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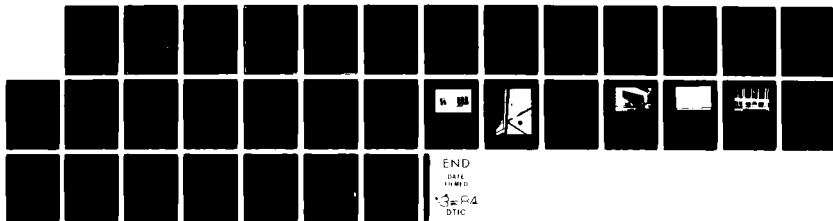
DESIGN GUIDELINES FOR HEATING AIRCRAFT HANGARS WITH
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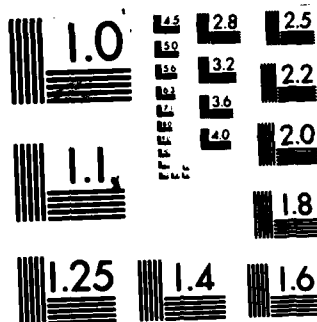
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AUTHOR: **Edward L. Correa**

DATE: **December 1983**

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METRIC CONVERSION FACTORS

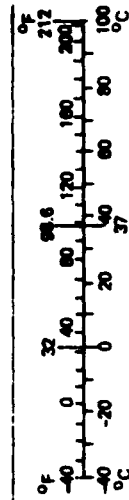
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
in ft yd mi	inches	<u>LENGTH</u> *2.5 30 0.9 1.6	centimeters	cm
	feet		centimeters	cm
	yards		meters	m
	miles		kilometers	km
in ² ft ² yd ² mi ²	square inches	<u>AREA</u> 6.5 0.09 0.8 2.6 0.4	square centimeters	cm ²
	square feet		square meters	m ²
	square yards		square meters	m ²
	square miles		square kilometers	km ²
oz lb	ounces	<u>MASS (weight)</u> 28 0.45 0.9	grams	g
	pounds		kilograms	kg
	short tons		tonnes	t
	(2,000 lb)			
tsp Tbsp fl oz c pt qt gal ft ³ yd ³	teaspoons	<u>VOLUME</u> 5 15 30 0.24 0.47 0.96 3.8 0.03 0.76	milliliters	ml
	tablespoons		milliliters	ml
	fluid ounces		milliliters	ml
	cups		liters	l
	pints		liters	l
	quarts		liters	l
	gallons		liters	l
	cubic feet		cubic meters	m ³
°F	cubic yards	0.76	cubic meters	m ³
<u>TEMPERATURE (exact)</u>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Mon. Publ. 280, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10-286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<u>LENGTH</u>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
<u>AREA</u>				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
<u>MASS (weight)</u>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
<u>VOLUME</u>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
<u>TEMPERATURE (exact)</u>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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efficiency burners, (4) reducing building heat loss, and (5) heating only occupied areas rather than the whole building. This report includes the principles of radiant heating in hangars, guidelines for optimum system design, and discussion of the physiological aspects of radiant heating. Cost analysis procedures are given for determining the cost-effectiveness of the radiant systems for comparison with other types of heating systems.

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INTRODUCTION

Over the past several years, costs for space heating large open bay buildings (e.g., aircraft hangars, warehouses) have increased with the rise in costs for energy. In addition, forced-air convective heaters currently in use can cause heat stratification and air stagnation. Stratification results in air temperatures being high near the ceiling but low at the floor level, resulting in thermal discomfort for personnel. Long periods of time are needed for heat recovery because the hangar air volume must be reheated when the main doors are opened to the cold outside air.

The Naval Civil Engineering Laboratory (NCEL) evaluated the use of radiant heaters in aircraft hangars as part of a Navy hangar heating investigation.

Presented in this report are the principles of radiant heating in aircraft hangars, guidelines for optimum system design, and information on the physiological aspects of radiant heating. Comparative cost analysis procedures are included for evaluating the cost-effectiveness of radiant heating systems with other types of heating systems. The report also presents information on what measures must be taken to comply with the National Fire Protection Association (NFPA) codes.

BACKGROUND

Aircraft hangars, because of their large open interiors, have always been difficult to space heat during the winter months because of heat stratification, slow heat recovery, and high heating costs. When forced-air convective heaters are used, the warm air rises, resulting in high air temperatures near the ceiling and lower temperatures at the floor level. In addition, when the main doors are opened, heated air is lost to the colder outside environment. Once the doors are closed, the heating process must start all over again.

CONVECTIVE HEATING

Convective heaters are suitable for moderately low ceiling applications where the heated air maintains a reasonably uniform temperature throughout the room. As the ceiling height increases, however, convective heaters become inefficient in maintaining thermal comfort temperatures at floor levels. Natural convection forces the warm air to rise to the ceiling - away from the floor level where it is needed.

In buildings such as aircraft hangars, once the air is heated it is difficult to keep it at floor level. As the warm air rises, more heated air must be produced to replace it. As this cycle continues, more heated

air collects at the ceiling, resulting in higher temperatures in that area. The higher temperatures increase the heat loss through the upper walls and roof surfaces. Thermal comfort at the floor level is achieved at the expense of heating the overhead spaces. The rising hot air also causes a "stack effect" which increases air infiltration, another major source of hangar heat loss.

PRINCIPLES OF RADIANT HEATING

Radiant heaters (Figure 1) are best applied where and when convective heaters are less than satisfactory. Radiant heaters radiate heat in the form of infrared (IR) waves in a straight, line-of-sight direction that makes them impractical for applications below 8 feet in height because of uneven heat distribution. Areas shaded from the radiant heat do not receive the same heat flux density as exposed areas.

Air, the medium for convective heat, is a poor absorber of IR radiation; like light energy, IR radiation is transmitted in the form of invisible electromagnetic radiation. Upon striking an absorbing mass, IR radiant energy is converted into heat, and this absorptive mass (e.g., concrete floor) becomes a reservoir of heat storage. Once the floor temperature is greater than the interior ambient air temperature this heat reservoir gives off heat to the surrounding environment by convection, conduction, and radiation. Quick heat recoveries are possible because the hangar is heated from the floor up rather than from the ceiling down, as is the case with convective heaters.

The performance of a radiant heater depends upon the emissivity of the heater's emitter surface and the absorptivity of the receiver surface. The emissivity of the emitter determines the output efficiency of the emitter while the absorptivity of the receiver determines at what efficiency the heat is being absorbed. For any given material at thermal equilibrium, the emissivity and absorptivity factors are the same, and either surface factor is determined on a scale from 0 to 1.00 where 0 means no emission of any IR radiation and 1.00 means emission of all its radiation. Realistically, neither can be achieved. For an opaque material, reflectivity is the complement absorptivity, as shown in Figure 2.

IR radiation is the primary mode of heat transmission; all matter, whether solid, liquid, or gas, above a temperature of absolute zero emits IR radiation.

The emitter's surface temperature determines the wavelength and intensity of the radiant energy: the higher the surface temperature, the shorter the wavelength and the greater the intensity. The intensity q , or rate of heat transfer, is directly proportional to the fourth power of the surface temperatures, as shown in Equation 1:

$$q = K\epsilon AT^4 \quad (\text{Btu/hr}) \quad (1)$$

where: q = rate of IR emission or emissive power (Btu/hr)
 $K = 0.173 \times 10^{-8} \text{ Btu/hr ft}^2 \text{ } ^\circ\text{R}^4$
 (Stephan-Boltzman constant)
 ϵ = emissivity of the emitter surface (dimensionless)
 A = surface area of the emitter (ft^2)
 T = absolute temperature of the emitter surface ($^\circ\text{R}$)

ADVANTAGES OF RADIANT HEATERS

A properly designed and installed radiant heating system can eliminate many of the heating problems associated with hangars. Radiant heaters achieve energy savings in a number of ways:

- Lower air temperatures for the same thermal comfort provided by convective heaters.
- Less building heat loss - Lower air temperatures reduce the quantity of heat transmitted through exterior building surfaces.
- Lower energy cost - The reduced building heat loss results in less fuel required for heating.
- Less air stratification and air infiltration - Lower air temperatures reduce heat stratification and air stagnation at the upper levels. The reduced temperature difference between the inside and outside air reduces the air infiltration losses through gravity ventilation or stack effect.
- Zone heating - Zones can be heated independently for changing work requirements. Rather than heating the whole hangar, work areas may be fully heated while storage areas may be heated to just above the dew point or freezing temperatures. Unoccupied areas may be left unheated. Zone heating requires additional heaters and thermostat controls than whole building radiant heating, but the additional expense for heating flexibility should be cost-effective.
- Heat storage - The radiant energy striking the concrete floor is converted into heat energy, which is absorbed by the floor. The floor thus becomes a heat storage reservoir. In addition, since the floor surface heats more quickly than the ambient air temperature, the floor acts as a radiator and gives off heat. Even when the hangar doors are opened to the cold outside air, the radiant heaters continue to store heat in the floor. When the

doors are closed again, this stored heat plus the direct heat from the IR radiant heaters enable the temperature at the floor level to recover quickly (15-20 minutes).

- Condensation/corrosion control - If humidity or condensation is a problem, radiant heaters can supply just enough heat to keep the floor or an object just above the dew point or freezing temperature. This helps eliminate unwanted moisture and corrosion problems.

DESIGNING A RADIANT HEATING SYSTEM

Several factors must be carefully considered when a radiant heating system is being designed for any building. As indicated earlier, a properly designed and installed heating system in an aircraft hangar can eliminate many operational and cost problems for the hangar manager.

Emissivities

The critical factor in designing an efficient radiant heating system is to match the emissivity of the radiant heater to the absorptivity of the objects to be heated (i.e., personnel, concrete floors, or other items). The emissivity of a material may vary under different temperatures and IR wavelengths. For example, the emissivity of white paint is approximately 0.18 (18% absorptance) for a solar light IR wavelength of 0.6 micron and 0.95 (95% absorptance) for IR radiation of 9.3 microns at 100°F. Appendix A in Reference 1 has a list of emissivities for building materials exposed to various heat temperatures and wavelengths. To maximize the thermal efficiency of a radiant heating system, radiant heaters need to emit IR energy in the range that the objects to be heated will most readily absorb.

National Fire Protection Association Codes

The purpose of the NFPA regulations are to insure that the heaters are safely installed and will not create a hazard or interfere with the existing fire protection systems.

Volume 10 of Reference 2 indicates that heaters employing an open flame or glowing element that are listed for use in aircraft hangars may be installed if they meet the spacing requirements in that chapter. Further information on installation requirements for IR radiant heaters can be found in the NFPA Codes listed below:

- Heaters/heating equipment/heating systems

Volume 10: NFPA 409-1979 Aircraft Hangars, Chapter 9, Hangar Services and Utilities (Ref 2)

Volume 9: NFPA 90A-1978 Standard on Installation of Air Conditioning and Ventilating Systems (Ref 3)

Volume 3: NFPA 31-1978 Installation of Oil Burning Equipment (Ref 4)

Volume 4: NFPA 54-1974 National Fuel Gas Code Parts I & II (Ref 5)

- Ventilation/blower/exhaust systems

Volume 9: NFPA 90A-1978 (Ref 3)

Volume 10: NFPA 409-1979, and Chapter 6, Section 6-7.32, Mechanical Ventilation (Ref 2)

Volume 9: NFPA 91-1973 Standard for the Installation of Blower and Exhaust Systems (Ref 6)

- Electrical Systems

Volume 6: NFPA 70-1978 National Electrical Code, Article 513, Aircraft Hangars (Ref 7)

Clearances

Radiant heaters will most likely be suspended from the ceiling or roof structural members to avoid contact with moving cranes or aircraft with high tail sections. These heaters cannot be installed above fire detection or sprinkler systems as the heat may be sufficient to activate these systems. Also, if the units are to be suspended among the roof structural members, the path of the IR radiant heat must be unobstructed to the floor level. Structural members, wiring, pipes, and other items can be damaged. Figure 3 shows the damage that can occur when an IR radiant heater is installed just above a structural member; the intense heat charred the paint and exposed the metal to heat stress and corrosion.

Layout

Perimeter. A perimeter layout of radiant heaters such as that in Figure 4 will heat the hangar from the base of the wall to the center floor. The heaters should be oriented so that their field of coverage starts at the floor edge with the wall and continues toward the center (Figure 5). The walls should not be included in the heater's line-of-sight to minimize heat loss through the walls. If the hangar is extra large, an additional center row mounting may be necessary. Additional heaters will be required over the main hangar doors as shown in Figure 6 because of the larger heat loss when the doors are open.

Checkerboard. An overhead checkerboard layout would evenly disperse the heaters throughout the hangar (Figure 7). However, this layout would require more heaters than for the perimeter layout and would increase the network of piping and electrical wiring required for the heaters.

Venting

Venting is required for gas-fired radiant heaters. Building materials that are contiguous to the exterior (e.g., glass skylights) are potential collection points for condensation from warm moist air or from flue gases. If the outside temperature is below the dew point temperature, condensation can form and drip down on the floor below, which is unacceptable both for aircraft maintenance and personnel safety. Also, products of combustion from fuels with LPG and propane mixed in with natural gas may have a high sulfur content. When these are combined with water vapor, these products can form sulphuric acid. Venting of IR heaters will remove the combustion gases and prevent condensation.

Direct. Direct venting of the gas-fired radiant heaters will remove flue gases directly from the hangar through exhaust stacks in the roof (Figure 8). If such venting is used, these stacks should have dampers at the top to prevent downdrafts. These dampers prevent the IR burners from being "blown-out" by downdrafts and help eliminate the funneling of cold air down through the stack when the heaters are not in use. The exhaust stacks must rise directly from the IR radiant burners (Figure 9); a horizontal stack will impede the rise of hot flue gases. When two vent stacks are joined together, the diameter of the resulting stack must be sufficient to handle the combined flow rate from the feeding stacks. Also, the stack height above the roof must be sufficient to allow flue gases to mix with the outside atmosphere.

Exhaust. Another venting method is the use of exhaust fans with spring-loaded draft shutters installed in the ceiling (Figure 10). When the exhaust fans are operating, positive air pressure forces the draft shutters to open and exhaust the flue gases. When the exhaust fans are shut off, the positive pressure of the exhaust airflow decreases and is overcome by the force of the loaded spring on the draft shutters, forcing them closed, thus preventing both warm air from escaping and cold air downdrafts from entering. These exhaust fans can be controlled automatically either of two ways:

1. A relay switch can turn on the exhaust fan whenever the heater operates and can turn it off whenever the heater is turned off. A timed delay of several seconds or minutes can be included to delay the fan shutoff to ensure purging of the flue gases.
2. The on-off function of the fans can be automatically controlled by a humidity control device. That is, whenever the moisture content from the flue gases reaches the sensor's pre-set level, the humidity control automatically turns the exhaust fans on. Once the moisture content of the air drops below the lower pre-set moisture range, the exhaust fans shut off. These sensors could be placed at several points in the roof structural members.

A manual override switch included in the above circuits could be used to bypass the above two systems should the need arise (e.g., to vent smoke or odors).

Minimizing Building Air Leakage

When the air temperature inside a hangar exceeds the outside air temperature, the difference in the densities between warm and cold air can cause gravity ventilation (Figure 11). To minimize the effects of gravity ventilation, IR heater flue gas stacks or vents must have dampers which close when the unit is not operating.

Heater Ignition

Electronic glow coils or electronic spark ignition should be used to ignite the gas-fired burners. They are very reliable and provide additional safety to prevent an accumulation of gas fumes (such as when a pilot light gets blown out). These ignition systems have built-in safety features to shut down the gas supply if the spark fails to ignite the burner in a specified number of seconds. This safety feature prevents gas from flowing through the ceramic burner into the aircraft hangar. Elimination of pilot lights saves additional energy as well as the inconvenience of re-lighting pilot lights if they blow out.

Thermostats

Thermostatic controls should be shielded to prevent heat buildup in the controls that are installed below radiant heaters. Thermostats should be located outside the line-of-sight of the IR radiant energy.

Maintenance Access

Section 9-1.2.3 of Reference 2 states that access to suspended heaters shall be assured for recurrent maintenance. Though a truck with a hydraulic lift may fulfill this requirement, catwalks with an access ladder is a better alternative. Catwalks are more expensive initially, but will give immediate and assured access to heater units at any time and for any hangar floor configuration. With catwalks, the direction of the heater may be changed easily and at any time to meet changing heating requirements at the floor level.

Trucks with hydraulic lifts have access only when the floor space below is clear and only if there is a path to that floor space. If an aircraft is in the way, it may have to be removed or the maintenance may have to be rescheduled. The truck would require a minimum of two persons and whatever additional manpower necessary to relocate aircraft for the truck's access. With the truck, crew, and additional wingwalkers and aircraft tow vehicle, a simple inspection or maintenance repair can turn into a costly logistic problem requiring advanced scheduling. Also, changing floor arrangements in open bay buildings, such as the installation of a storage area or other fixed obstacles, can obstruct access to these overhead heaters.

Electric Solenoid Shutoff Valves

Installation of an electrical solenoid shutoff valve to each heater (Figure 12) is recommended to isolate each heater. With this installation, other units on the same line can be used while an isolated unit is

awaiting maintenance. In another example, if a tall tail section of an aircraft is placed too close to a heater, the switch can be shut off to the affected heater temporarily to prevent heat damage to the aircraft. The shutoff switch can be located directly below the heater, at a central control point or at both locations.

Loss of one heater may not degrade a heating system, but the loss of several may degrade it if several units are on the same line and do not have separate shutoff solenoids. In addition, manual shutoff valves for each heater are required (NFPA regulations, Ref 2 through 7) for gas-fired units.

Certification by Manufacturer

A survey was conducted to determine the experience of engineering organizations (government and civilian) in designing radiant heating systems. The survey indicated knowledge of radiant heating system design is not widespread.

The contract for the installation of a radiant radiating system should specify that the blueprints for the system design must be reviewed by the product's manufacturer. The manufacturer should follow up with an on-site certification of the system. Though this may increase the installation cost slightly, it will help eliminate costly correction of design errors. Some examples of design errors in existing IR heating systems are:

- High intensity IR heaters installed just above roof structural members (Figure 3).
- Vent stacks installed horizontally (Figure 8) which can cause the flue gases to stagnate.
- Vent stacks installed without downdraft dampers, resulting in cold downdrafts.

Periodic Inspections

Pre-season and post-season inspections should be made as part of a preventive maintenance plan. These inspections will greatly reduce the maintenance and increase the reliability of the heating system. Access catwalks will facilitate conducting these inspections.

Prior to the heating season the system should be visually inspected and operationally checked out to insure that the units are functional. Dust, debris, spider webs, or bird nests that may have accumulated in the units over the summer months should be removed.

For the post-heating season the units should be secured for the summer months. The gas jets for gas-fired units should be wrapped with tape, cloth, or vinyl wrap to help prevent dust and debris from accumulating.

PHYSIOLOGICAL EFFECTS OF IR RADIATION ON PERSONNEL

Physiological concerns with use of IR radiant energy are those adverse effects that may damage eyes and skin of personnel.

The eye normally has two forms of protection from excessive exposure to IR radiation energy: (1) the iris naturally contracts and (2) photophobia or painful reaction to intense light occurs. However, the lens of the eye can focus concentrated IR radiant energy onto the retina. Damage to the eye in the form of cataracts and retinal burns can occur if the iris does not have enough time to contract and the intensity of the IR radiant energy is great enough (Ref 8). The eye does not have a circulatory system to act as a cooling system to dissipate heat quickly (Ref 9).

In various studies it has been shown that short wavelengths of IR energy in the range of 1.0 to 2.0 microns may cause cataracts of the eye after prolonged and intimate exposure, but this exposure must be close and for a prolonged period of time for the damage to occur. Eye damage does not occur at IR radiant energy wavelengths longer than 2.0 microns. Gas-fired IR radiant heaters emit energy in the range of 2.0 to 6.0 microns (Ref 8).

Studies by J. Hardy (Ref 10) show that skin absorption is sensitive to the wavelength of the IR radiation; the skin absorptance is variable in the range between 0.4 to 2.0 microns (Figure 13). For wavelengths from 2.5 to 20.0 microns the skin absorptance of IR radiant energy is approximately 97 to 99% (Ref 10). For IR wavelengths longer than 2.6 microns, the skin, regardless of color, is essentially a black body. IR radiant energy penetrates to between 0.0008 and 0.00012 inch beneath the skin surface and, thus, interacts directly with the nerve endings and small blood vessels. This interaction gives the sensation of warmth.

The skin is more sensitive to the longer IR wavelengths than the shorter IR wavelengths. Also, objects with high moisture content absorb longer (>2 microns) wavelength energy more readily and at a higher percentage. Thus, smaller amounts of longer IR wavelength energy are needed to produce a sensation of warmth.

In summary, no adverse health effects associated with IR radiant energy with wavelengths longer than 2.0 microns have been detected. The skin is more responsive to these longer wavelengths for heat absorptance and warmth sensation.

COMPARATIVE COST ANALYSIS

Before designing a radiant heating system, the designer should prepare a cost analysis on the existing heating system and any proposed IR radiant heating system. An estimate can then be made on the seasonal fuel cost for each system. Once these estimates are made, then a cost comparison can be made to determine if the payback period will justify the cost of retrofitting a building with an IR radiant heating system.

A total seasonal fuel cost can be estimated by using the degree-day method presented in the ASHRAE Handbook. This estimate is based upon average weather data collected for the locality:

$$\text{AFCU} = \frac{24(\text{HL})(\text{DD})}{E(T_i - T_d)C} \quad (2)$$

where: AFCU = annual fuel consumption units (units of fuel)

HL = calculated total building heat loss (Btu/hr)

E = heating system efficiency

T_i = inside design temperature ($^{\circ}\text{F}$)

T_d = average winter outside air temperature ($^{\circ}\text{F}$)

C = heating value per unit of fuel (Btu/unit of fuel)

DD = degree days

After the annual fuel consumption is calculated for each system, the projected annual savings can be used to determine the payback period of the retrofit.

$$\text{AHC} = \text{AFCU} \times \text{fuel cost/unit of fuel (annual heating cost)} \quad (3)$$

$$\text{PCS} = \text{AHC}_{\text{existing system}} - \text{AHC}_{\text{IR}} \quad (4)$$

$$\text{PBP} = \frac{\text{Installation Cost of IR}}{\text{PCS}} \quad (5)$$

where: PCS = projected cost savings for fuel per year (\$/yr)

PBP = pay back period

CONCLUSIONS

The results of this investigation indicate that radiant heaters are practical heaters for use in large open bay buildings. Generally, radiant heaters surpass convective forced-air counterparts in heating large open bays in the following ways:

- by providing increased thermal comfort at the floor level while substantially reducing heating costs and heat stagnation
- by being able to heat objects to just above the dew point temperature to prevent condensation and corrosion
- by allowing heating flexibility with zone or whole building heating

Gas-fired, high-intensity, porous, refractory, IR radiant heaters are recommended for use in aircraft hangars if natural gas is available because of the following:

- the porous, refractory, IR burners emit heat energy primarily in the longer wavelengths (2 to 6 microns) which is within the optimum absorptance range for personnel and concrete floors and has no adverse physiological effects
- porous, refractory heaters are safe for use in aircraft hangars
- when the burners glow a dull red, a malfunctioning burner would be visually apparent by intermittent burner incandescence

However, the following disadvantages should be noted:

1. Due to the inherent nature of suspending these heaters near the ceiling of an aircraft hangar, access to these heating units is restricted for inspections and maintenance. However, these difficulties can be overcome with the installation of:

- a wall ladder and access catwalks with safety rails
- an electrically operated solenoid shutoff valve for each heater to isolate a malfunctioning heater from the main gas supply line

2. Natural gas may not be available at the hangar location

3. The gas-fired heaters require ventilation for elimination of the flue gases. This can be provided by the following:

- direct exhaust vents for the flue gases for vented heaters (Figure 8)
- exhaust fans to vent the flue gases for unvented heaters (Figure 10)

RECOMMENDATIONS

1. As an energy conservation measure, radiant heaters are recommended for heating large open-bay buildings such as aircraft hangars and warehouses (both in new construction and retrofit).

2. When installing radiant heaters near the ceiling, include catwalks with safety rails and a built-in access ladder. Though this will increase the initial installation costs, the catwalks and access ladder will reduce the cost and inconvenience of inspections and maintenance over the life cycle of the heaters while providing immediate access to these systems.

3. Incorporate a zone heating capability into the heating system. This will require more heaters for the entire structure, but it will provide the hangar's manager with the flexibility to heat only the occupied areas rather than the whole hangar.

4. Use glow coil or electronic ignition systems instead of pilot light ignition for gas-fired heaters. The elimination of pilot lights will also save energy.

5. The heaters should have centralized, electrically controlled solenoid shutoff switches to enable the hangar manager to shut off unneeded heaters. Also, a malfunctioning heater can be isolated until repaired.

6. High-intensity gas-fired IR heaters, if gas is available, are recommended over other radiant heating systems.

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Figure 1. High-intensity porous refractor IR radiant heaters.

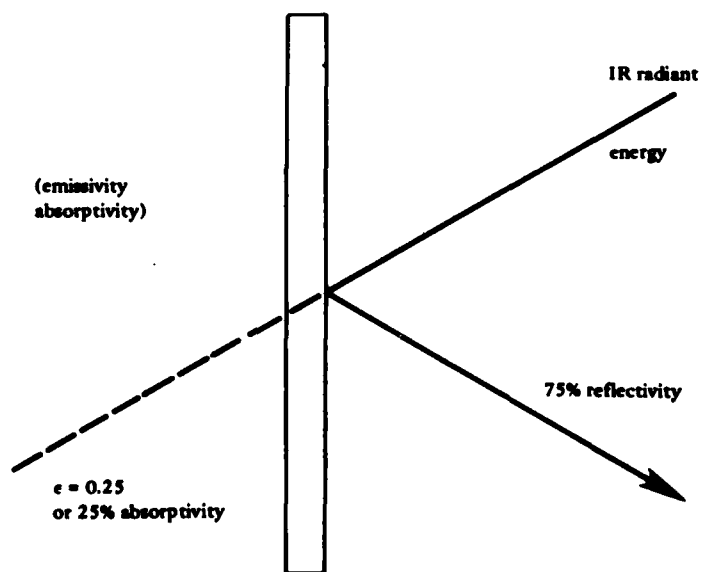


Figure 2. Reflectivity, the complement of absorptivity.



Figure 3. Damage to structural member caused by incorrectly mounted IR radiant heater.

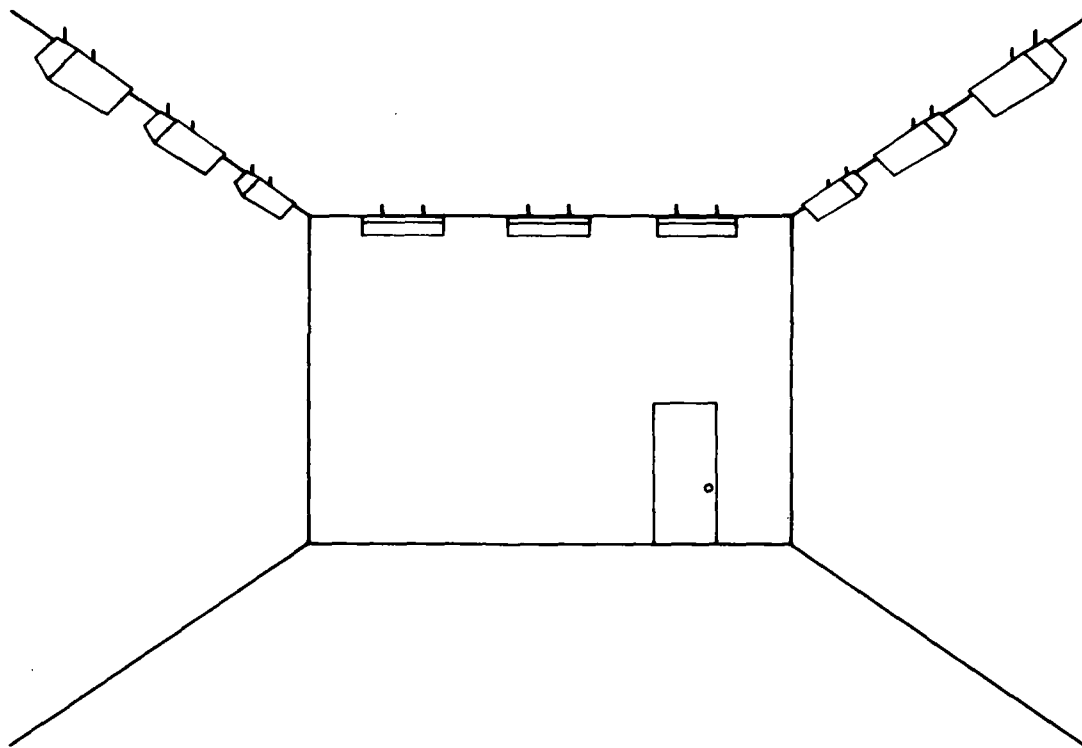


Figure 4. Perimeter arrangement of high-intensity IR radiant heaters.

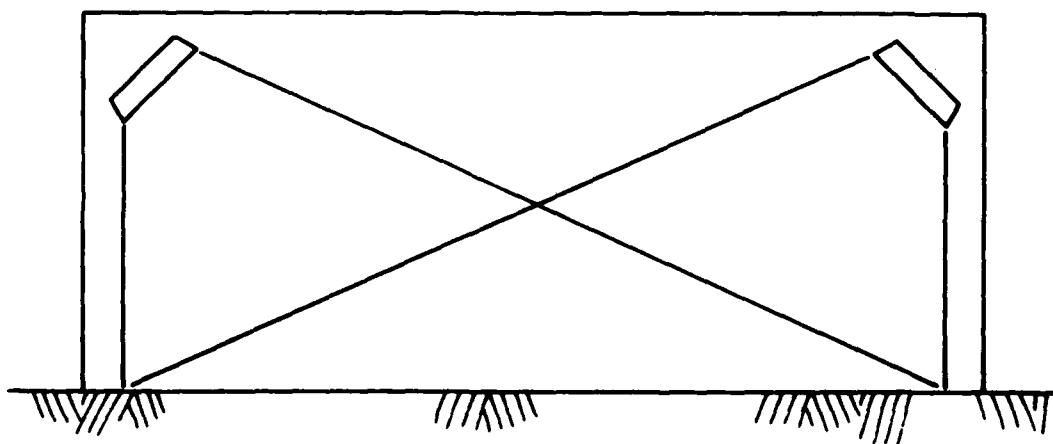


Figure 5. Recommended IR radiant heaters line-of-sight coverage.

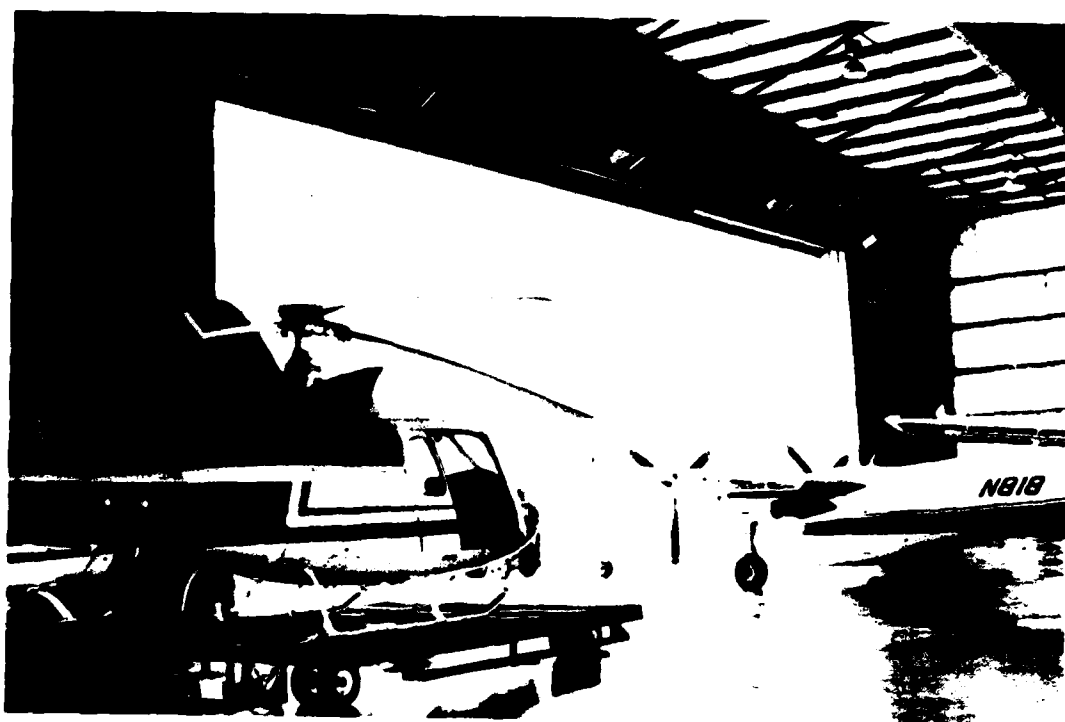


Figure 6. Additional heaters required over hangar doors.

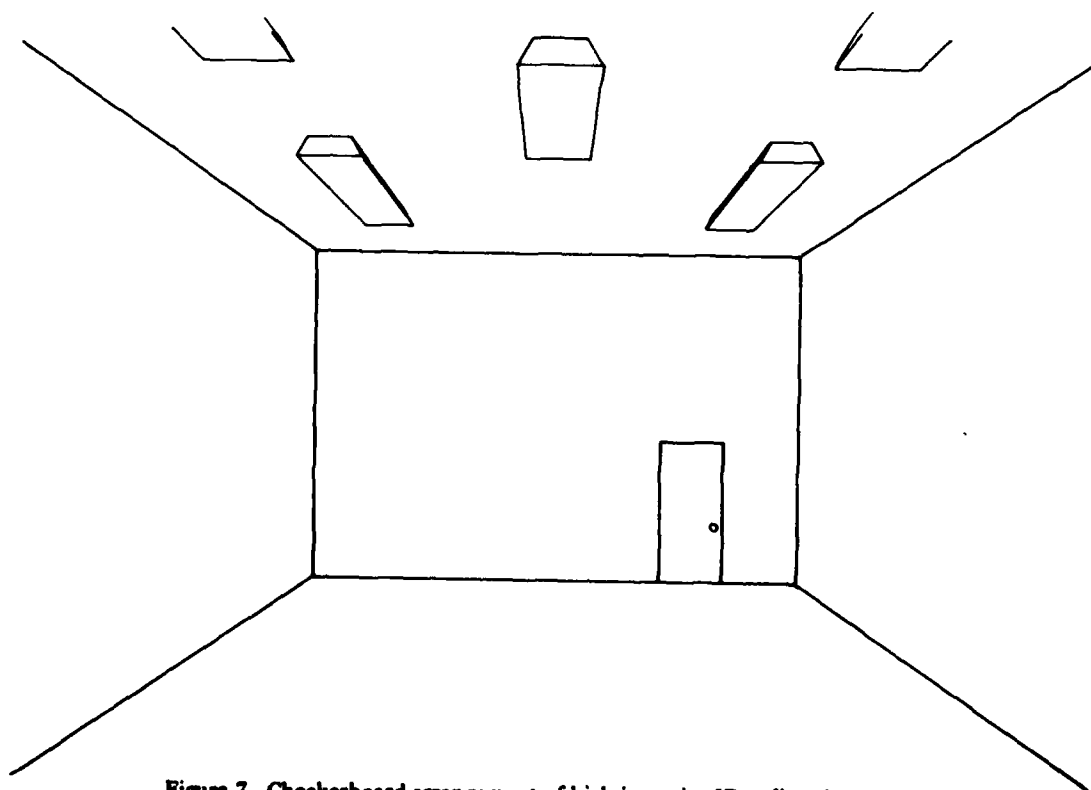


Figure 7. Checkerboard arrangement of high-intensity IR radiant heaters.

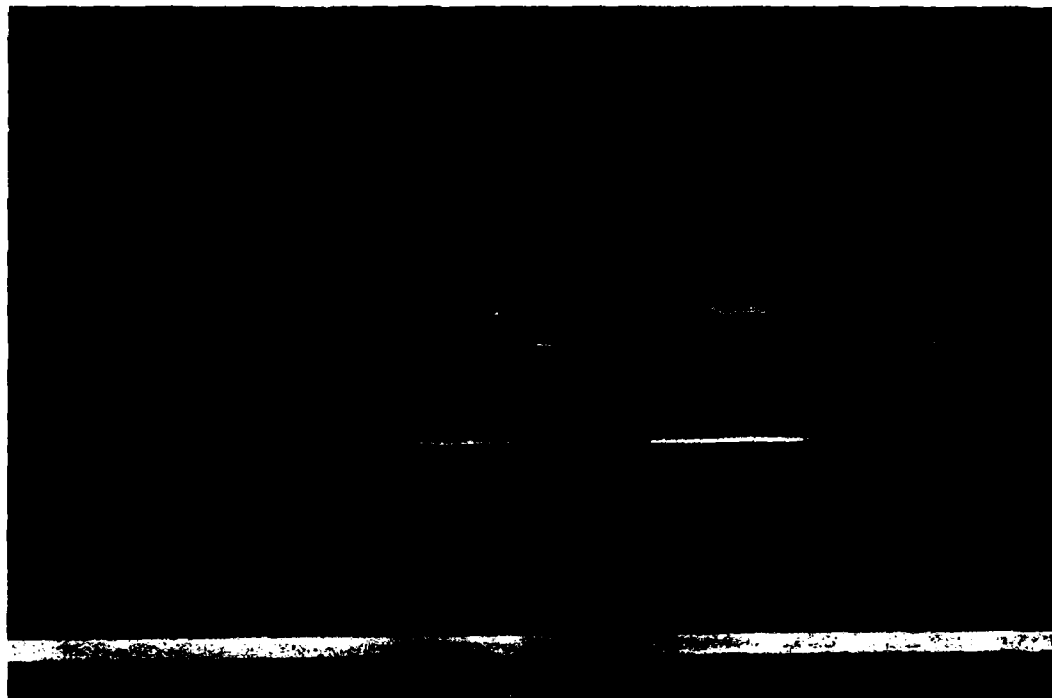


Figure 8. Venting of burners through the roof via exhaust stacks.

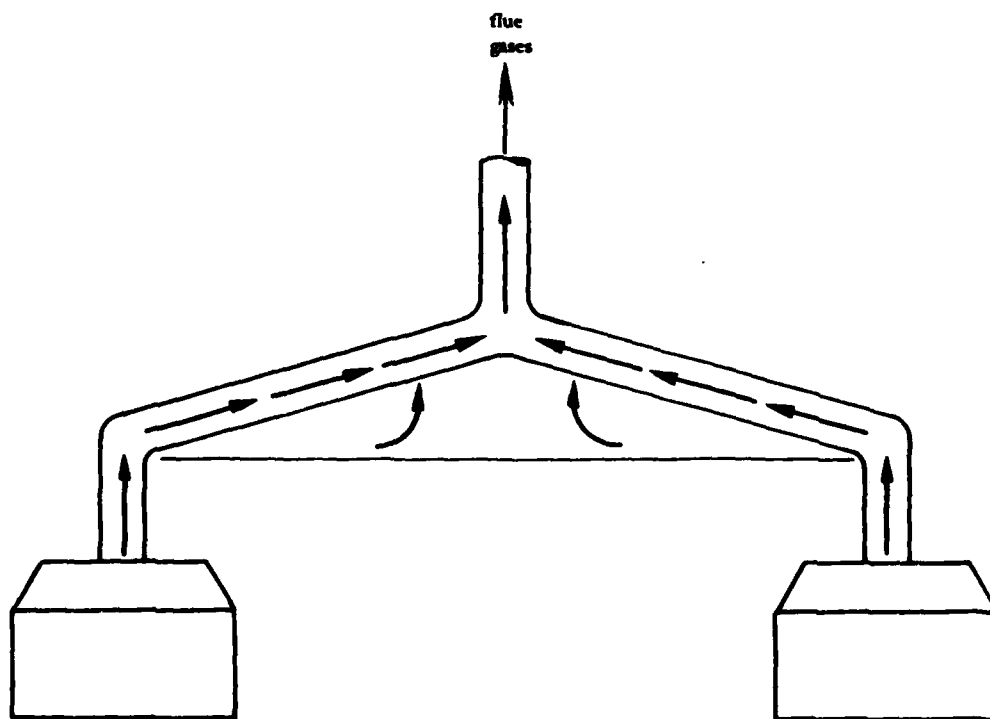
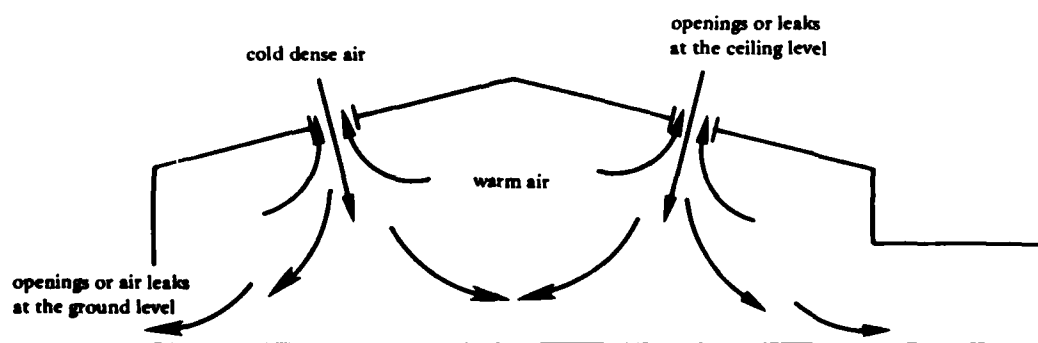


Figure 9. Incline of exhaust stacks to assure continuous rise from the IR radiant burners.



Figure 10. Exhaust fans with spring-loaded draft shutters used to vent the flue gases.



Requirements:

1. Outside air temperature < inside air temperature.
2. Ground level openings > ceiling level openings.

Figure 11. Gravity ventilation.

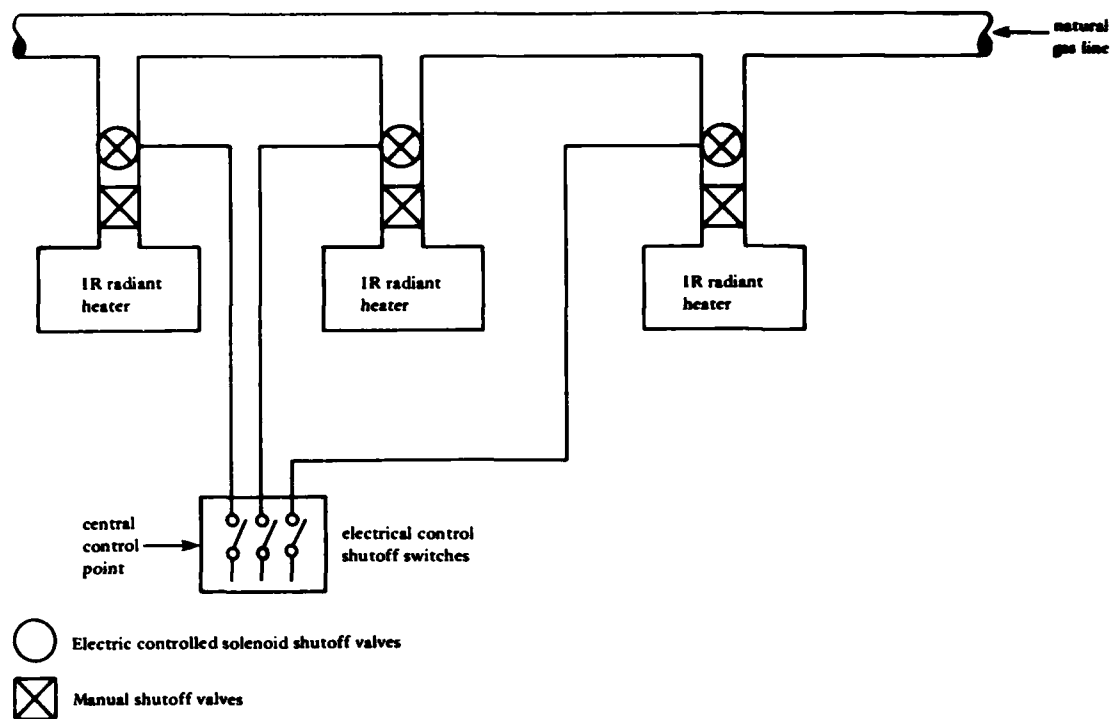


Figure 12. Individual and central shutoff valves to isolate each heater.

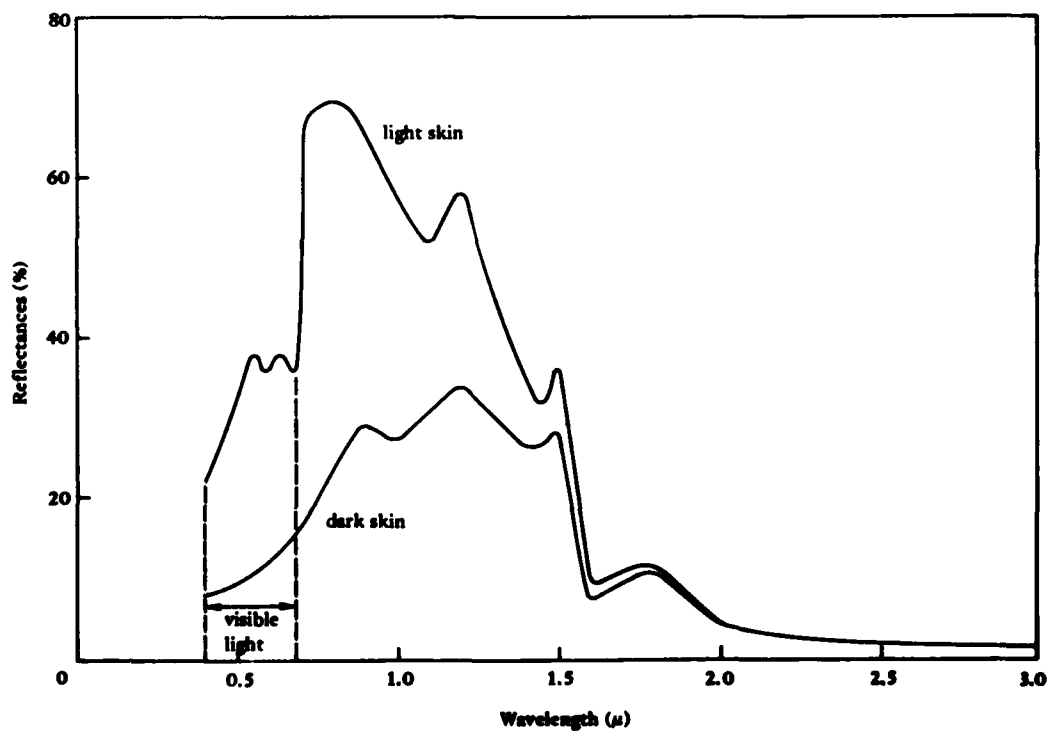


Figure 13. Average spectral reflectance values for human skin (reflectance is the complement of absorptance).

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