceiling with a surface temperature of 60°F; 670 ft^2 of partitions with a surface temperature of 70°F; and 540 ft^2 of floor with a surface temperature of 70°F. If the air movement is 20 fpm, determine the air temperature necessary for comfort.

Solution

$$\text{Mean radiant temperature} = \text{MRT} =$$

$$\text{MRT} = \frac{275(54) + 45(20) + 540(60) + 670(70) + 540(70)}{275 + 45 + 540 + 670 + 540}$$

$$\text{MRT} = 64.1\,°\text{F}$$

for sedentary activity with light clothing at 20 fpm from Figure 4-3 of Chapter 4 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition:

$$t_{\text{dry bulb}} = 90\,°\text{F for comfort}$$

4 References and Bibliography

Amende, K.L., J.A. Keen, L.E. Catlin, M. Tosh, A.M. Sneed, and R.H. Howell. 2021. *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition.

ASHRAE. 2016. *ASHRAE Handbook—HVAC Systems and Equipment*.

ASHRAE. 2020. *ASHRAE Handbook—HVAC Systems and Equipment*.

Baumen, F., J. Feng, and S. Schiavon. 2013. Cooling load calculations for radiant systems: are they the same as traditional methods? *ASHRAE Journal* 55(12): 20.

Kim, K.W., and B.W. Olesen. 2015. Radiant heating and cooling systems—Part I. *ASHRAE Journal*, February: pp. 28.

Kim, K.W., and B.W. Olesen. 2015. Radiant heating and cooling systems—Part II. *ASHRAE Journal*, March: pp. 34.

Sastry, G., and P. Rumsey. 2014. VAV vs. radiant: Side-by-side comparison. *ASHRAE Journal*, May: pp. 16.

5 Problems

Problem 1 A room has a net outside wall area of 300 ft^2 that has a surface temperature of 55°F; 50 ft^2 of glass with a surface temperature of 30°F; 560 ft^2 of ceiling with a surface temperature of 70°F; and 560 ft^2 with a surface temperature of 70°F. Estimate the average unheated surface temperature or the area-weighted mean radiant temperature.

Problem 2 For the room in Problem 1, estimate the following:

1. Radiant output for a 100 ft^2 heating panel with a panel surface temperature of 120°F
2. Natural convection output for the ceiling panel when the air temperature is 70°F

Problem 3 A room has 1500 ft^2 of surface area and 320 ft^2 is to be heated. The average unheated surface temperature in the room is 67°F. The air temperature in the room is 75°F. The room is occupied by adults in light clothing at a sedentary activity. Determine the surface temperature of the heated panel necessary to produce comfort if the air velocity is 20 fpm.

Problem 4 For Problem 3, determine the total heat transferred by the ceiling heating panel.