CHAPTER 15

INFRARED RADIANT HEATING

INFRARED radiant heating principles discussed in this chapter apply to equipment with thermal radiation source temperatures ranging from 300 to 5000°F. (Equipment with source temperatures starting from below the indoor air temperature to 300°F is classified as panel heating and cooling equipment, discussed in Chapter 6.) Infrared radiant heaters with source temperatures in this range are categorized into three groups as follows:

- **Low-intensity** source temperatures range from 300 to 1200°F. A typical low-intensity heater is mounted on the ceiling and may be constructed of a 4 in. steel tube 10 to 80 ft long. A gas burner inserted into the end of the tube raises the tube surface temperature, and because most units are equipped with a reflector, thermal radiation is directed down to the heated space.
- **Medium-intensity** source temperatures range from 1200 to 1800°F. Typical equipment types include porous matrix gas-fired infrared heaters or metal-sheathed electric heaters.
- **High-intensity** source temperatures range from 1800 to 5000°F. A typical high-intensity heater is an electrical reflector lamp with a resistor temperature of 4050°F.

Low-, medium-, and high-intensity infrared heaters are frequently applied in aircraft hangars, factories, warehouses, foundries, greenhouses, and gymnasiums. They are applied to open areas such as loading docks, racetrack stands, under marquees, vestibules, outdoor restaurants, carwashes, and around swimming pools. Infrared heaters are also used for snow and ice melting (see Chapter 50 of the 2007 *ASHRAE Handbook—HVAC Applications*), condensation control, and industrial process heating. Reflectors are frequently used to control the distribution of heat flux from thermal radiation in specific patterns.

When infrared radiant heating is used, the environment is characterized by

- A directional thermal radiation field created by the infrared heaters
- A thermal radiation field consisting of reradiation and reflection from the walls and/or other enclosing surfaces
- Ambient air temperatures often lower than those found with convective systems

The combined action of these factors determines occupant thermal comfort and the thermal acceptability of the environment.

ENERGY CONSERVATION

Infrared heaters are effective for spot heating. However, because of their efficient performance, they are also used for total heating of large areas and entire buildings (Buckley 1989). Radiant heaters transfer heat directly to solid objects. Little heat is lost during transmission because air is a poor absorber of radiant heat. Because an intermediate transfer medium such as air or water is not required, fans or pumps are not needed.

The preparation of this chapter is assigned to TC 6.5, Radiant and In-Space Convective Heating and Cooling.

As thermal radiation warms floors, walls, and objects, they in turn release heat to the air by convection. Reradiation to surrounding objects also contributes to comfort in the area. An energy-saving advantage is that infrared heaters can be turned off when not needed; when turned on again, they are effective in minutes. Even when the infrared heater is off, the heated surrounding objects at occupant level continue to contribute to comfort by reradiating heat and releasing heat by convection.

Human thermal comfort is primarily governed by the operative temperature of the heated space (ASHRAE *Standard* 55). Operative temperature may be approximated by the arithmetic average of the mean radiant temperature (MRT) of the heated space and dry-bulb air temperature, if air velocity is less than 1.3 fps and MRT is less than 120°F. See Chapter 53 of the 2007 *ASHRAE Handbook—HVAC Applications* for further details. In radiant heating, the dry-bulb air temperature may be kept lower for a given comfort level than with other forms of heating because of increased MRT. As a result, heat lost to ventilating air and via conduction through the shell of the structure is proportionally smaller, as is energy consumption. Infiltration loss, which is a function of dry-bulb air temperature, is also reduced.

Because of the unique split of radiant and convective components in radiant heating, air movement and stratification in the heated space is minimal. This further reduces infiltration and transmission heat losses.

Buckley and Seel (1987) compared energy savings of infrared heating with those of other types of heating systems. Recognizing the reduced fuel requirement for these applications, Buckley and Seel (1988) noted that it is desirable for manufacturers of radiant heaters to recommend installation of equipment with a rated output that is 80 to 85% of the heat loss calculated by methods described in Chapters 29 and 30 of the 2005 *ASHRAE Handbook—Fundamentals*. BSR/ASHRAE *Standard* 138P describes a rated output system for ceiling radiant heaters.

Chapman and Zhang (1995) developed a three-dimensional mathematical model to compute radiant heat exchange between surfaces. A building comfort analysis program (BCAP) was developed as part of ASHRAE research project RP-657 (Jones and Chapman 1994). The BCAP program was later enhanced to analyze the effect of radiant heaters over 300°F on thermal comfort calculations, and to analyze the thermal comfort effect of obstacles in the heated space in ASHRAE research project RP-1037 (Chapman 2002).

INFRARED ENERGY SOURCES

Gas Infrared

Modern gas-fired infrared heaters burn gas to heat a specific radiating surface. The surface is heated by direct flame contact or with combustion gases. Studies by the Gas Research Board of London (1944), Haslam et al. (1925), and Plyler (1948) reveal that only 10 to 20% of the energy produced by open combustion of a gaseous fuel is infrared radiant energy. The wavelength span over which radiation from a heated surface is distributed can be controlled by design. The specific radiating surface of a properly designed unit directs

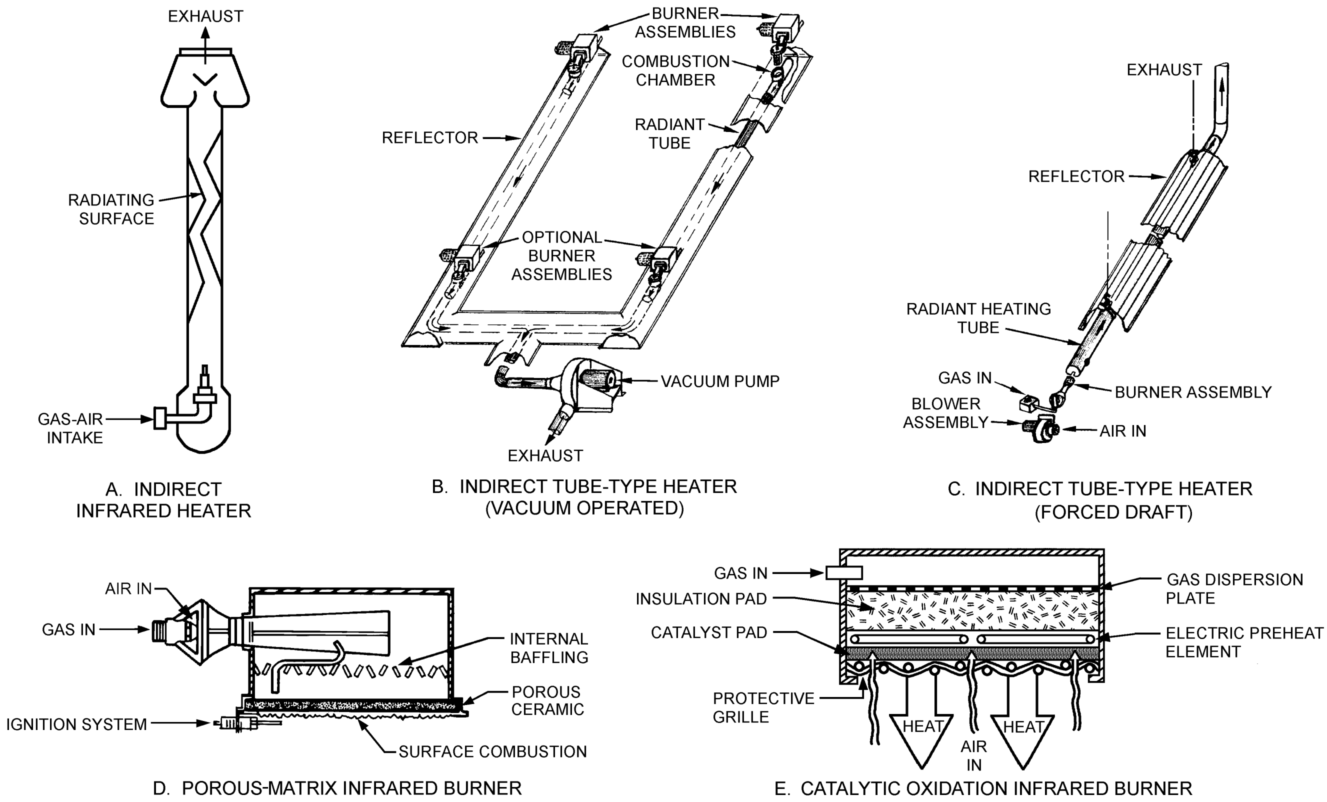

Fig. 1 Types of Gas-Fired Infrared Heaters

Table 1 Characteristics of Typical Gas-Fired Infrared Heaters

Characteristics	Indirect	Porous Matrix	Catalytic Oxidation
Operating source temperature	Up to 1200°F	1600 to 1800°F	650 to 700°F
Relative heat flux,[a] Btu/h·ft²	Low, up to 7500	Medium, 17,000 to 32,000	Low, 800 to 3000
Response time (heat-up)	180 s	60 s	300 s
Thermal radiation-energy input ratio[b]	0.35 to 0.55	0.35 to 0.60	No data
Thermal shock resistance	Excellent	Excellent	Excellent
Vibration resistance	Excellent	Excellent	Excellent
Color blindness[c]	Excellent	Very good	Excellent
Luminosity (visible light)	To dull red	Yellow red	None
Mounting height	9 to 50 ft	12 to 50 ft	To 10 ft
Wind or draft resistance	Good	Fair	Very good
Venting	Optional	Nonvented	Nonvented
Flexibility	Good	Excellent—wide range of heat fluxes and mounting possibilities available	Limited to low-heat-flux applications

[a]Heat flux emitted at burner surface.
[b]Ratio of thermal radiation to energy output to input.
[c]Color blindness refers to absorptance by various loads of energy emitted by different sources.

radiation toward the load. Gas-fired infrared radiation heaters are available in the following types (see Table 1 for characteristics).

Indirect infrared radiation heaters (Figures 1A, 1B, and 1C) are internally fired and have the radiating surface between the hot gases and the load. Combustion takes place within the radiating elements, which operate with surface temperatures up to 1200°F. The elements may be tubes or panels with metal or ceramic components. Indirect infrared radiation units are usually vented and may require eductors.

Porous-matrix infrared radiation heaters (Figure 1D) have a refractory material that may be porous ceramic, drilled port ceramic, stainless steel, or a metallic screen. The units are enclosed, except for the major surface facing the load. A combustible gas-air mixture enters the enclosure, flows through the refractory material to the exposed face, and is distributed evenly by the porous character of the refractory. Combustion occurs evenly on the exposed surface. The flame recedes into the matrix, which adds radiant energy to the flame. If the refractory porosity is suitable, an atmospheric burner can be used, resulting in a surface temperature approaching 1650°F. Power burner operation may be required if refractory density is high. However, the resulting surface temperature may also be higher (1800°F).

Catalytic oxidation infrared radiation heaters (Figure 1E) are similar to porous-matrix units in construction, appearance, and operation, but the refractory material is usually glass wool, and the radiating surface is a catalyst that causes oxidation to proceed without visible flames.

Electric Infrared

Electric infrared heaters use heat produced by electric current flowing in a high-resistance wire, graphite ribbon, or film element. The following are the most commonly used types (see Table 2 for characteristics).

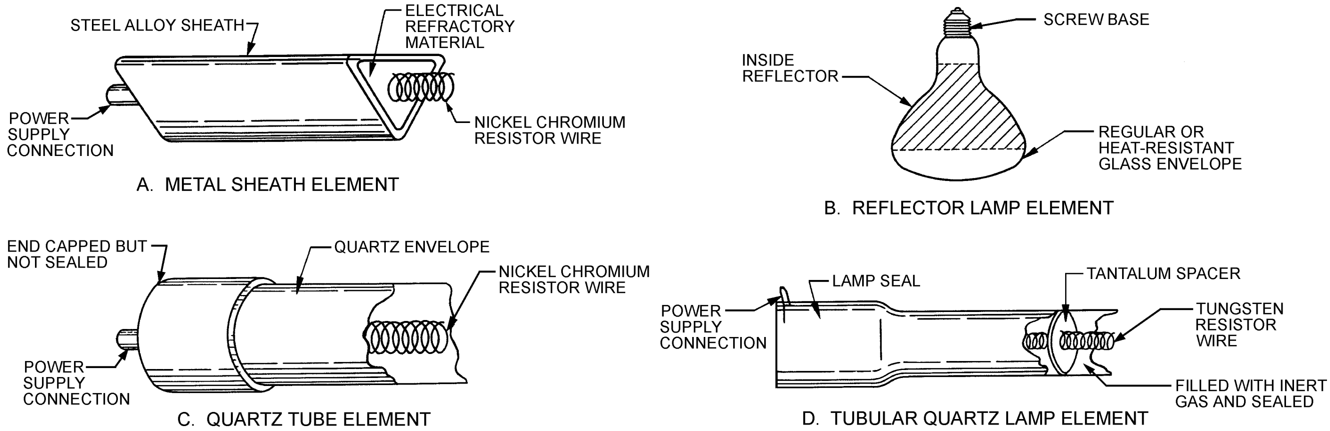

Fig. 2 Common Electric Infrared Heaters

Table 2 Characteristics of Four Electric Infrared Elements

Characteristic	Metal Sheath	Reflector Lamp	Quartz Tube	Quartz Lamp
Resistor material	Nickel-chromium alloy	Tungsten wire	Nickel-chromium alloy	Tungsten wire
Relative linear heat flux	Medium, 60 W/in., 0.5 in. diameter	High, 125 to 375 W/spot	Medium to high, 75 W/in., 0.5 in. diameter	High, 100 W/in., 3/8 in. diameter
Resistor temperature	1750°F	4050°F	1700°F	4050°F
Envelope temperature (in use)	1550°F	525 to 575°F	1200°F	1100°F
Thermal radiation-energy input ratio[a]	0.58	0.86	0.81	0.86
Response time (heat-up)	180 s	A few seconds	60 s	A few seconds
Luminosity (visible light)	Very low (dull red)	High (8 lm/W)	Low (orange)	High (7.5 lm/W)
Thermal shock resistance	Excellent	Poor to excellent (heat-resistant glass)	Excellent	Excellent
Vibration resistance	Excellent	Medium	Medium	Medium
Impact resistance	Excellent	Medium	Poor	Poor
Wind or draft resistance[b]	Medium	Excellent	Medium	Excellent
Mounting position	Any	Any	Horizontal[c]	Horizontal
Envelope material	Steel alloy	Regular or heat-resistant glass	Translucent quartz	Clear, translucent, or frost quartz and integral red filter glass
Color blindness	Very good	Fair	Very good	Fair
Flexibility	Good—wide range of power density, length, and voltage practical	Limited to 125-250 and 375 W at 120 V	Excellent—wide range of power density, diameter, length, and voltage practical	Limited—1 to 3 W for each V; 1 length for each capacity
Life expectancy	Over 5000 h	5000 h	5000 h	5000 h

[a]Ratio of thermal radiation output to energy input (elements only).
[b]May be shielded from wind effects by louvers, deep-drawn fixtures, or both.
[c]May be provided with special internal supports for other than horizontal use.

Metal sheath infrared radiation elements (Figure 2A) are composed of a nickel-chromium heating wire embedded in an electrical insulating refractory, which is encased by a metal tube. These elements have excellent resistance to thermal shock, vibration, and impact, and can be mounted in any position. At full voltage, the elements attain a sheath surface temperature of 1200 to 1800°F. Higher temperatures are attained by configurations such as a hairpin shape. These units generally contain a reflector, which directs radiation to the load. Higher radiosity is obtained if the elements are shielded from wind because the surface-cooling effect of the wind is reduced.

Reflector lamp infrared radiation heaters (Figure 2B) have a coiled tungsten filament, which approximates a point source radiator. The filament is enclosed in a clear, frosted, or red heat-resistant glass envelope, which is partially silvered inside to form an efficient reflector. Units that may be screwed into a light socket are common.

Quartz tube infrared radiation heaters (Figure 2C) have a coiled nickel-chromium wire lying unsupported within an unevacuated, fused quartz tube, which is capped (not sealed) by porcelain or metal terminal blocks. These units are easily damaged by impact and vibration but stand up well to thermal shock and splashing. They must be mounted horizontally to minimize coil sag, and they are usually mounted in a fixture that contains a reflector. Normal operating temperatures are from 1300 to 1800°F for the coil and about 1200°F for the tube.

Tubular quartz lamp units (Figure 2D) consist of a 0.38 in. diameter fused quartz tube containing an inert gas and a coiled tungsten filament held in a straight line and away from the tube by tantalum spacers. Filament ends are embedded in sealing material at the ends of the envelope. Lamps must be mounted horizontally, or nearly so, to minimize filament sag and overheating of the sealed ends. At normal design voltages, quartz lamp filaments operate at about 4050°F, while the envelope operates at about 1100°F.

Oil Infrared

Oil-fired infrared radiant heaters are similar to gas-fired indirect infrared radiant heaters (Figures 1A, 1B, and 1C). Oil-fired units are vented.

SYSTEM EFFICIENCY

Because many factors contribute to the performance of a specific infrared radiant heating system, a single criterion should not be used to evaluate comparable systems. Therefore, at least two of the following indicators should be used when evaluating system performance.

Thermal radiation-energy input ratio is the thermal energy transferred by radiation in the infrared wavelength spectrum divided by the total energy input.

Fixture efficiency is an index of a fixture's ability to radiate thermal energy from the source; it is usually based on total energy input. The housing, reflector, and other parts of a fixture absorb some infrared energy and convert it to heat, which is lost through convection. A fixture that controls direction and distribution of energy effectively may have higher fixture efficiency.

Pattern efficiency is an index of a fixture's effectiveness in directing infrared energy into a specific pattern. This effectiveness, plus effective application of the pattern to the thermal load, influences the system's total effectiveness (Boyd 1963). Typical thermal radiation-energy input ratios of gas infrared heaters are shown in Table 1. Limited test data indicate that the amount of thermal radiation from gas infrared units ranges from 35 to 60% of the amount of convective heat. The Stefan-Boltzmann law can be used to estimate thermal radiation if reasonably accurate values of true surface temperature, emitting area, and surface emittance are available (DeWerth 1960). DeWerth (1962) also addresses the spectral distribution of energy curves for several gas sources.

Table 2 lists typical thermal radiation-energy input ratios of electric infrared heaters. Fixture efficiencies are typically 80 to 95% of the thermal radiation-energy input ratios.

Infrared heaters should be operated at rated input. A small reduction in input causes a larger decrease in radiant output because of the fourth-power dependence of radiant output on source temperature. Because a variety of infrared units with a variety of reflectors and shields are available, the manufacturers' information should be consulted.

REFLECTORS

Radiation from most infrared heating devices is directed by the emitting surface and can be concentrated by reflectors. Mounting height and whether spot heating or total heating is used usually determine which type of reflector will achieve the desired heat flux pattern at floor level. Four types of reflectors can be used: (1) parabolic, which produce essentially parallel beams of energy; (2) elliptical, which direct all energy that is received or generated at the first focal point through a second focal point; (3) spherical, which are a special class of elliptical reflectors with coincident foci; and (4) flat, which redirect the emitted energy without concentrating or collimating the rays.

Energy data furnished by the manufacturer should be consulted to apply a heater properly.

CONTROLS

Normally, all controls (except the thermostat) are built into gas-fired infrared heaters, whereas electric infrared fixtures usually have no built-in controls. Because of the effects of direct radiation, as well as higher MRT of the heated space and decreased air temperature compared to convective systems, infrared heating requires careful selection and location of the thermostat or sensor. A thermostat sensing the operative temperature rather than the air temperature is desirable; placing the thermostat or sensor in the radiation pattern increases accuracy. The nature of the system, type of infrared heaters, and nature of the thermostat or sensor dictate the appropriate approach. Furthermore, no single location appears to be equally effective after a cold start and after a substantial period of operation. To reduce high and low temperature swings, a long rather than a short thermostat cycling time is preferred. A properly sized system and modulating or dual-stage operation can improve comfort conditions.

An infrared heater controlled by low-limit thermostats can be used for freeze protection. For freeze protection systems and heat flux requirement, refer to Chapter 50 of the 2007 *ASHRAE Handbook—HVAC Applications*.

On gas-fired infrared heaters, a thermostat usually controls an electronic ignition system that monitors the gas flame and operates the automatic valve to provide on-off control of gas flow to all burners. For all gas-fired infrared heaters, conform to all applicable standards and codes covering proper venting, safety, and indoor air quality.

Gas and electric infrared systems for full-building heating may have a zone thermostatic control system in which a thermostat representative of one outside exposure operates heaters along that outside wall. Two or more zone thermostats may be required for extremely long wall exposures. Heaters for an internal zone may be grouped around a thermostat representative of that zone. Manual switches or thermostats are usually used for spot or area heating, but input controllers may also be used.

Input controllers effectively control electric infrared heaters having metal sheath or quartz tube elements. An input controller is a motor-driven cycling device in which *on* time per cycle can be set. A 30 s cycle is normal. When a circuit's capacity exceeds an input controller's rating, the controller can be used to cycle a pilot circuit of contactors adequate for the load.

Input controllers work well with metal sheath heaters because the sheath mass smooths the pulses into even radiation. The control method decreases the efficiency of infrared generation slightly. When controlled with these devices, quartz tube elements, which have a warm-up time of several seconds, have perceptible but not normally disturbing pulses of infrared, with only moderate reduction in generation efficiency.

Input controllers should not be used with quartz lamps because the cycling luminosity would be distracting. Instead, quartz lamp output can be controlled by changing the voltage applied to the lamp element, using modulating transformers or by switching the power supply from hot-to-hot to hot-to-ground potential.

Electrical power consumed by the tungsten filament of the quartz lamp varies approximately as the 1.5 power of the applied voltage, whereas that of metal sheath or quartz tube elements (using nickel-chromium wire) varies as the square of the applied voltage. Multiple circuits for electric infrared systems can be manually or automatically switched to provide multiple stages of heat. Three circuits or control stages are usually adequate. For areas with fairly uniform radiation, one circuit should be controlled with input control or voltage variation control on electric units, while the other two are full on or off control. This arrangement gives flexible, staged control with maximum efficiency of infrared generation. The variable circuit alone provides zero to one-third capacity. Adding another circuit at full on provides one-third to two-thirds capacity, and adding the third circuit provides two-thirds to full capacity.

PRECAUTIONS

Precautions for applying infrared heaters include the following:

- All infrared heaters covered in this chapter have high surface temperatures when operating and should, therefore, not be used when the atmosphere contains ignitable dust, gases, or vapors in hazardous concentrations.
- Manufacturers' recommendations for clearance between a fixture and combustible material should be followed. If combustible material is being stored, warning notices defining proper clearances should be posted near the fixture.
- Manufacturers' recommendations for clearance between a fixture and personnel areas should be followed to prevent personnel stress from local overheating.
- Infrared fixtures should not be used if the atmosphere contains gases, vapors, or dust that decompose to hazardous or toxic

materials in the presence of high temperature and air. For example, infrared units should not be used in an area with a degreasing operation that uses trichloroethylene unless the area has a suitable exhaust system that isolates the contaminant. Trichloroethylene, when heated, forms phosgene (a toxic compound) and hydrogen chloride (a corrosive compound).

- Humidity must be controlled in areas with unvented gas-fired infrared units because water formed by combustion increases humidity. Sufficient ventilation [NFPA 54 (ANSI Z223.1), *National Fuel Gas Code*], direct venting, or insulation on cold surfaces helps control moisture problems.
- Lamp holders and electrical grounding for infrared heating lamps should comply with Section 422-15 of the *National Electrical Code*® (NFPA *Standard* 70).
- Sufficient makeup air (NFPA 54, *National Fuel Gas Code*) must be provided to replace the air used by combustion heaters, regardless of whether units are direct vented.
- If unvented combustion infrared heaters are used, the area must have adequate ventilation to ensure that combustion products in the air are held to an acceptable level (Prince 1962). See Chapter 45 of the 2007 *ASHRAE Handbook—HVAC Applications* for information on IAQ concerns.
- For comfort in areas such as hangars and docks, conditioned space should be protected from substantial wind or drafts. Suitable wind shields seem to be more effective than increased radiation heat flux (Boyd 1960).

In the United States, refer to Occupational Safety and Health Administration (OSHA) guidelines for additional information. For nonvented infrared radiant heaters, IAQ and occupant comfort are important. For IAQ concerns, see Chapter 45 of the 2007 *ASHRAE Handbook—HVAC Applications*.

MAINTENANCE

Gas- and oil-fired infrared heaters require periodic cleaning to remove dust, dirt, and soot. Reflecting surfaces must be kept clean to remain efficient. Annual cleaning of heat exchangers, radiating surfaces, burners, and reflectors with compressed air is usually sufficient. Chemical cleaners must not leave a film on reflector surfaces.

Air ports of gas-fired units should be kept free of lint and dust. The nozzle, draft tube, and nose cone of oil-fired unit burners are designed to operate in a particular combustion chamber, so they must be replaced carefully when they are removed.

Electric infrared heaters require little care beyond cleaning the reflectors. Quartz and glass elements must be handled carefully because they are fragile, and fingerprints must be removed (preferably with alcohol) to prevent etching at operating temperature, which causes early failure.

DESIGN CONSIDERATIONS FOR BEAM RADIANT HEATERS

Chapter 53 of the 2007 *ASHRAE Handbook—HVAC Applications* introduces design principles for spot beam radiant heating. The effective radiant flux (ERF) represents the radiant energy absorbed by an occupant from all temperature sources different from the ambient. ERF is defined as

$$\text{ERF} = h_r(\bar{t}_r - t_a) \quad (1)$$

where

ERF = effective radiant flux, Btu/h·ft²
h_r = linear radiation heat transfer coefficient, Btu/h·ft²·°F
$\bar{t}_r$ = mean radiant temperature affecting occupant, °F
t_a = ambient dry-bulb air temperature near occupant, °F

ERF may be measured as the heat absorbed at the skin-clothing surface from a beam heater treated as a point source:

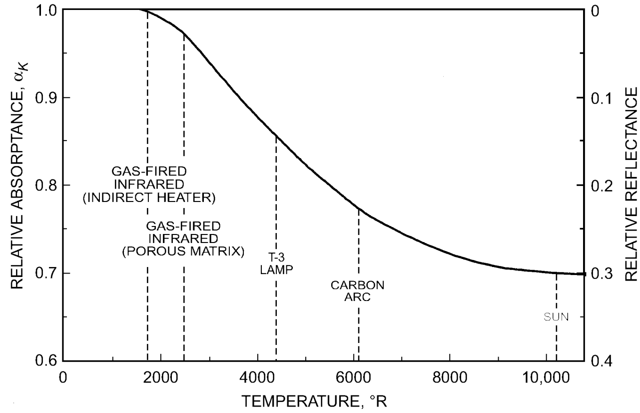

Fig. 3 Relative Absorptance and Reflectance of Skin and Typical Clothing Surfaces

$$\text{ERF} = \frac{\alpha_K I_K (A_p/d^2)}{A_D} \quad (2)$$

where

α_K = absorptance of skin-clothing surface at emitter temperature (Figure 3), dimensionless
I_K = irradiance from beam heater, Btu/h·sr
A_p = projected area of occupant on plane normal to direction of heater beam, ft²
d = distance from beam heater to center of occupant, ft
A_D = body surface area of occupant, ft²

A_p/d^2 is the solid angle subtended by the projected area of the occupant from the beam heater. See Figure 5 in Chapter 53 of the 2007 *ASHRAE Handbook—HVAC Applications* for a representation of these variables. The value of the DuBois area A_D has been defined as follows:

$$A_D = 0.108 W^{0.425} H^{0.725}$$

where

W = weight of occupant, lb
H = height of occupant, in.

Two radiation area factors are defined as

$$f_{eff} = A_{eff}/A_D \quad (3)$$

$$f_p = A_p/A_{eff} \quad (4)$$

where A_{eff} is the effective radiating area of the total body surface. Equation (2) becomes

$$\text{ERF} = \alpha_K f_{eff} f_p I_K/d^2 \quad (5)$$

Fanger (1972) developed precise optical methods to evaluate the angle factors f_{eff} and f_p for both sitting and standing positions and for males and females. An average value for f_{eff} of 0.71 for both sitting and standing is accurate within ±2%. Variations in angle factor f_p over various azimuths and elevations for seated and standing positions are illustrated in Figures 4 and 5, and according to Fanger, apply equally to both males and females.

Manufacturers of infrared heaters usually supply performance specifications for their equipment (Gagge et al. 1967). Design information on sizing infrared heating units is also available (Howell and Suryanarayana 1990), as is the relation between color temperature of heaters and the applied electric potential (voltage) or electrical power. Gas-fired radiators usually operate at constant source temperatures of 1340 to 1700°F (1800 to 2160°R). Figure 3 relates the

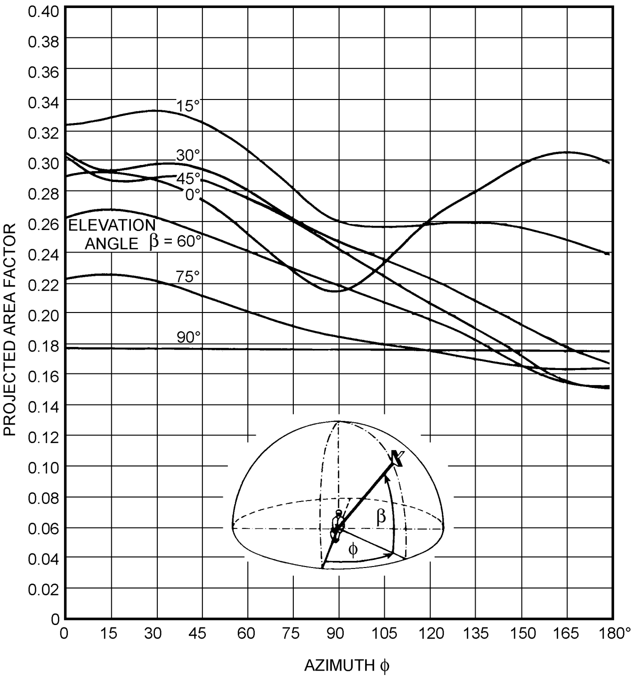

Fig. 4 Projected Area Factor for Seated Persons, Nude and Clothed
(Fanger 1972)

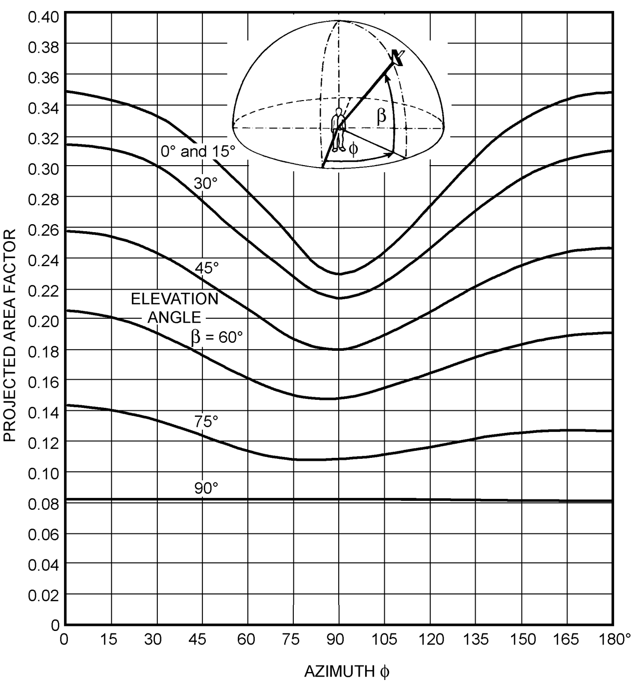

Fig. 5 Projected Area Factor for Standing Persons, Nude and Clothed
(Fanger 1972)

absorptance α_K to the radiating temperature of the radiant source. Manufacturers also supply the heat flux distribution of beam heaters with and without reflectors. Figures 6 to 9 illustrate the heat flux distribution for four typical electric and gas-fired radiant heaters. Generally, in electrical beam heaters, 70 to 80% of the total heat transfer occurs by thermal radiation, in contrast to 40% for gas-fired types.

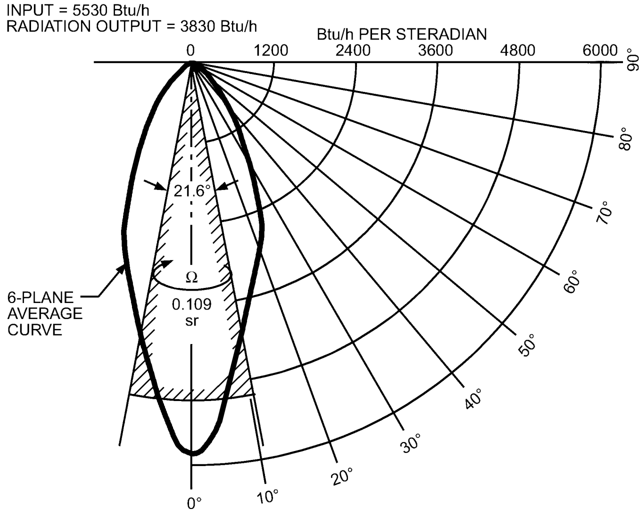

Fig. 6 Radiant Heat Flux Distribution Curve of Typical Narrow-Beam High-Intensity Electric Infrared Heaters

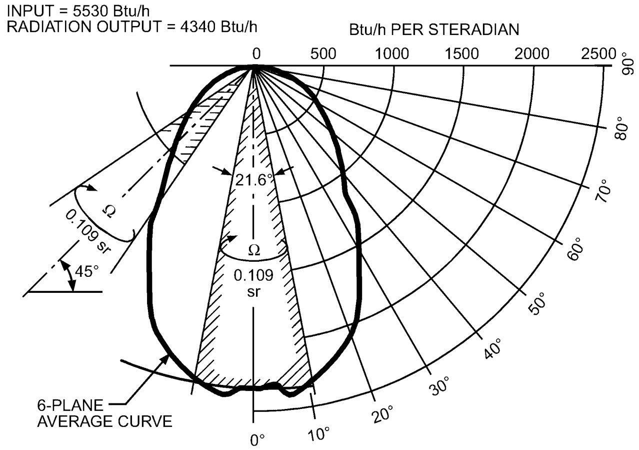

Fig. 7 Radiant Heat Flux Distribution Curve of Typical Broad-Beam High-Intensity Electric Infrared Heaters

In practice, the designer should choose a beam heater that will illuminate the subject with acceptable uniformity. Even with complete illumination by a beam 0.109 sr (21.6°) wide, Figure 6 shows that only 8% (100 × 1225 × 0.109/1620) of the initial electrical power input to the heater is usable for specifying the necessary I_K in Equation (5). The corresponding percentages for Figures 7, 8, and 9 are 5%, 4%, and 2%, respectively. The last two are for gas-fired beams.

The input energy to the beam heater not used for directly irradiating the occupant ultimately increases the ambient air temperature and mean radiant temperature of the heated space This increase will reduce the original ERF required for comfort and acceptability. The continuing reradiation and convective heating of surrounding walls and the presence of air movement make precise calculations of radiant heat exchange difficult.

The basic principles of beam heating are illustrated by the following examples.

Example 1. Determine the irradiance required for comfort from a quartz lamp (Figure 6) when the worker is sedentary, lightly clothed (0.5 clo), and seated. The dry-bulb indoor air temperature t_a near the

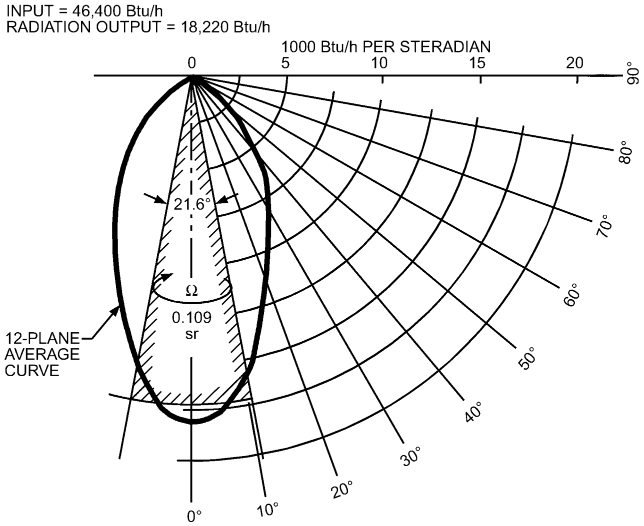

Fig. 8 Radiant Heat Flux Distribution Curve of Typical Narrow-Beam High-Intensity Atmospheric Gas-Fired Infrared Heaters

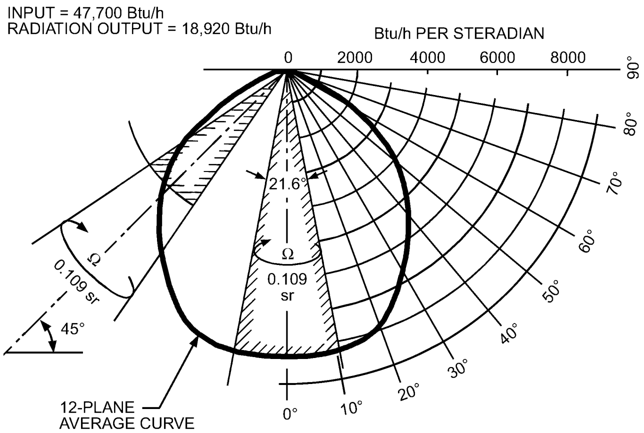

Fig. 9 Radiant Heat Flux Distribution Curve of Typical Broad-Beam High-Intensity Atmospheric Gas-Fired Infrared Heaters

occupant is 59°F, with air movement at 30 fpm. The lamp is mounted on the 8 ft high ceiling and is directed at the back of the seated person so that the elevation angle β is 45° and the azimuth angle ϕ is 180°. Assume the ambient and mean radiant temperatures of the unheated space are equal. The lamp operates at 240 V and has a source temperature of 4500°R.

Solution: The ERF for comfort can be calculated as 19.3 Btu/h·ft^2 by the procedures outlined in the section on Design Criteria for Acceptable Radiant Heating in Chapter 53 of the 2007 *ASHRAE Handbook—HVAC Applications*. $\alpha_K = 0.85$ at 4500°R (from Figure 3); $f_{eff} = 0.71$; $f_p = 0.17$ (Figure 3); $d = 8 - 2 = 6$ ft, where 2 ft is sitting height of occupant.

From Equation (5), the irradiance I_K from the beam heater necessary for comfort is

$$I_K = \text{ERF}(d^2/\alpha_K f_{eff} f_p)$$
$$= 19.3(6)^2/(0.85 \times 0.71 \times 0.17) = 6772 \text{ Btu/h} \cdot \text{sr}$$

Example 2. For the same occupant in Example 1, when two beams located on the ceiling and operating at half of rated voltage are directed downward at the subject at 45° and at azimuth angle 90° on each side, what would be the I_K required from each heater?

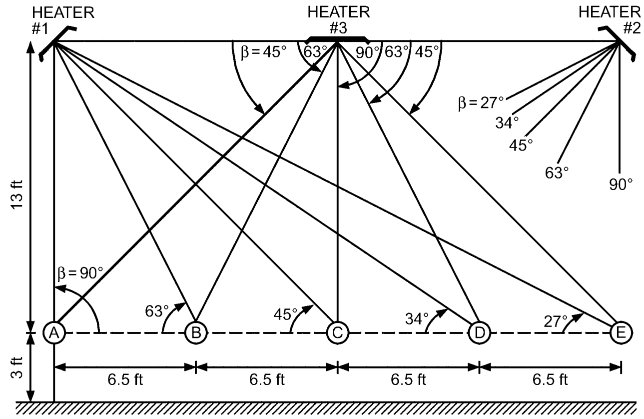

Fig. 10 Calculation of Total ERF from Three Gas-Fired Heaters on Worker Standing at Positions A Through E

Solution: The ERF for comfort from each beam is 19.3/2 or 9.65 Btu/h·ft^2. The value of f_p is 0.25 (from Figure 3). At half power, $V = 170$, $R \approx 3600$, and $\alpha_K \approx 0.9$. Hence, the required irradiation from each beam is

$$I_K = 9.65(6)^2/(0.9 \times 0.71 \times 0.25) = 2174 \text{ Btu/h} \cdot \text{sr}$$

This estimate indicates that two beams similar to Figure 7, each operating at half of rated power, can produce the necessary ERF for comfort. A comparison between the I_K requirements in Examples 1 and 2 shows that irradiating a sitting person from the back is much less efficient than irradiating from the side.

Example 3. A broad-beam gas-fired infrared heater is mounted 16 ft above the floor. The heater is directed 45° downward toward a standing subject 13 ft away (see Heater #1 in Figure 10, position C).

Question (1): What is the resulting ERF from the beam acting on the subject?

Solution: From Equation (5),

$$\text{ERF} = \alpha_K f_{eff} f_p I_K/d^2 = 4.2 \text{ Btu/h} \cdot \text{ft}^2$$

where

α_K = 0.97 (Figure 3)
f_{eff} = 0.71
f_p = 0.26 (Figure 5 at β = 45° and ϕ = 0°)
I_K = 8000 Btu/h·sr (Figure 9)
$d^2 = 13^2 + 13^2 = 338$ ft^2 (center of standing subject is 3 ft above floor)

If the heater were 10 ft above the center of the standing subject (13 ft above floor), the ERF would be 5.3 Btu/h·ft^2.

Question (2): How does the ERF vary along the 0° azimuth, every 6.5 ft beginning at a point directly under Heater #1 (Figure 10) and for elevations β = 90° at A, 63.4° at B, 45° at C, 33.6° at D, and 26.6° at E? From Figure 9, the values for f_p for the five positions are (A) 0.08, (B) 0.19, (C) 0.26, (D) 0.30, and (E) 0.33.

Solution: Because the beam is directed 45° downward, the respective deviations from the beam center for a person standing at the five positions A through E are 45°, 18.4°, 0°, 11.4°, and 18.4°; the corresponding I_K values from Figure 9 are 5000, 8000, 8000, 8000, and 8000 Btu/h·sr. The respective d^2 are 169, 211, 338, 549, and 845 ft^2. The ERFs for a person standing in the five positions are (A) 1.6, (B) 4.9, (C) 4.2, (D) 3.0, and (E) 2.1 Btu/h·ft^2.

Question (3): How will the total ERF at each of the five locations A through E vary if two additional heaters (#2 and #3 in Figure 10) are added 16 ft above the floor over positions C and E? The center heater is directed downward, the outer one directed as above, 45° towards the center of the heated space.

Solution: At each of five locations in the heated space (A, B, C, D, E), add the ERF from each of the three radiators to determine the total ERF affecting the standing person.

A	1.6 + 2.5 + 2.1	or	6.2
B	4.9 + 4.2 + 3.0	or	12.1
C	4.2 + 2.5 + 4.2	or	10.9
D	3.0 + 4.2 + 4.9	or	12.1
E	2.1 + 2.5 + 1.6	or	6.2

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