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# Evaluation of Infrared Radiant Heaters for Army Applications

R. J. Kedl

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Energy Division

# EVALUATION OF INFRARED RADIANT HEATERS FOR ARMY APPLICATIONS

R. J. Kedl

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# EXECUTIVE SUMMARY

Radiant heaters require less fuel than forced-air heaters to achieve the same level of human comfort. Thus, the use of infrared radiant heaters in the commercial and industrial sectors has increased substantially in recent years. Radiant heaters are widely used for both process applications (e.g., drying paint) and space heating. This document evaluates the use of radiant heaters for space heating applications at Army installations.

Radiant heaters operate entirely differently than conventional (forced-air) heaters. Radiant heaters transmit their heat energy in the form of electromagnetic radiation in the infrared region. The unique characteristic of this method of heat transfer is that the heat is absorbed *directly* by the personnel and objects being heated (air does not absorb infrared radiation). By comparison, forced-air heaters heat *indirectly* by first warming the air space, which, in turn, warms the personnel and objects being heated. The result of this is that air temperature will be slightly *cooler* than the personnel and objects under radiant heat, but air temperature will be *warmer* than the personnel and object under forced-air heaters.

Radiant heaters depend on the efficient generation of infrared radiation. Although an open flame will emit infrared radiation, a heated surface is more efficient. Therefore, all manufactured radiant heaters generate a hot surface as their mode of operation. Gas, oil, or electricity can be used to generate the hot surface. Gas-fired heaters are, by far, the most common. The gas flame can be on the inside of a tube (called "indirect" or "low-intensity" heater), or it can be exposed on a porous surface (called "direct" or "high-intensity" heater). Surface temperatures typically run from 800 to 2800°F. For electric heaters the resistance wires can be as high as 4000°F.

Fuel requirements are less for radiant heaters for two principal reasons. First, the thermal stratification of warm air, which is common in a building heated by forced air, is reduced or eliminated with radiant heaters. Second, because the radiant energy is absorbed directly by the

personnel being heated, they will be comfortable at a lower air temperature (thermostat setting) than with forced-air heaters. It is difficult, however, to predict accurately the fuel savings that result from radiant heaters, but manufacturers claim 20 to 50%. Professionally obtained measurements of fuel savings and numerous testimonials in the literature support the manufacturers' claims. Usually, the largest savings are associated with large industrial-type buildings with high roofs, poor insulation, and high infiltration. High-bay maintenance buildings and aircraft hangars, which are common in the Army, are ideal for installation of gas- or oil-fired radiant heaters. Electric-resistance radiant heaters find their principal application as spot heaters for outdoor, semienclosed, or poorly heated areas.

Simple payback periods of 2 to 5 years were estimated achieveable for retrofit installation of radiant heaters when fuel costs are $4/MBtu or greater and the fuel saved is 40% or greater.

The potential for energy savings in the retrofit installation of radiant heaters is high. However, the cost-effectiveness is uncertain because of the wide range of estimated fuel savings. A program that would lead to a better understanding of the fuel savings in a given class of buildings is recommended. If the fuel savings are sufficiently high, as they are expected to be, then widespread retrofit of radiant heaters could follow.

# EVALUATION OF INFRARED RADIANT HEATERS FOR ARMY APPLICATIONS

R. J. Kedl

ABSTRACT

This report evaluates the use of infrared radiant heaters for Army applications. Radiant-heater operation and the kinds of heaters available are described. Based on information published in the literature and furnished by the manufacturers, energy savings of 20 to 50% can be expected, compared with conventional heating systems. The greatest savings are usually associated with large industrial-type buildings with high roofs, poor insulation, and high infiltration. High-bay maintenance shops and aircraft hangars, which are common in the Army, are ideal candidates for gas- or oil-fired radiant heaters (both new and retrofit applications). A simple payback period of 2 to 5 years is estimated achievable for a retrofit installation when the fuel cost is $4/MBtu or more and the fuel savings are 40% or more. A program that would lead to a better understanding of the fuel saving potential for different classes of buildings is recommended.

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## 1. PURPOSE

The purpose of this investigation is to (1) evaluate infrared radiant heaters for space heating at Army facilities, (2) identify building types where installation of radiant heaters will result in the greatest fuel savings and cost-effectiveness while maintaining or increasing the level of human comfort, and (3) make recommendations concerning the installation of radiant heaters.

## 2. SCOPE

Infrared radiant heaters are commonly used for space heating and for a variety of process applications. This evaluation concerns itself with only space heating. The emphasis is on heating industrial or heavy commercial large buildings, such as maintenance shops, aircraft hangars, and warehouses. All forms of radiant heaters, including gas- and oil-fired direct and indirect heaters and electric-resistance heaters, are considered. The operation of radiant heaters is discussed, and the various kinds available are described. The radiant-heater characteristics that result in fuel savings are discussed, comparatively, with forced-air heaters. The kinds of buildings best suited for radiant heaters, along with heater selection criteria, are described. Recommendations that could lead to widespread retrofit of radiant heaters and to corresponding fuel savings within the Army are made.

## 3. BACKGROUND

The U.S. Army Facilities Engineering Support Agency (FESA), Fort Belvoir, Virginia, issued Task Order No. 0016 on May 5, 1986, requesting that infrared radiant heaters be evaluated for Army applications. To meet the objectives of this task, the following actions were taken:

1. A computerized literature search of several data bases was conducted. About 50 reprints of technical articles were received. Many concerned process applications of radiant heaters and were not suitable for this evaluation.
2. A form letter describing the task and requesting product literature and other information was sent to ~40 radiant-heater manufacturers. Responses from ~30 companies were received. Several sales representatives of the companies telephoned and asked about the study.
3. Letters to the appropriate professional and trade associations describing the task and requesting appropriate information were sent. Each responded by sending information about its association.

An interesting finding from the above sources of information was that the Navy had previously conducted an extensive study of radiant heaters for application in aircraft hangars. It was also disclosed during telephone conversations with radiant-heater manufacturers that the Army already has many radiant-heater installations.

This evaluation of radiant heaters for Army installation is based solely on input from the above sources of information.

# 4. RADIANT-HEATER TECHNOLOGY

Infrared radiant heaters have the unique characteristic that they apply heat *directly* on the person or object requiring heat. By comparison, forced-air heaters heat *indirectly* by warming the air that surrounds the person or object. When properly applied, this "direct" heating process exhibits a number of advantages, the main one being that less energy is required to achieve the same comfort level as forced-air heaters. Other advantages and disadvantages will be pointed out in the text that follows. Radiant heaters have been used to heat industrial and commercial buildings for many years. In recent years, their application has increased considerably because of the decrease in fuel requirements associated with their use.

## 4.1 RADIANT-HEATER OPERATION

The method of heat transmission used by radiant heaters is completely different than the method used by conventional forced-air heaters. It is necessary to understand these differences for a proper understanding of radiant heaters. Thus, a short discussion of the physics involved is initially necessary.

A fundamental principle of physics is that at all times all materials radiate energy in the form of electromagnetic waves. This is a temperature-related phenomenon, and two physical laws are appropriate to this discussion. First, Wien's Law states that the wavelength of electromagnetic radiation decreases as the material temperature increases:

$$\text{wavelength} = \text{constant/absolute temperature} .$$

Second, the Stefan-Boltzmann Law states that the intensity of radiation increases as the material's temperature to the fourth power:

$$\text{radiation intensity} = \text{constant X (absolute temperature)}^4 .$$

Strictly speaking, these laws are valid only for materials that are opaque (not transparent) and do not reflect radiation. This is not a serious limitation because most materials found in buildings that are

appropriate for radiant heaters are opaque and do not reflect a great deal of radiant energy. The strong dependence of radiation intensity on temperature forms the basis for radiant-heater operation. Fortunately, the intensity of radiation from materials at temperatures over ~1000°F is high enough to be useful for building heating applications. These temperatures are readily attainable with gaseous or liquid fuels or electricity; thus, all of the requirements for a heating system are present. The wavelength of most radiant energy from materials in this temperature range is in the infrared region of the electromagnetic spectrum, thus, the name "infrared" radiant heater. Nevertheless, some of the radiation is in the visible light region of the spectrum, and radiant heaters appear to glow red at lower temperatures or yellow at higher temperatures.

Two unique characteristics of infrared radiant heaters determine their nature as a heating system and, thus, their advantages and disadvantages compared with forced-air heaters:

1. Energy is transferred from the heater to the object being heated by electromagnetic radiation; therefore, the energy transfer occurs instantaneously (at the speed of light) on an unobstructed straight line between the heater and heated object.
2. Air is a poor absorber of infrared radiation. However, the more common solid materials (e.g., clothes, people, concrete, plaster, paint, soil, wood, and protected metals) are good absorbers of infrared radiation. Polished materials tend to reflect infrared radiation rather than absorb it.

Probably the most significant consequence of these unique characteristics is that objects are heated directly. The heaters release infrared radiation that shines down on the area being heated. Air does not absorb the radiation; therefore, it is not heated directly by the radiation. Rather, the solid objects on the ground (floor, personnel, equipment, materials, etc.) absorb the radiation and are heated to temperatures greater than the air temperature. Then, the air is warmed by convective heating from the warmer objects. Thus, in general, the air temperature will be slightly *cooler* than the objects being heated. By comparison, a forced-air heater heats the air in a building. The warmer

air then heats the objects in the building by convective heat transfer. In general, with forced-air heaters the air temperature will be *warmer* than the objects being heated. The "objects" in this comparative example include personnel. Thus, human comfort may be achieved with a lower thermostat setting with radiant heaters than with forced-air heaters. More will be discussed later about this phenomenon and its relationship to energy conservation.

The idea that the floors and material objects are warmer for a radiant-heated space than a forced-air heated space has other implications. Consider a building with large doors that must be opened and closed frequently (e.g., aircraft hangars, certain maintenance shops, and warehouses). After the doors are closed, the large mass of warm objects (including the floor) will usually reheat the building to its thermostat setting much faster than will forced-air heaters. Even when the doors are left open, radiant heat will beam down on the personnel, and they will experience warmth. Forced-air heaters may be ineffective in this situation because their warm air would tend to rise to the roof. Of interest to certain military posts is another advantage to having the objects in a heated space warmer than the air; it concerns rusting of unprotected steel parts. In certain climates, particularly near the ocean, some manufacturers have reported significant rusting of metal as a result of condensation or mist settling on the metal. Radiant heaters alleviated the problem by keeping the metal temperature above the dew point, thus preventing condensation and evaporating mist that settled on the metals.

Radiant heaters are often used for outdoor applications. When positioned above loading docks or outdoor maintenance areas, working personnel experience warmth even in the cold outside air. To illustrate the point, one known application is in a large ice skating rink for ice shows. It was necessary to heat the seating area while maintaining a cold ambient temperature to protect the ice. This was accomplished with radiant heaters, which had reflectors that focused the infrared radiation on the seating area. The seated spectators were relatively comfortable, and the ice was protected.

A problem with radiant heaters is that the object or person being heated must be in line of sight of the heater. For example, in a vehicle repair shop, a person working beneath a vehicle would generally be out of sight of the heaters and, thus, receive no direct radiant heat. Manufacturers claim that for a properly designed system, this is usually not a problem. In a well-designed heating system, personnel receive radiant heat from several different places. They may be in the shade of one heater but probably not in the shade of all heaters. Secondly, the warm floor would contribute to the spread of warmth at the working level. Portable heaters may be used for the situation where virtually no heat is available to the repair person.

## 4.2 KINDS AND AVAILABILITY

The use of radiant heaters has increased substantially in recent years because of their decrease in fuel use. Many different kinds of heaters are available, and to describe their characteristics, these heaters are classified by fuel use.

### 4.2.1 Gas-Fired Radiant Heaters

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)[1] defines four basic types of gas-fired, infrared radiant heaters. Their characteristics are listed in Table 4.1, and examples are illustrated in Fig. 4.1. An open gas flame will generate infrared radiation; however, heated surfaces are more efficient. Therefore, all manufactured heaters rely on hot surfaces as their source of radiation.

Type 1 is an indirect heater because combustion takes place on the inside of a metallic or ceramic tube. The tube surface temperatures may be as high as 1200°F. The combustion gases are usually vented to the outside, and an eductor fan [Fig. 4.1(*b*)] is required. Shaped reflectors above the radiant tube focus the radiant energy and also help to prevent convective heat loss from the tube to the ambient air. Actual installations are shown in Figs. 4.2 and 4.3.

Type 2 is a direct heater because the fuel-air mixture is forced through a porous plate and exposed combustion occurs on the outer surface

Table 4.1. Characteristics of typical gas-fired infrared heaters

| Characteristics | Type | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Operating temperature, °F (°C) | To 1200 (649) | 1600 to 1800 (871 to 982) | 1650 to 2800 (899 to 1538) | 650 (343) |
| Relative heat intensity,[a] Btu/h•ft$^2$ (W/m$^2$) | Low to 7,500 (204) | Medium 17,000 to 32,000 (462 to 870) | High 10,000 to 62,000 (272 to 1,686) | Low 800 to 3,000 (22 to 82) |
| Response time (heatup), s | 180 | 60 | 60 | 300 |
| Radiation generating ratio[b] | 0.35 to 0.55 | 0.35 to 0.60 | 0.35 to 0.50 | No data |
| Thermal shock resistance | Excellent | Excellent | Excellent | Excellent |
| Vibration resistance | Excellent | Excellent | Excellent | Excellent |
| Color blindness[c] | Excellent | Very good | Good | Excellent |
| Luminosity (visible light) | To dull red | Yellow red | To white | None |
| Mounting height, ft (m) | 7 to 50 (2 to 15) | 7 to 50 (2 to 15) | No data | To 10 (3) |
| Wind or draft resistance | Good | Fair | Fair | Very good |
| Venting | Optional | Nonvented | Nonvented | Nonvented |
| Flexibility | Good | Excellent — wide range of heat intensities and mounting possibilities available | Excellent — wide range of heat intensities possible | Limited — to low-heat intensity applications |

[a]Heat intensity emitted at burner surface.

[b]Ratio of radiant output to Btu (kJ) input.

[c]Color blindness refers to absorptivity by various loads of energy emitted by the different sources.

*Source*: Reprinted with permission from *ASHRAE Handbook and Product Directory — 1979 Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1979, Table 1, p. 29.1.

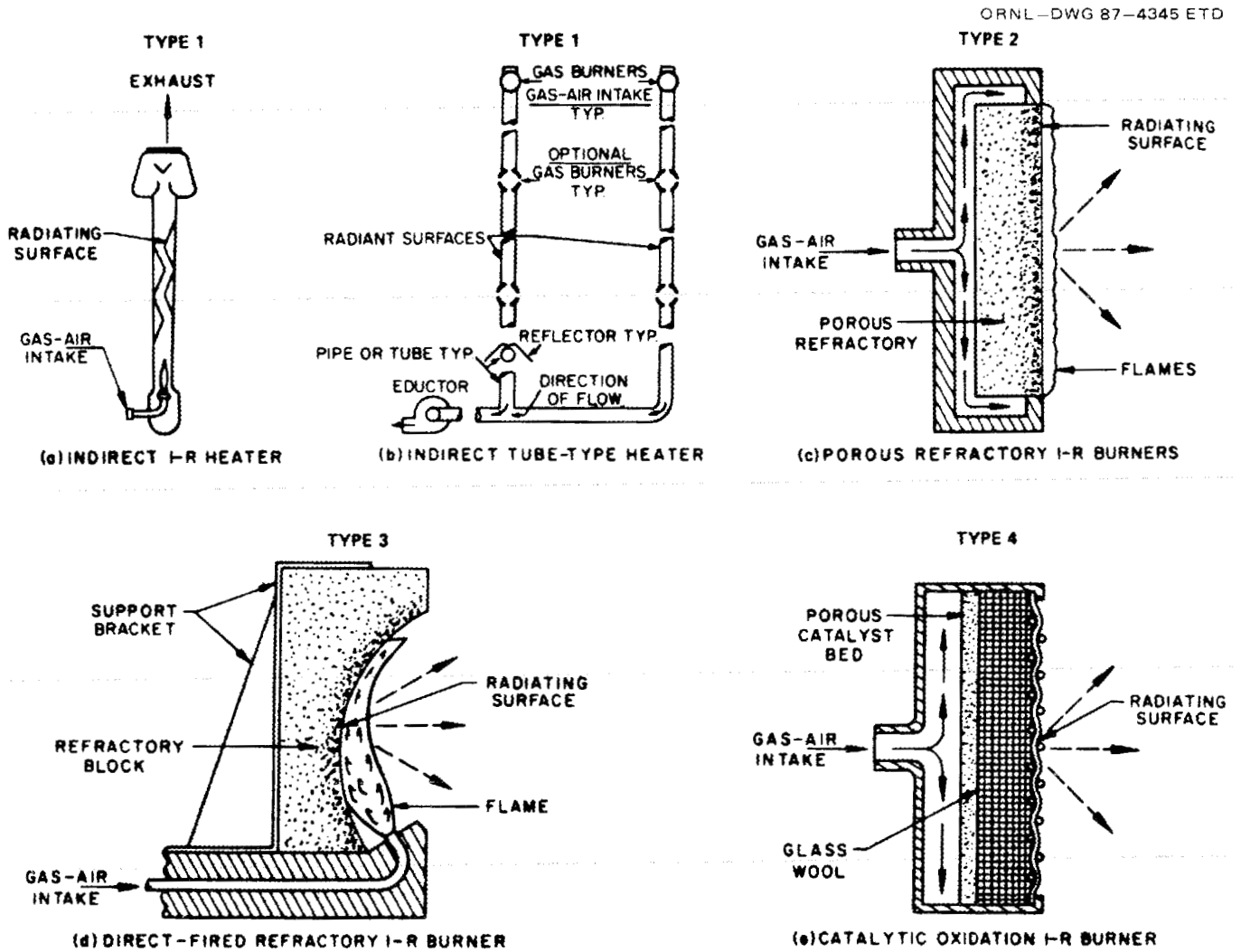


Fig. 4.1. Five different types of gas-fired infrared burners, *Source*: *ASHRAE Handbook and Product Directory: 1979 Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1979, Fig. 1, p. 29.2.

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Fig. 4.2. Installed indirect radiant heaters in an industrial setting. *Source*: *Wondaire® Automatic Heating Equipment*, Cox Manufacturing Company, Inc., Ridgeville, Ind., 1986.

ORNL–PHOTO 5548–87

Fig. 4.3. Installed indirect radiant heaters in an aircraft hangar. *Source*: *Wondaire® Automatic Heating Equipment*, Cox Manufacturing Company, Inc., Ridgeville, Ind., 1986.

of the plate in the building space. The porous plate may be porous ceramic or a metallic screen configuration. Surface temperatures may be 1600 to 1800°F. Because these heaters operate at considerably higher temperatures than the Type 1 heaters, their radiation intensity is much greater. Unless properly installed, the hot convective air plume rising from one of these heaters may cause charing of wooden structures located above it. Typically, these heaters are not vented. Because one of the products of combustion is water vapor, problems with condensation beneath the roof can result. These heaters also have reflectors to focus the radiant energy. Actual installations are shown in Figs. 4.4 and 4.5.

In Type 3, which is also a direct-fired heater, the hot surface is generated by impingment of an open flame on an exposed refractory surface. This type of heater will have many of the same characteristics and problems associated with Type 2 heaters because they both feature an exposed flame. Heaters of this type are not in common use for building heating.

Type 4 is a catalytic combustion heater. Structurally, it is similar to the Type 2 heater, but the refractory material is usually glass wool. The distinctive feature of this heater is that the radiating surface contains a chemical catalyst that causes the gas to "burn" at a low temperature and without visible flame. There are special applications where low-temperature radiant heaters are required. Because of their low temperature, their radiant intensity is quite low. As with the Type 2 heaters, problems could develop from condensation of water vapor.

Radiant heater Types 1 and 2 are by far the most common for building heating applications. Table 4.1 shows that radiation generating ratios range from 0.35 to 0.60. This is the ratio of radiant output to the heat input as unburned gas and, therefore, can be thought of as a thermal efficiency in the same sense as for a forced-air heater.

### 4.2.2 Electric Radiant Heaters

ASHRAE defines four basic types of electric infrared radiant heaters.[1] Their characteristics are listed in Table 4.2, and examples are illustrated in Fig. 4.6. In this case, the hot surface is generated

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Fig. 4.4. Installed direct radiant heaters in an industrial setting. *Source*: *The Significant Advantages of Gas in Infra-Red Space Heating: The Basic Principle. The Technique. The Economics.* Perfection Schwank Infra-Red, Waynesboro, Ga.

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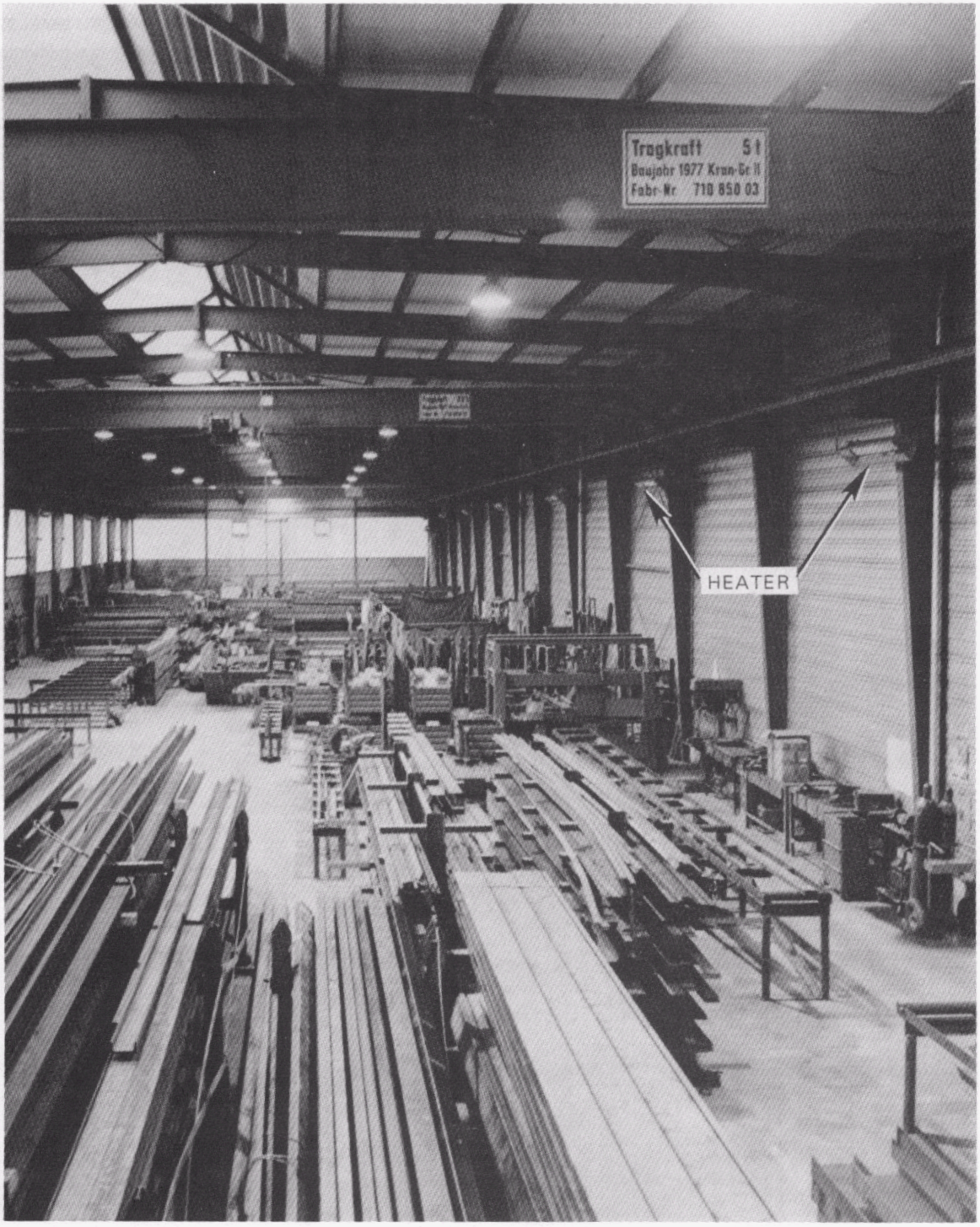


Fig. 4.5. Installed direct radiant heaters in an industrial storage area. *Source*: *The Significant Advantages of Gas in Infra-Red Space Heating: The Basic Principle. The Technique. The Economics.* Perfection Schwank Infra-Red, Waynesboro, Ga.

Table 4.2. Characteristics of four electric infrared elements

| Characteristic | Type | | | |
|---|---|---|---|---|
| | 1: Metal sheath | 2: Reflector lamp | 3: Quartz tube | 4: Quartz lamp |
| Resistor material | Nickel-chromium alloy | Tungsten wire | Nickel-chromium alloy | Tungsten wire |
| Relative heat intensity | Medium 60 W/in. (2.4 kW/m), 1/2-in. (12.7-mm) diam | High, 125—375 W/spot | Medium to high, 75 W/in., 1/2-in. (12.7-mm) diam | High, 100 W/in. (3.9 kW/m), 3/8-in. (0.96-mm) diam |
| Resistor temperature, °F (°C) | 1750 (954) | 4050 (2232) | 1700 (927) | 4050 (2232) |
| Envelope temperature (in use) °F (°C) | 1550 (843) | 525—575 (274—302) | 1200 (649) | 1100 (593) |
| Radiation generating ratio[a] | 0.58 | 0.86 | 0.61 | 0.86 |
| Response time (heatup), s | 180 | A few seconds | 60 | 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 |
| Resistance to drafts or wind[b] | Poor | 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 watts density, length, and voltage practical | Limited to 125—250 and 375 W at 120 V | Excellent — wide range of watts density, diameter, length, and voltage practical | Limited, 1 to 3 wattages for each voltage; 1 length for each capacity |
| Life expectancy, h | >5000 | 5000 | 5000 | 5000 |

[a]Ratio of radiant output to watt 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.

*Source*: Reprinted with permission from *ASHRAE Handbook and Product Directory — 1979 Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1979, Table 2, p. 29.4.

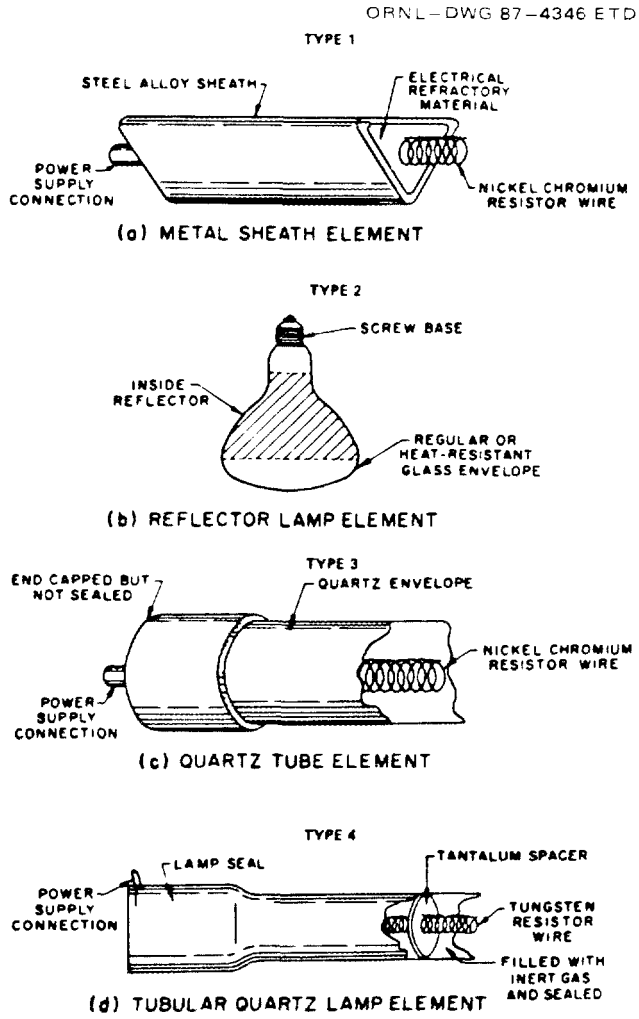


Fig. 4.6. Commonly used electric infrared elements.

by resistance-heating a wire or ribbon. The main difference in the various types is the way that the wire or ribbon is supported and heat transferred.

Type 1 features a nickel-chromium resistance wire embedded in an electric insulating refractory material and encased in a metal sheath. Construction is very similar to the heating elements of an electric stove or oven. These heaters are the most rugged of the four types and can be mounted in any position. Sheath temperatures range from 1200 to 1800°F. Heating elements are usually built into shaped reflectors.

Type 2 is an infrared lamp. These are commonly used in restaurants to keep food warm, and many homes have these lamps in the bathroom as an

additional source of heat when getting out of the shower. They feature a tungsten filament in a heat-resistant glass globe. The inside is partially silvered to act as a reflector. They are commonly available to screw into an ordinary 120-V light socket.

Type 3 features a coiled nickel-chromium wire lying unsupported in an evacuated quartz tube. These units stand up well to thermal shock but are easily damaged by mechanical shock. They must be mounted horizontally, usually in a fixture that contains a reflector.

Type 4, similar in appearance to Type 3, features a tungsten filament, held in place with tantalum spacers, inside a quartz tube. It differs from Type 3, however, because the tungsten can be heated to a much higher temperature, and, thus, the radiant intensity is greater.

In most cases, the cost of electricity compared with gas will preclude the use of electric radiant heaters for general building heating. However, as a spot heater they are quite useful. Because they can be obtained to operate in 120 V, it is relatively easy to install a single (or a few) heaters for a small area. Electric radiant heaters can be obtained in a variety of portable configurations.

Electric radiant heaters have the advantage that they can be modulated. There may be applications where this is a desirable feature. Gas-fired heaters are generally provided only with an on/off control.

### 4.2.3 Oil-Fired Radiant Heaters

Oil-fired, infrared radiant heaters are similar to the gas-fired Type 1 units. However, they must always be vented. They are available commercially but are not as widely used as gas-fired heaters.

## 4.3 COMPARISON WITH FORCED-AIR HEATERS

Radiant heaters are most appropriate for shops, warehouses, and similar buildings, generally commercial and industrial. Today, these kinds of buildings are most commonly heated with some variety of forced-air heaters. The thrust of this comparison will be to illustrate why radiant heaters usually require less fuel than forced-air heaters. There are primarily two operating characteristics of radiant heaters that are

responsible for reduced fuel requirements:

1. reduction in the vertical temperature gradient within a building, and
2. the effect of radiant energy on human comfort.

Both of these characteristics result from the fact that radiant heaters heat objects directly rather than heat the air that surrounds the objects.

### 4.3.1 Temperature Stratification

The density of air is inversely proportional to its absolute temperature; that is, as the temperature of air increases, its density decreases. Thus, warm air always rises. This fact influences the performance of all forced-air heaters. Consider a common gas-fired unit heater suspended from the ceiling. The discharge from such a heater is usually ~100 to 130°F and directed downward toward the floor. If the building space is maintained at 60 to 70°F, then the discharge air is considerably warmer than the thermostat setting. Much of this warm discharge air will rise to the ceiling or roof area. In such a building, the air temperature near the ceiling is commonly found to be greater than the air temperature at the working level (near the floor). The air in such a building is said to be stratified.

The exact temperature difference in a stratified building air space is determined by the interaction of a number of parameters and is a function of building characteristics (e.g., roof elevation and insulation level), heater characteristics (e.g., discharge velocity and temperature), and outside weather conditions. Measurements have been made and reported in the literature. In measurements made in ten aircraft hangars (Navy and Air Force) by the U.S. Navy,[2] the air temperature near the roof averaged 15°F higher than at the floor level with a minimum temperature increase of 9°F and a maximum of 27°F. The outside temperature ranged from 31 to 45°F for these measurements. Other authors[3,4] report that temperatures near the roof of industrial buildings as much as 25 to 30°F greater than temperatures near the floor are not uncommon.

Radiant heaters by their nature do not generate vertical temperature gradients. Recall from Sect. 4.1 that, sequentially, radiant heaters first heat the floor and materials on the floor by direct radiation. The

air in the building space is heated subsequently by convective heat transfer from the floor and other objects. Thus, the floor and other objects are typically a few degrees warmer than the air temperature. Furthermore, the temperature of the air space cannot exceed the temperature of the floor and other objects unless, of course, the building contains an intense heat source, such as a furnace. For this reason, the air space in buildings heated with radiant heaters tends to be isothermal. Note that a small but rather hot plume does convect upward from each heater. In actual practice, this represents a smaller amount of heat than that which rises from forced-air heaters.

The general reduction in air temperature near the roof with the use of radiant heaters results in a general reduction in heat loss from infiltration and by conduction through the roof and walls and in a corresponding reduction in fuel requirements. Note that several manufacturers produce blower assemblies (ducted and unducted) that are specifically intended to destratify commercial and industrial buildings. These devices draw warm air from the roof area and blow it down to the working area.

### 4.3.2 Radiant Heat and Human Comfort

Radiant heaters operate much like the sun. On a sunny day, a person will be comfortable at a cooler temperature than on a cloudy day. Similarly, a person will be comfortable at a somewhat cooler air temperature with radiant heaters than with forced-air heaters.

The concept and criteria of human thermal comfort have been subject to considerable research.[5] The mathematics required to include the effect of radiant energy into the comfort equation are involved and beyond the scope of this assessment. Nevertheless, some background in theory would be desirable. For a large number of cases, the following relationship between temperatures can be shown to be approximately true with radiant heat.

$$T_o = 1/2(T_a + T_r) ,$$

or $$T_a = 2T_o - T_r ,$$

where

$T_o$ = operative temperature,

$T_a$ = air temperature surrounding the occupant,

$T_r$ = mean radiant temperature.

$T_a$ is the air temperature and is a measurable quantity; $T_o$ and $T_r$ are imaginary or equivalent temperatures. $T_r$, the mean radiant temperature, can be thought of as the imaginary temperature that is responsible for the net flow of radiant heat to (or from) the occupant. $T_o$, the operative temperature, can be thought of as the resultant room temperature after the air temperature is corrected for the radiant flow of heat. The operative temperature is the temperature imagined by the occupant. Note that the operative temperature is the average of $T_a$ and $T_r$. Now, consider an example of a person standing in a room and say that this person is comfortable in a conventionally heated room at 80°F. If the walls, ceiling, and floor of this room are at 80°F, then $T_r$ will be ~80°F. Then, to solve, $T_o$ = 80°F. In other words, the man is comfortable when the operative temperature equals the air temperature. Thus, the thermostat should be set at 80°F. Now, say that the walls, ceiling, and floor are raised to 90°F. For the occupant to maintain the same comfort level, he must imagine that the temperature is 80°F ($T_o$). For this to be true, the air temperature (thermostat setting) must be lowered to (2)(80) − 90 = 70°F. Infrared radiant heaters operate in the same fashion. The radiation they emit has the effect of raising the mean radiant temperature. Thus, the air temperature may be lowered to achieve the same level of comfort.

The above example was simplistic and was intended to illustrate the principals involved. Realistic estimates of the reduction in air temperature that results from radiant heaters have been reported in the literature for commercial and industrial environments. One of the most comprehensive studies is reported by Janssen,[6] who reviewed data from an ASHRAE-supported project directed toward the comfort criteria associated with radiant heaters. Four commercial buildings were selected in Connecticut (automotive garage, tank fabricator, parts warehouse, and swimming pool). The study lasted for 2 years. Each year the buildings

were heated by conventional means for one-half of the heating season and with radiant heaters the other half of the heating season. The occupants of these buildings were interviewed relative to their comfort. The conclusion of this study is that with radiant heaters the same comfort level was achieved with the air temperatures ~5°F less than would be required with a conventional heating system. A. A. Field reports on a study of a large aircraft hangar where it was estimated that the air temperature could be reduced from 21 to 15°C (70 to 59°F) with the installation of radiant heaters.[7] A staff report claims that the use of radiant heaters generally results in reduction of ~4°C (7.2°F) in air temperatures while maintaining the same comfort level.[8]

The lower air temperatures with radiant heaters result in less heat loss through the walls and infiltration, thus resulting in energy conservation.

### 4.3.3 Expected Fuel Savings

The use of infrared radiant heaters instead of forced-air heaters results in fuel savings for the following principal reasons:

1. reduction of temperature stratification in the heated space,
2. lower space temperature requirements because of the effect of radiant heat on human comfort, and
3. the fact that radiant heaters are more amenable to zone or local control than many kinds of forced-air heating systems.

It is very difficult to predict the precise energy savings that would result from the installation in a building of radiant heaters rather than forced-air heaters. The savings depend on the building itself (height, infiltration, and vertical temperature gradient), the building use (door openings, internal heat sources, and number of occupants), and the alternate heating system (unit heaters, and central heating system).

Studies have been conducted on the energy savings that resulted from the retrofit of a radiant heating system in an existing building. ASHRAE[1] notes that a 1973 New York State Interdepartmental Fuel and Energy Committee ad hoc report based on investigations in New York claims annual fuel savings as high as 50%. ASHRAE also notes that it is common

practice to install less total heating capacity in buildings heated with infrared radiant heaters. The study by Janssen (reported in Sect. 4.3.2) concluded that the dry-bulb temperature in four commercial buildings was reduced ~5°F following the installation of radiant heaters.[6] It was estimated that this reduction in dry-bulb temperature would result in a 20% fuel savings. Bailey reports on two buildings (engine test lab and gymnasium) at the Rose-Hulman Institute of Technology that were retrofitted with radiant heaters.[9] The resulting energy savings were measured to be ~15% in each building. Most of these savings were attributed to the reduction in vertical temperature gradients. Buckley obtained annual gas use in four large manufacturing buildings (in New York, Illinois, and Pennsylvania) before and after retrofit with radiant heaters.[10] The author states that in each case, the entire building was maintained at the same comfort level before and after retrofit. In each case, the annual fuel use before and after retrofit was normalized to the heating-degree-days to compute the fuel savings. Thus computed, the fuel savings were measured to be 70.1, 41.5, 53.4, and 54.1%. Part of these measured fuel savings may be attributed to the fact that replaced heating systems were old and inefficient. Other claims of fuel savings of as much as 50% and even more abound in the literature. Most of these claims are in the form of testimonials and are not well documented.

The fuel savings that result from retrofitting a forced-air heating system with a radiant heating system seem to be greatest when the building involved is large, has a high ceiling, is poorly insulated, and has an old and inefficient existing heating system.

In summary, fuel savings will result from selecting radiant heat over forced-air heaters, and the fuel savings will range from 20 to 50%. To predict the fuel savings more precisely would be very difficult.

No studies documenting the installation cost of the radiant heaters were found in the open literature.

# 5. APPLICATIONS

## 5.1 BEST-SUITED BUILDING CHARACTERISTICS

Because of their unique characteristics, there are space heating applications in which radiant heaters are the most suitable; there are heating applications where radiant heaters are unsuitable; and there is a large, indeterminant area in between. In this section, building characteristics that are most suitable for a radiant-heater installation will be outlined. In the context of this report, "most suitable" means that radiant heaters will maintain the same (or better) level of human comfort with less fuel consumption than conventional heating systems.

### 5.1.1 Infiltration/Ventilation

Radiant heaters deposit their heating energy directly on the personnel and objects being heated. Thus, personnel will experience warmth even when standing in a draft of cold air. The warm air discharge from a forced-air system, however, would be blown away, or it would tend to rise to the ceiling area because of its lower density. Buildings with high infiltration rates or with an internal process that requires a high ventilation rate — including maintenance shops and warehouses where the doors remain open for significant periods — are very well suited for radiant heaters. Aircraft hangars may be especially well suited for radiant heaters because of their large doors. Temperature recovery of building air after the doors are closed is more rapid with radiant heaters than with forced-air heaters because radiant heaters maintain a warmer floor than forced-air heaters (see Sect. 4.3) and the large, warm floor reheats the air.

The point of this section, that radiant heaters work very well in a cold draft, can be emphasized by noting that radiant heaters are often used in outdoor and semienclosed areas. They are often found over loading docks, outdoor work stations, outdoor restaurants, and sporting arenas. Electric-resistance radiant heaters are usually most appropriate for an outdoor or semienclosed work station that is manned by a single, or a few, personnel.

### 5.1.2 Building Size and Roof Height

It was noted in Sect. 4.3 that temperature stratification exists in most conventionally heated buildings and it is often warmer near the roof than the floor. The larger the building, both in floor area and in roof elevation, the greater the potential for this energy-wasting phenomenon. In buildings heated with radiant heaters, this temperature stratification does not exist. Thus, the larger the building, and especially the higher the roof, the more suited is the building for radiant heaters. Again, high-bay maintenance shops, aircraft hangars, and warehouses are well suited for these heaters.

Indirect tube-type heaters (Fig. 4.1-Type 1) are mounted a minimum of ~10 ft off the floor and usually higher. Because of their greater operating temperature and radiation intensity, direct heaters (Fig. 4.1-Type 2) are mounted higher than the indirect type.

### 5.1.3 Nature of Building

From the previous discussions, radiant heaters of the type described here are obviously best suited for buildings of an industrial or heavy commercial nature. Stated another way, these radiant heaters are not well suited for offices, classrooms, laboratories, etc., where spaces are small, have low ceilings, and have much lower infiltration rates than industrial buildings. In addition, the gas- and oil-fired heaters described here are not considered to be aesthetically pleasing.

A new class of electrical-resistance heated radiant ceiling panel that is appropriate for office and other light commercial businesses has recently become available. The panels, which are attached to the ceiling and come in a variety of sizes, colors, and textures, are designed to operate with a surface temperature of 165 to 200°F.

### 5.1.4 Other Considerations

Other considerations may either enhance the suitability of radiant heaters or render them unsuitable.

1. Radiant heaters keep materials on the floor slightly warmer than air temperature. Thus, radiant heaters may alleviate problems with moisture condensation on these materials.

2. Radiant heating systems are often more appropriate than other heating systems for zone control, thus offering the potential for greater fuel savings.
3. Radiant heaters with exposed flames or high surface temperatures should not be used when highly volatile and inflammable materials are present.
4. Structural and operational materials and equipment in the region of the radiant heater can sometimes impose problems. Structural materials must be maintained an adequate distance from the heaters' shine and also from its hot plume. Inflammable materials (e.g., wooden roofs) can char from the hot plume. Traveling cranes also may sometimes impose limitations. Note in Fig. 4.2 that a guard attached to the overhead crane protects the switchgear from direct shine.
5. The plume from an unvented, gas-fired heater contains water vapor. The possibility of moisture condensation on the roof can present a problem and must be considered. This is discussed in more detail in Sect. 5.3.

### 5.1.5 Summary of Building Type

Most suitable for radiant heaters are large industrial or heavy commercial buildings that have high roofs, are poorly insulated, and have high infiltration or ventilation rates. Two classes of buildings — both common in the Army and both widely heated with radiant heaters in the nonmilitary sector — stand out as having all of these characteristics: high-bay maintenance shops and aircraft hangars. Warehouses also have these characteristics; however, care must be taken not to overheat materials that may be stacked high. Radiant heaters are best positioned over the aisles in warehouses. After conducting an extensive study on energy conservation in aircraft hangars, the Navy recommends that radiant heaters be used for heating large, open-bay buildings, such as aircraft hangars and warehouses (both in new construction and retrofit).[11,12] The National Fire Protection Association allows the use of radiant heaters in aircraft hangars if the heaters are listed for use in hangars by an appropriate authority and if certain other requirements are met.[13]

### 5.1.6 Cost-Effectiveness

The Army has in use many old buildings with old, inefficient (possibly obsolete) heating systems that should be replaced. This section will address this situation and concentrate on the cost-effectiveness of the retrofit installation of radiant heaters into existing buildings. The analysis is conducted using an existing building for which the thermal and physical characteristics are known. The building, industrial and located in Pittsburgh, Pennsylvania, has the following characteristics:

floor area — 60,000 $ft^2$

walls — brick

roof — wooden deck ~28 ft above the floor

insulation — essentially none

heating system — gas-fired boilers supplying steam to wall-hung and floor-mounted heaters

design heat loss — 4,000,000 Btu/h (calculated)

preretrofit heating fuel use in 1983 — $6.4 \times 10^9$ Btu of gas (6280 heating-degree-days)

This building has been retrofitted with radiant heaters, and the measured fuel savings were 54%.[10]

The calculation is performed for two regions in the United States: a northern region (8000 heating-degree-days; —15°F design temperature) and a central region (5000 heating-degree-days; 5°F design temperature). The results of the calculation (shown in Table 5.1) were obtained in the following manner.

1. The design heat loss for each region was obtained by correcting the estimated value for Pittsburgh with the ratio (inside temperature — outside design temperature)$_{Region}$/(inside temperature — outside design temperature)$_{Pittsburgh}$. The inside temperature is assumed to be 65°F.
2. The annual fuel use for each region was obtained by correcting the measured value for Pittsburgh with a ratio of heating-degree-days.
3. The radiant heaters selected for installation are gas fired, unvented, and rated for 120,000 Btu/h (input). These were selected

Table 5.1. Cost-effectiveness of radiant-heater retrofit

| Parameter | Regional location | | | | | |
|---|---|---|---|---|---|---|
| | Central | | | Northern | | |
| Heating-degree-days (65°F) | 5,000 | | | 8,000 | | |
| Outside design temperature, °F | 5 | | | −15 | | |
| Design heat loss from building, Btu/h | $4.0 \times 10^6$ | | | $5.3 \times 10^6$ | | |
| Annual fuel use (gas), Btu/year | $5.1 \times 10^9$ | | | $8.2 \times 10^9$ | | |
| Radiant-heater size selected, Btu/h (input) | 120,000 | | | 120,000 | | |
| Installed cost of single heater, $ | 1,365 | | | 1,365 | | |
| Number of heaters required | 34 | | | 44 | | |
| Total installation cost, $ | 46,400 | | | 60,100 | | |
| Assumed cost of gas, $/MBtu | 4.0 | | | 4.0 | | |
| Annual fuel cost before retrofit, $ | 20,400 | | | 32,800 | | |
| Annual fuel cost savings, $ | 4,100[a] | 8,200[b] | 12,200[c] | 6,600[a] | 13,100[b] | 19,700[c] |
| Simple payback period, years | 11.3[a] | 5.7[b] | 3.8[c] | 9.1[a] | 4.6[b] | 3.1[c] |
| SIR[d] | 1.13[a] | 2.26[b] | 3.37[c] | 1.41[a] | 2.79[b] | 4.20[c] |

[a]Computed at a fuel savings of 20%.

[b]Computed at a fuel savings of 40%.

[c]Computed at a fuel savings of 60%.

[d]SIR = savings-to-investment ratio.

because they are the largest listed in R. S. Means' *Building Construction Cost Data — 1983*.[14]

4. The installed cost of a single heater, obtained from R. S. Means' *Building Construction Cost Data — 1983*,[14] includes overhead and profit but not piping, wiring, and design cost. Therefore, the cost from Means was multiplied by 1.5 to include these additional costs.
5. The number of heaters required was computed by

$$\text{Number of Heaters} = \frac{(\text{Design Heat Loss})(0.85)}{(\text{Heater Rating})(0.85)} .$$

   The 0.85 in the numerator is used because manufacturers typically recommend that 85% of the design heat loss be used when sizing a radiant-heater installation. Because gas-fired heaters are rated according to the gas input, the heater rating must be multiplied by an efficiency. The 0.85 in the denominator represents the radiant-heater efficiency. The radiation generating ratio (ratio of radiant output to thermal heat input) is ~50%; therefore, the lower limit on efficiency is 50%. On the other hand, for an unvented heater all of the heat stays inside the building; therefore, the upper limit on efficiency is 100%. The 0.85 (85%) represents the author's judgment as to an effective value of efficiency for this equation.
6. The total installation cost is the number of heaters times the installed cost per heater.
7. The cost of gas is an assumed parameter.
8. The annual fuel cost is the annual fuel use times the cost.
9. The annual fuel cost savings are the indicated percentage of the annual fuel cost.
10. The simple payback period is the total installation cost divided by the annual fuel savings.
11. The savings-to-investment ratio (SIR) was computed as specified in Energy Conservation Investment Program (ECIP) guidance. The economic life was taken to be 15 years, and the discount factor was the U.S. average of 12.8.

Results of these calculations, including two additional fuel costs ($2.0/MBtu and $6.0/MBtu) are shown in Fig. 5.1(*a*) and (*b*). For fuel

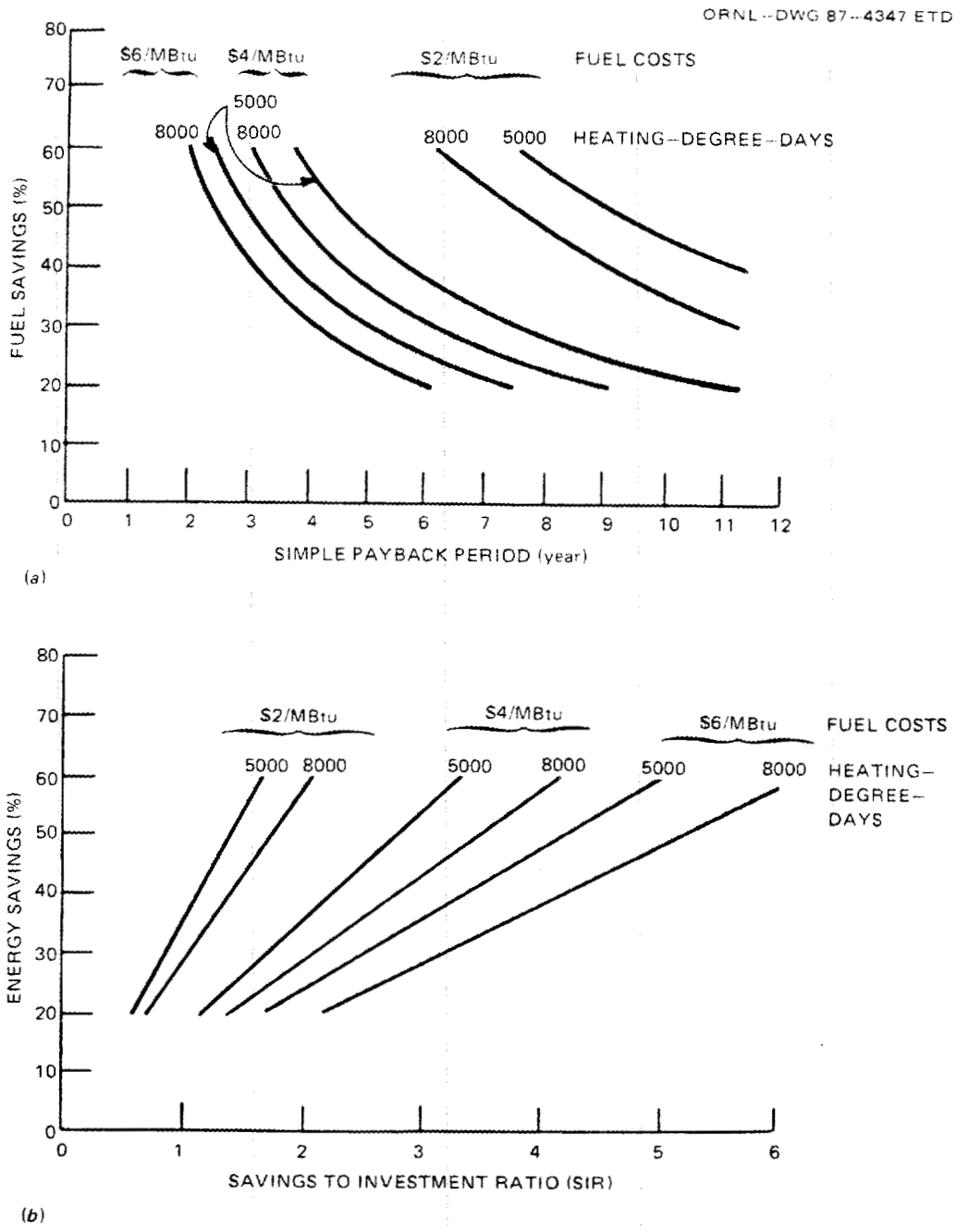


Fig. 5.1. (*a*) Simple payback period for radiant-heater retrofit, (*b*) SIR for radiant-heater retrofit.

costs of $4/MBtu and greater and for reductions of fuel use of 40% or more, simple payback periods from 2 to 5 years may be achieved.

## 5.2 RADIANT-HEATER SELECTION

In this section, the application areas in which each of the various kinds of radiant heaters are usually considered most appropriate for consideration will be described. The discussion is very general, and there will undoubtedly be exceptions and overlapping of the applications areas. Nevertheless, the reader will develop a feeling about where the various kinds of radiant heaters are best applied.

The nationwide average cost of energy by sector in 1983 is shown in Table 5.2. Energy costs in the commercial and industrial sectors are probably representative of the energy costs to the military. In these sectors, the cost of electricity is about four times the cost of gas and two and one-half to three times the cost of oil. For the general large space heating application, electric-resistance radiant heaters probably cannot compete economically with gas-fired radiant heaters on a life-cycle costing basis. Thus, electric-resistance radiant heaters are most

Table 5.2. Average U.S. cost of energy by sector in 1983

| Sector | Average cost of energy [$/MBtu (¢/kWh)] | | |
|---|---|---|---|
| | Gas | Oil | Electricity |
| Residential | 5.1 | 8.8 | 19.9 (6.8) |
| Commercial | 4.7 | 6.8 | 20.2 (6.9) |
| Industrial | 3.6 | 6.1 | 14.4 (4.9) |

*Source*: Adapted with permission from *State Energy Overview*, DOE/EIA-0354(83), DOE Energy Information Administration, August 1985.

appropriate for special situations, such as the following.

1. Certain regions of the nation where the cost of electricity is abnormally low. In Washington state, for example, the average cost of electricity in 1983 was $8.5/MBtu (2.9¢/kWh) and $5.6/MBtu (1.9¢/kWh) for the commercial and industrial sectors, respectively, and was almost the same as the cost of gas and oil in terms of dollars per millions of British thermal units.
2. Military reservations that do not have gas.
3. Buildings that are isolated from the gas mains. In most cases, these buildings would already be supplied with electric power.
4. Spot heating. Electric-resistance radiant heaters are particularly attractive for this application, and many models are available from the manufacturers. In this application, they are used outdoors, and in semienclosed areas and underheated buildings. They can be hung from the ceiling as a permanent fixture or are available as portable heaters mounted on wheels. They can be obtained to plug into a conventional 120-V outlet.

Catalytic combustion heaters (Gas Fired — Type 4) have a lower operating temperature and, thus, a low radiant-heat intensity. Considerably more square feet of heater surface would be required to meet a given heat rate than would be required with either direct- or indirect-fired radiant heaters (Gas Fired — Types 2 and 1, respectively). Thus, they are not normally used for general space heating unless the low operating temperature is required for some other reason, usually related to safety. For example, these heaters find space heating application where a highly volatile (or gaseous) and inflammable material is present. Known applications are in paint rooms, propane fill stations, naptha fill stations, etc. Catalytic radiant heaters are available as permanently mounted fixtures or as portable heaters.

The most readily available and commonly used radiant heaters are the gas-fired direct radiant heater (Figs. 4.4. and 4.5) and the gas-fired indirect radiant heater (Figs. 4.2 and 4.3). The indirect radiant heater is also available in an oil-fired version. Within the industry, direct radiant heaters are often called "high-intensity" heaters because of

their high operating temperature and corresponding high radiant-heat intensity. Conversely, indirect radiant heaters are often called "low-intensity" heaters because of their low operating temperature and low radiant-heat intensity. The direct radiant heaters are probably in more common use than the indirect radiant heaters.

The choice between direct and indirect radiant heaters is often determined simply by economics — which system costs less. However, between the two radiant-heating systems there are operational differences that may influence the choice. One of the more significant considerations concerns the release of combustion products into the heated space. Indirect radiant heaters are usually vented, and the products of combustion are exhausted to the atmosphere with an electric exhaust blower. Direct radiant heaters, however, are not normally vented, and their products of combustion are released to the building air space. One of the products of combustion is water vapor, which will rise to the roof with the hot plume from the heater. Problems can easily develop with moisture condensation on the roof structure and on other materials in the roof region. These problems can be especially severe with an uninsulated roof during cold weather when the heaters are operating near full capacity. Often the problems can be eliminated by adding insulation to the roof or by installing an exhaust fan in the roof. Using inside air for combustion and discharging the products of combustion into the building air space may also lead to concerns about oxygen depletion.

Direct radiant heaters operate at considerably higher temperatures than indirect radiant heaters. Thus, the radiant energy intensity is much greater from the direct radiant heater, and less square feet of heater are required to meet the heating load. To dissipate the energy over a larger area, the direct radiant heaters are usually positioned higher above the floor than are indirect radiant heaters. The hot plume of combustion gases that rises from a direct radiant heater can char combustible materials (wood and some insulation) and cause other damage to various items that are located above it. The same problem can be experienced with indirect radiant heaters but to a lesser extent.

As a general rule, direct radiant heaters are usually considered most suitable for use in a building that has a high roof and a high infiltration or ventilation rate and for outdoor or semienclosed areas. Conversely, indirect radiant heaters are usually considered most suitable for a building with a relatively lower roof and infiltration rate.

## 5.3 INSTALLATION, OPERATION, MAINTENANCE, AND SAFETY

This section concerns miscellaneous aspects of radiant heaters, generally associated with some aspect of installation, operation, maintenance, and safety. Most of the following information was extracted from Refs. 1, 11, 12, and 15.

### 5.3.1 Physiological Effects

Physiological concerns result from the exposure of the skin and eyes to infrared radiation.

The eye has two protective responses to infrared radiation: the iris contracts, and the sensation of pain causes the eyes to close. If the infrared intensity is great enough and if neither protective response occurs, the damage to the eye in the form of retinal burns or cataracts can result.

Studies have shown that infrared radiation with wavelengths in the range of 1.0 to 2.0 μm may cause cataracts, but the exposure must be prolonged and intimate for damage to occur. Eye damage does not occur for wavelengths over 2.0 μm. Typically, ~15% of the energy from an infrared heater has a wavelength between 1.0 and 2.0 μm.

Human skin absorbs virtually all infrared radiation longer than ~2.0 μm. Between 0.4 and 1.5 μm (which includes part of the visible light range) dark skin will absorb most of the radiation, but white skin tends to reflect it. The absorbed radiation penetrates the skin sufficiently to interact directly with nerve endings, thus producing the perception of warmth. Exposure to an intense infrared beam can cause burning or blistering of the skin.

The radiation intensity from typical radiant-heater installations is considerably below that required for any of the above physiological

effects to be a problem. Thus, no adverse health effects were identified that would result from the low infrared intensity experienced under normal working conditions.

### 5.3.2 Venting

Indirect radiant heaters (Fig. 4.1, Type 1) are normally exhausted to the outside with an eductor fan. Direct radiant heaters (Fig. 4.1, Type 2) normally release their products of combustion to the building air space. The combustion products are very hot and rise to the roof area as a plume. Condensation of water vapor can occur on the colder roof structures and drip down to the floor. The situation can be exaggerated if the fuel contains sulfur because the condensate may then contain sulfurous or sulfuric acid. If the building is large enough or if the infiltration is great enough, the water vapor may dissipate, and condensation may not be a problem. If a problem is anticipated, the usual solution is to vent the roof with exhaust fans, which may be controlled by either of two ways.

1. The fans may be connected so that they turn on when the heaters turn on and off when the heaters turn off.
2. The fans may be controlled with a humidity sensor that turns the fans on when the humidity in the roof area reaches a predetermined level.

The National Fire Protection Association requires that where unvented infrared heaters are used, natural or mechanical means shall be provided to supply and exhaust at least four CFM per 1000 Btu/h input of installed heaters. Advice should be sought from the heater manufacturer or an experienced architect engineer on the need for additional ventilation. The ventilation system also relieves any concern about oxygen depletion in the building air space.

### 5.3.3 Layout

The most common layout pattern for direct radiant heaters is to locate them around the perimeter of the area to be heated (see Figs. 4.4 and 4.5). The heaters are positioned so that their field of coverage starts at the floor edge directly beneath them and extends toward the

other side of the building. To minimize heat loss, the building walls should not be included in the heaters' coverage. If the building is sufficiently large, then an additional row of heaters may be required down the middle.

Indirect radiant heaters are usually located in a uniformly dispersed arrangement over the entire area to be heated (see Figs. 4.2 and 4.3). They are positioned so that their field of coverage is directly beneath them. Note in Fig. 4.2 that attached to the overhead crane is a guard that protects the motor and switch gear from direct radiation from the heaters.

### 5.3.4 Clearance

Proper clearance must be maintained between the radiant heater and materials that may be adversely affected by the heat. Considerable care must be taken to ensure that proper operation of fire detection and sprinkler systems will not be affected by the radiant-heat energy or by the hot plume rising above the heater. Adequate clearance must be maintained between the heater and noncombustible materials (e.g., structural members, pipes, and wires) and combustible materials (e.g., wood, insulation, and plastics). The radiant-heater manufacturer is the best source of information on the clearances required to prevent damage to building structure and operational materials. The National Fire Protection Association sometimes specifies clearances for buildings that serve a specific function (e.g., aircraft hangars[13]).

### 5.3.5 Maintenance

A preseason inspection and maintenance plan consisting of visually and operationally checking the heater to make sure that all components are functional is recommended. The gas jets (in gas-fired units), combustion air inlet, and exhaust should be inspected and cleaned as necessary. Dust, spider webs, and bird nests that may have accumulated over the summer months should be removed. Radiant surfaces and reflector surfaces should be wiped clean with a dry cloth or cleaning solution, as necessary.

## 6. CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion of this assessment is that infrared radiant heaters require less fuel than forced-air heaters to maintain the same level of human comfort. This comparison is made with forced-air heaters because they are the most common heater type used in buildings that are most appropriate for radiant heaters. The amount of fuel savings is difficult to estimate, but manufacturers claim 20 to 50%. Professionally obtained field data and, also, unprofessional testimonials reported in the literature confirm this range. The greatest fuel savings are associated with large buildings with high roofs, poor insulation, and high infiltration rates. The simple payback period for retrofit installation of radiant heaters may be from 2 to 5 years, when fuel costs are $4/MBtu or more, and fuel savings are 40% or more.

A secondary conclusion of this assessment is that infrared radiant heaters will actually achieve a greater level of human comfort than forced-air heaters in certain situations. Consider, for example, an aircraft hangar. When the large aircraft doors are opened, the warm air in the hangar is lost almost immediately. Personnel in the hanger will continue to experience warmth from radiant heaters but probably not from forced-air heaters. In addition, when the hangar doors are closed, temperature recovery of the air space will be more rapid than with forced-air heaters.

Many Army posts already have radiant-heater installations, but most are retrofit installations into existing buildings. It is recommended that radiant heaters be considered for new commercial or industrial buildings, including aircraft hangars. The cost of the radiant-heating system and the conventional heating system (e.g., forced-air unit heaters) should be compared on a life-cycle basis. For this comparison involving two new heating systems, it is suggested that annual fuel requirements of the radiant heaters be assumed to be 20 to 50% less than the annual fuel requirements of the conventional heaters.

Radiant heaters could have their greatest impact on military fuel use as a retrofit installation in existing buildings. The uncertainty

for this application is that the cost-effectiveness is unknown. To estimate a credible SIR, a reasonably accurate value from the fuel savings is necessary. A program intended to resolve this uncertainty is recommended. If resolution is favorable, as expected, widespread retrofit of radiant heaters could proceed rapidly with a high level of confidence in the projected fuel savings, cost-effectiveness, and human comfort. The program is based on the following assumptions.

1. A building type in which the expected fuel savings will be 40% or more can be identified. There are probably many military buildings that are old and have inefficient heating systems where this assumption can be presumed to be true.
2. The fuel savings that result from radiant-heater installation can be extrapolated with reasonable certainty between buildings of the same type.

The proposed program involving four steps is carried out over two heating seasons in the following manner.

1. Select one or more conventionally heated buildings for retrofit with radiant heaters. The buildings selected should be representative of a class of buildings that are expected to yield the greatest fuel savings from this retrofit. High-bay maintenance buildings and aircraft hangars would be an ideal choice of building class (see Sect. 5.1).
2. Measure the heating fuel requirements weekly for one heating season before retrofit. Normalize the fuel requirements to the heating-degree-days for the week of fuel use, thus obtaining fuel requirements that are independent of the outside temperature during that week. Measure certain temperatures (discussed in Sect. 4.3) that are involved with fuel savings and human comfort: at a minimum, floor temperature, air temperature about chest high, and air temperature near the roof. Survey the permanent work force concerning their general comfort level.
3. During the following summer install an infrared radiant-heating system. The installation should be designed by an architect engineer

(AE) who has experience with radiant heaters, and radiant heaters should be selected from a manufacturer that also has had considerable experience. Note that in recent years, many AEs and small manufacturers are becoming involved with radiant heaters but have not yet developed a background of experience. The construction drawings should be reviewed by the radiant-heater manufacturer. If gas fired, the radiant heaters should be certified by the American Gas Association.[16]

4. During the next heating season repeat all of the measurements and analysis described in No. 2 above. With the emphasis on whether the comfort level is greater/lesser/the same as before retrofit, the permanent work force should be interviewed again.

The above program will yield definitive information on the fuel savings, cost-effectiveness, and human comfort that result from the retrofit of radiant heaters in these buildings. By using the measurements taken in Nos. 2 and 4 above, the energy savings and cost-effectiveness can be extrapolated with a high level of confidence to other similar buildings of the same general class.

An experimental procedure designed to measure the fuel savings that result from retrofit of radiant heaters in eight aircraft hangars at Ft. Campbell, Kentucky, has been developed.[17] The radiant-heater installation was cancelled; thus, the effort to measure fuel savings was never carried out. Nevertheless, the experimental measurements and the analysis required to determine fuel savings are described in detail in this report.

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