USACERL Technical Report FE-93/06
November 1992

US Army Corps
of Engineers
Construction Engineering
Research Laboratory

Issues in the Design of Infrared Radiant Heating Systems

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
November 1992

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Issues in the Design of Infrared Radiant Heating Systems

5. FUNDING NUMBERS
PR 4A162784
PE AT45
TA EB
WU XY1

6. AUTHOR(S)
Jeffrey D. Morton, Linda K. Lawrie, Robert J. Nemeth, Jerry Reed, and Bruce L. Rives

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratories (USACERL)
PO Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
TR FE-93/06

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Headquarters, U.S. Army Corps of Engineers (HQUSACE)
ATTN: CEMP-ET
20 Massachusetts Avenue, NW.
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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14. SUBJECT TERMS
infrared energy
heating equipment and supplies

15. NUMBER OF PAGES
164

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

FOREWORD

This work was performed for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162784AT45, "Energy Conservation"; Technical Area EB, "Energy System Planning, Design and Acceptance"; Work Unit XY1, "Design Guidelines for Infrared Heating Systems." Nash Sood, CEMP-ET, was the HQUSACE Technical Monitor.

The work was conducted by the Energy and Utility Systems Division (FE), Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Jeffrey Morton. Appreciation is expressed to Larry Stillwagon, Energy Engineer, Fort Riley, KS, and Gary Harper, Chief, Mechanical/Electrical Branch, Kansas City District, for their extensive assistance with our investigations. Appreciation is also expressed to James Turner, Kansas City District, and Russell Goering of Fort Riley for sharing their experience with radiant heating system design. Thanks are also due to Mark Imel of Kansas State University, Environmental Control Systems, and the Roberts Gordon Corporation. Dr. David Joncich is Acting Chief, CECER-FE. Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was William J. Wolfe, Information Management Office.

COL Daniel Waldo, Jr., is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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ISSUES IN THE DESIGN OF INFRARED RADIANT HEATING SYSTEMS

1 INTRODUCTION

Background

Radiant heating is an ancient form of supplying heat for human comfort. Earliest forms were camp fires used for comfort, cooking, and security. Today, we have a more sophisticated infrared heating supply with many of the same principles.

Radiation is an important component in maintaining human comfort, though air temperature is usually used as the basic indicator of human comfort. In the 1970s and 1980s, infrared heaters were widely introduced into Army buildings to take advantage of their energy conservation potential. Often, this heating source was introduced at the end of building design as part of Value Engineering.* Radiant systems may require less maintenance, have lower first costs, and have been advertised as more energy conserving than conventional heating systems.

Though operations and maintenance personnel at the Army installations were pleased with radiant systems, designers felt that the energy conservation benefits of radiant systems had not been proven. Thus, an investigation was undertaken by the U.S. Army Construction Engineering Research Laboratories (USACERL) under the Facilities Technology Applications Test (FTAT, now known as the Facilities Engineering Applications Program [FEAP]) program. This investigation looked at facilities at Fort Riley, KS which had both conventional heating and radiant heating systems.

This report focuses on gas-fired indirect infrared radiation units, particularly tube-type appliances. This restriction applies since most of this research is based upon a multiyear field test of these types of units at Fort Riley. The Fort Riley investigation uncovered several operational issues, revealing that little design guidance was issued from Army sources to their designers. A Research, Development, Test, and Evaluation (RDT&E) work unit was formed to further investigate how designers should analyze and specify radiant systems.

Objectives

The objectives of this project were to explore the energy conservation possibilities of radiant heating systems in Army applications and to produce a lessons learned document that would recommend design guidance for applying radiant systems.

Approach

The work progressed through the following steps:

1. Army installations were surveyed to identify places where radiant systems had been applied and where possible comparisons between radiant and conventional systems might be monitored.

*Value Engineering is a program that rewards contractors for approved suggestions that lower costs or operational expenditures.

2. Fort Riley, KS, was selected as the site for the field test.

3. Using two nearly identical buildings, one with a conventional heating system and one with a radiant system, automated data collection equipment was installed in each building to record significant energy consumption, and thermal environment building dynamics parameters (air temperature, air velocity, dew point temperature, globe thermometer temperature, fan/door status, air stratification temperatures, and total energy consumption).

4. Starting in the winter of 1987-1988, 3-minute and hourly energy use data were collected from the two buildings.

5. Observations of correctable operational measures were observed, changed, and further collection was done in the winter of 1988-1989.

6. In fiscal year 1991 (FY91), the RDT&E work unit was funded for 1 year to incorporate both the lessons learned from the field test and current design practices.

Scope

This report is not itself a design guide. However, it does formulate preliminary design lessons that could later be used in creating a specific guidance for radiant heating systems.

Mode of Technology Transfer

Information from this study will be put in a Facilities Engineering Applications Program (FEAP) decision paper, published in the *DEH Digest*, and disseminated through Energy Awareness Seminars. Design information will be distributed in the *Engineering Improvement Recommendations System (EIRS) Bulletin*.

2 PRINCIPLES OF INFRARED RADIANT HEATING

History of Radiant Heating

Radiant heating, in various forms, has been used for centuries. The simplest form is the familiar fireplace. The ancient Romans devised a more sophisticated form of radiant heating by forcing flue gases from a fireplace through a channel under the floor before exiting from a stack on the opposite side of the building. Infrared radiant heating is a much more recent development. The infrared band of electro-magnetic radiation was discovered in 1800 by the English astronomer Sir William Herschel, who used a thermometer to measure the heat given off by each part of the spectrum when sunlight is diffused from a prism. He discovered that the blue part of the spectrum offered the least heat, and that the temperature rose as he moved to the red part of the spectrum. The highest temperature is actually reached past the red part of the spectrum (the infrared band).

Theory regarding high temperature surfaces or catalytic combustion for heat transfer was first developed by two Englishmen in the early 1900s. Professor W.A. Bone developed a theory for flameless incandescent surface combustion, and H.H. Gray reviewed this theory and presented one of his own. Technical development of systems based on surface combustion theory reached a peak in 1917 when 14 patents were issued for such devices.[1] Interest in the field tapered off until after World War II, when research rebounded. In 1956 Guenther Schwank developed a porous ceramic infrared burner, which was licensed to an American manufacturer, and many new manufacturers of infrared burners appeared.[2] At about that same time, another U.S. company, Roberts-Gordon, pioneered the concept of gas-fired infrared radiant tube heaters.[3] Over a 15-year period from about 1953 to 1968, the number of manufacturers producing infrared heaters for building heating increased from one to a total of 18.[4] Today there are fewer than 18 manufacturers of infrared radiant tube heating equipment. The field of radiant heating is broad, and even within the narrower context of infrared radiant heating, there are significant subtypes.

Types of Radiant Heat

There are three well known modes of heat transfer. *Conduction* is the transmission of heat through solids via transfer of kinetic energy from molecule to molecule. *Convection* is the transfer of heat by mixing one part of a fluid with another. If the mixing is entirely due to a difference of density in the fluid masses because of a difference in temperature, the phenomenon is called natural convection. If the motion of the fluid is caused by mechanical means, it is called forced convection. *Radiation* is the transfer of heat via electromagnetic waves emitted by any hot body. Heat transfer by radiation differs from that of convection and conduction in that matter is not required as a heat transfer medium. The transfer of heat is direct, from the high temperature body to the lower temperature body, even through a vacuum. When the radiation hits the lower temperature body, the energy from the wave causes a rise in temperature of the absorbing body through an increase in molecular activity.

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[1] D.W. DeWerth, *Literature Review of Infra-red Energy Produced With Gas Burners*, Research Bulletin 83 (American Gas Association Laboratories, May 1960), p 1.

[2] D.W. DeWerth, p 2.

[3] Roberts-Gordon, Inc., *Sir Wm Herschel Infrared Handbook* (Roberts-Gordon, Inc., Buffalo, NY, 1990), p 1.

[4] Fred J. Prince, "Infrared Heating for Overall Comfort," *ASHRAE Journal* (American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE], Atlanta, GA, December 1968), p 57.

Radiant heating is then any form of heating where the dominant mode of heat transfer is by radiation. Conduction and convection still play important roles in spaces where radiant heating is employed, but they are secondary modes of heat transfer in such systems. Radiant heating systems may be broadly categorized into three types. *Low temperature* or panel systems operate in the temperature range from 120 °F (49 °C) to 350 °F (177 °C). *Medium temperature* or low intensity systems operate in the 500 °F (260 °C) to 1500 °F (816 °C) range. *High temperature* or medium to high intensity systems operate at temperatures above 1500 °F (816 °C). High temperature radiant heating units are generally open flame devices, often with incandescent ceramic faces. Medium temperature units operate below incandescent temperatures, and are generally indirect fired units, such as those with heated tube emitters. Low temperature radiant heating is typically done with large heated surfaces, often floors, or wall or ceiling panels. It is important to note that the temperature ranges used to delineate these three categories of systems will vary from reference to reference. The values given here were selected as typical. Also, while there are various radiant heating systems for industrial applications (such as drying processes, etc.), this report focuses only on space-heating applications, for which some typical system types have been identified.

Low temperature radiant heating systems typically available for space heating include hydronic floor panels, electric floor panels, air floors, hydronic ceiling panels, electric ceiling panels, hydronic wall panels, and electric wall panels. Hydronic floor panel systems typically consist of pipes embedded in a concrete floor through which heated water is circulated to maintain a maximum floor temperature of about 85 °F (29 °C). Hydronic floor panel systems are generally best suited for applications where large changes in heating load do not occur over a short time since transient responses are slow due to the thermal mass of the floor. Electric floor panels have the same operating characteristics and application as hydronic floor panels, only instead of water in pipes to provide the heat, electric heating elements are used to heat the floor. Air floors use a third method to provide heat to the floor, that of circulating heated air from a furnace through passageways in the floor. The surface temperatures are the same as those for other floor systems, and transient response is still slow. Hydronic ceiling panels may be exposed modular metal panels laid in or suspended from the ceiling, or they may be tubing attached to the ceiling and covered with plaster. Hot water is circulated through the panels to produce a surface temperature between 120 °F (49 °C) and 180 °F (82 °C). The transient response time for hydronic ceiling panel systems is much shorter, so they may be used in applications where rapid load changes in the space are encountered. Electric ceiling panels are composed of various types of heaters sandwiched between the ceiling surface material and an insulated back on the panel. These systems operate in the same temperature range as their hydronic counterparts, and also respond quickly to changes in load in the space. Hydronic wall panels are constructed similarly to hydronic ceiling panels. Wall panels are used in place of ceiling panels where interference with lighting or other fixtures is a problem. Hydronic wall panels have the same operating characteristics as the ceiling panels, only more heated panel area is required than for ceiling panels, and surface temperatures must be limited if there is the possibility of contact with people. These same relationships hold true for electric wall panels with respect to their ceiling counterparts.

Medium temperature space heating appliances include gas-fired radiant tube infrared heaters, and some electric infrared units. Gas-fired radiant tube appliances consist of a combustion chamber where gas and air are burned and the products of combustion are then forced through a section of tubing and exhausted to the outdoors. The hot tube provides the radiant energy source (thus the name radiant tube). These units are also fitted with various types of reflectors and/or deflectors to direct the radiant energy toward the floor, and not onto exterior walls or the ceiling. These units may either have a U-shaped or linear tube, and are operated in on-off fashion. During operation, tube temperatures vary from 500 °F (260 °C) to 900 °F (482 °C) along the length of the tube. They can adapt rapidly to changing loads in a space and have a larger radiating surface than other types of gas-fired infrared units. Medium temperature electric infrared appliances use panels as their radiant energy source, which have a surface temperature from 200 °F (93 °C) to 1100 °F (593 °C). These units are typically used for direct spot heating of the space occupants, objects, or surfaces.

High temperature units include gas-fired radiant porous refractory surface infrared units and other types of electric infrared units. The gas-fired radiant porous refractory surface infrared appliances burn a mixture of air and gas through a porous refractory material to produce the high temperature radiant energy source. These units are unvented, so the products of combustion are placed in the space being heated. Some units include focusing devices to direct the heat to particular locations at a higher intensity. These units operate in a temperature range from 1500 °F (816 °C) to 2000 °F (1094 °C). Electric infrared units use metal rods, quartz tubes, or quartz lamps as their source of radiant energy. Metal rod and quartz tube units operate at surface temperatures between 1500 °F (816 °C) and 1800 °F (982 °C). Quartz lamps operate at a surface temperature of about 4000 °F (2204 °C). Both the gas-fired and electric units of this type are designed for space heating applications in large volumes where only the people, objects, and surfaces to be heated receive radiant energy (spot heating). Such units provide heat instantly when called upon to heat an occupant or object in their area of coverage.

Gas-fired infrared heating appliances operate in the medium and high temperature range. Gas-fired infrared units are generally considered to be either high intensity or low intensity appliances, the distinction being the temperature range in which the radiation source is operated (above or below incandescence, respectively). In many respects, this method of classification is unfortunate. For example, some practitioners will call any infrared application "high intensity" without indicating whether they are referring to "radiant" systems in general or "infrared" systems. While it may be true that tube-type heaters deliver more intense heat energy than do heated floor slabs, they are still low intensity infrared heaters. In the absence of better definitions, caution should be used when reviewing literature on radiant heating applications, as there is much inconsistent use of terminology.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has outlined three specific types of gas-fired infrared heaters:[5]

1. *Indirect infrared radiation units*, or indirect fired units, or Type 1 units for short. These units burn a gas-air mixture within the radiating elements and have a radiating surface interposed between the combustion products and the load. Operation temperatures are up to 1200 °F (650 °C). The units may be comprised of tubes or panels, and they may have metal or ceramic components. Type 1 units can be further classified into three subtypes. Type 1(a) units are those that have an atmospheric burner and vent combustion products through a vertical flue arrangement. Type 1(b) units may have multiple burners possibly with eductors operating in a horizontal tube arrangement. Type 1(c) units use a single forced draft burner, also in a horizontal tube. Type 1 units are usually vented (i.e., the combustion products are not released to the space).

2. *Porous matrix infrared radiation units*, or direct-fired (or Type 2) units burn a gas-air mixture in a refractory material, which may be porous ceramic, drilled port ceramic, stainless steel, or a metallic screen. This refractory is in an enclosure with an open face exposing the refractory to the load. The gas-air mixture is brought into the enclosure and through the refractory where it is burned. Due to the porous nature of the refractory, combustion is even across its face. The flame on the surface of and receding into the refractory material heats it, thus providing the radiant energy source.

3. *Catalytic oxidation infrared radiant units*, or simply catalytic (or Type 3) units are similar to the direct-fired units. The major difference is that the refractory material is usually glass wool and the

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[5] 1988 *Equipment Handbook* (ASHRAE, 1988), pp 29.1 - 29.2.

radiation source is a catalyst that induces oxidation without a visible flame. Figure 1 illustrates the various types of infrared radiant heaters as defined by ASHRAE.

There are distinctions to be made beyond the ASHRAE classifications of indirect-fired (Type 1) units. For example, Roberts-Gordon asserts that the ASHRAE infrared heating appliance types do not adequately reflect the products that have come to the market place. "The result is that the industry has moved beyond these definitions by introducing new appliances that fall into more than one of these categories. In addition, ASHRAE has not yet developed a way for the engineering community to distinguish between appliance performances within a category or between categories."[6] The problem lies in the fine distinction between Type 1(b) and Type 1(c) appliances.

The ASHRAE specification states that Type 1(b) appliances are *usually* vented and *may* require eductors (e.g., vacuum pumps to evacuate the exhaust). Some indirect-fired tube type units are installed without being vented, that is, they exhaust to the interior space. Also, the ASHRAE classification scheme makes no distinction between the type of eductor used. While some Type 1(b) units use vacuum pumps to evacuate combustion products, most Type 1(b) and 1(c) units do not use a vacuum assist, but

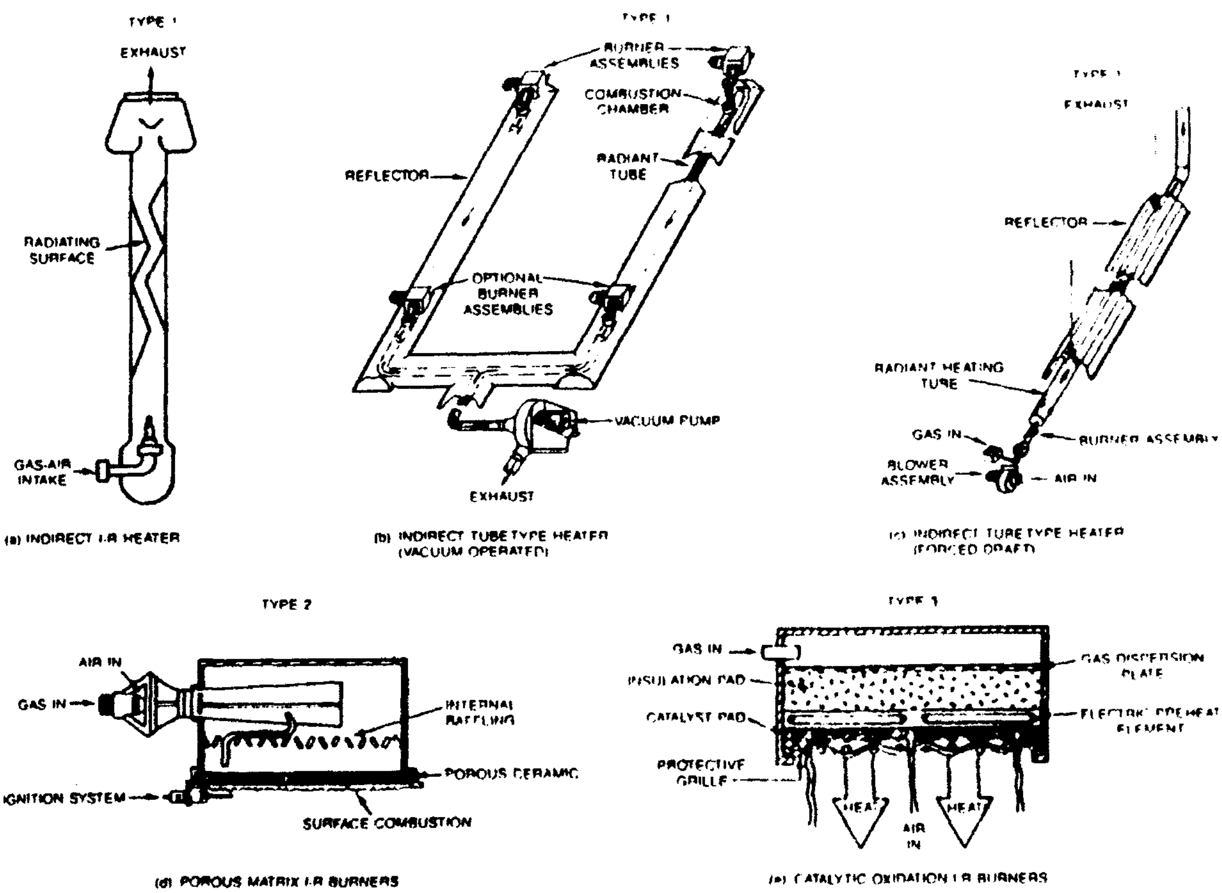

Figure 1. Types of Gas-Fired Heaters. (Reprinted with permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, from the 1988 ASHRAE Handbook - Equipment.)

[6] Roberts-Gordon, Inc., p 12.

rather are forced draft systems. In addition, no distinction is made in the ASHRAE scheme as to the exiting condition of the exhaust gases. Some appliances exhaust at a lower temperature such that there is condensate in the exhaust products (condensing units). Other units do not have a sufficient run of radiant piping for the gases to cool and are noncondensing units. A condensing unit will have a higher combustion efficiency than a noncondensing unit by virtue of its lower stack losses. Generally, Type 1(b) appliances are thought of as condensing, and Type 1(c) are thought of as noncondensing. Another distinction between the two types is implied by the ASHRAE drawing but not stated in the text. That distinction is that type 1(b) units use multiple burners in a run of tube and are site assembled, whereas Type 1(c) units use one burner on a set length of tube that is all factory assembled. However, products currently exist in the marketplace that are a hybrid of these two types. For example, multiple units that would be considered Type 1(c) in that they do not have multiple burners and are noncondensing may be field assembled on a common exhaust. This arrangement is less efficient than a Type 1(b) system with multiple burners, having an efficiency more like a Type 1(c) unit. However, this arrangement can be installed instead of the desired Type 1(b) system if contract specifications are not carefully or clearly written. Also, multiple burner appliances can be non-condensing units, lower in combustion efficiency than other condensing multiple burner units. Other variances in market offerings exist that are not readily delineated by the ASHRAE classification scheme. This discussion does not imply that the ASHRAE classification is not useful, only that it is not all-inclusive and that the potential user of infrared heating products should look further before making decisions.

Theory of Operation of Low-Intensity Infrared Heaters

The operation of infrared radiant heaters can be described in terms of physical equations, most of which are well known. Infrared radiation differs in no way from other forms of electromagnetic waves except for wavelength. For all forms of electromagnetic radiation including light and infrared waves, the relationship between velocity, frequency, and wavelength is given as:

$$c = f\lambda \qquad \text{[Eq 1]}$$

where f denotes frequency, λ denotes wavelength, and c is the velocity of light, a constant (186,000 mi/sec or 2.998×10^8 m/s). Infrared radiation is defined as the band of radiation between the frequencies of 0.7 micrometers (μm) to 400 μm. This band is sometimes further subdivided in the literature into near infrared radiation (0.7 to 2.7 μm) and far infrared radiation (2.7 μm to 400 μm). Figure 2 illustrates the relationship to wavelength of various forms of electromagnetic radiation.

When heat transfer by radiation is considered, the derivation of the physical equations is based upon the principle of a *blackbody*. A blackbody is an ideal surface with the following properties:

1. A blackbody absorbs all radiation incident upon it.
2. For a given temperature and wavelength, no surface can emit more energy than a blackbody.
3. The blackbody is a diffuse emitter. That is, radiation emitted by the blackbody is independent of direction.[7]

[7] F.P. Incropera and D.P. DeWitt, *Fundamentals of Heat Transfer* (John Wiley and Sons, New York, 1981), p 557.

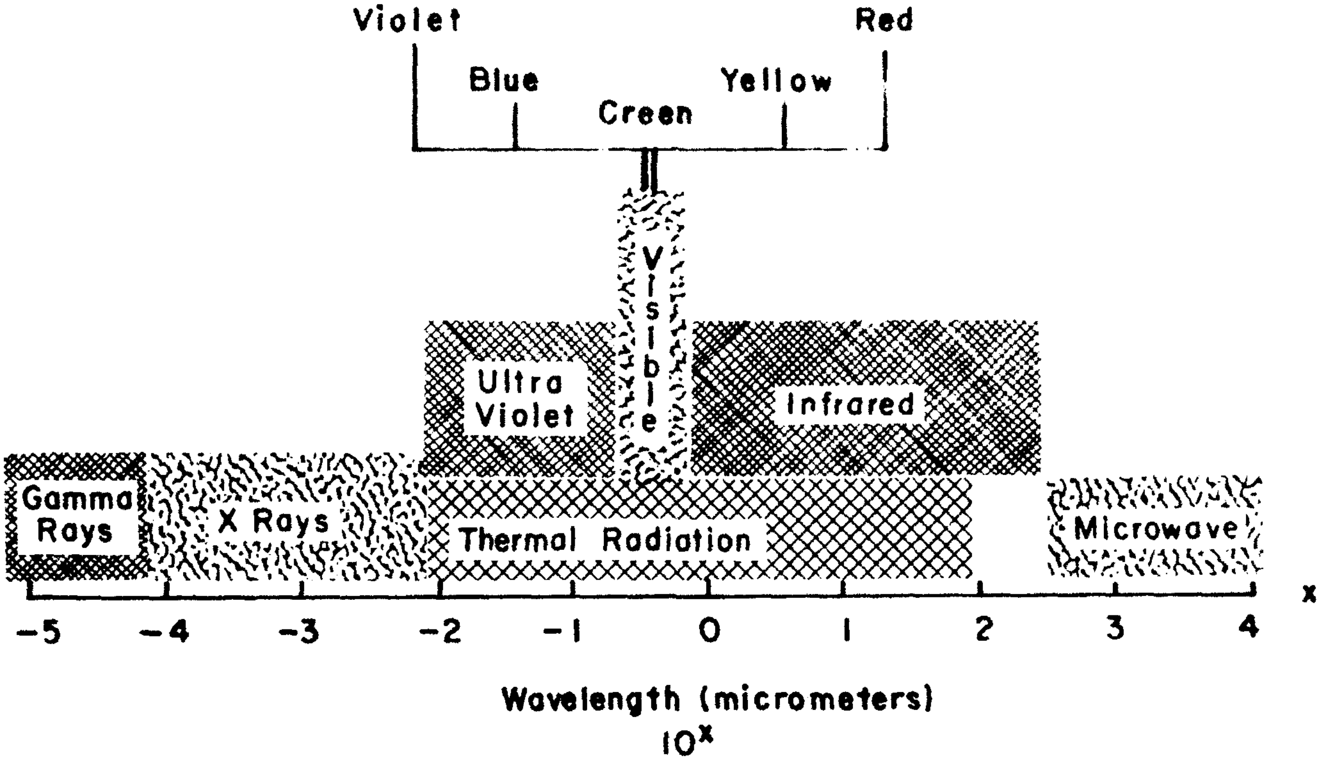

Figure 2. Spectrum of Electromagnetic Radiation.

The blackbody is a conceptually perfect absorber and emitter. The radiative properties of all actual surfaces are defined with respect to the blackbody. The amount of radiation emitted by a blackbody is given by the Stefan-Boltzman law:

$$E_b = \sigma T^4 \qquad \text{[Eq 2]}$$

where σ is the Stefan-Boltzman constant, whose numerical value is 0.173×10^{-8} Btu/hr·ft^2·°R^4 (5.670×10^{-8} W/m^2·K^4), and T is absolute temperature (in °R or K). The Stefan-Boltzman equation gives the total emission from a blackbody summed over all wavelengths. Any source of radiation will emit energy composed of an infinite number of wavelengths from the shortest to the longest. The wavelength of the maximum intensity is a function of temperature, and may be determined using Wien's displacement law:

$$\lambda_m T = b \qquad \text{[Eq 3]}$$

where b is the Wien displacement constant, 5290 microns·°R (0.2898 cm·K). Similarly, the spectral distribution of radiant intensity is given by Plank's Law, which will not be reproduced here. Also, radiant energy may be polarized and is found to be weaker with the inverse square of the distance from its source.

To consider radiant heat exchange between real objects, one must also consider some factors relating to the behavior of the objects (or surfaces) involved. Three related factors that are important to radiant heat exchange are the dimensionless parameters of: (1) absorptivity (α), (2) reflectivity (ϱ), and (3) transmissivity (τ). *Absorptivity* is that fraction of the incident radiation that is absorbed by the object. *Reflectivity* is the fraction of the radiation that is reflected by the object. *Transmissivity* is the part of the radiant energy that passes through the object. By taking an energy balance about an object receiving thermal radiation, it is obvious that:

$$\alpha+\varrho+\tau = 1 \qquad [\text{Eq } 4]$$

Most materials are opaque to infrared radiation. That is, for waves in the infrared range, no energy is passed through ($\tau = 0$). Therefore, when considering infrared energy, the above equation can be simplified to:

$$\alpha+\varrho = 1 \qquad [\text{Eq } 5]$$

A fourth dimensionless parameter, not directly related to the above three, is *emissivity* (ε). Emissivity is defined as the ratio of radiation emitted by a surface, to that radiated by a blackbody at the same temperature. Note that all four of these parameters can be considered in terms of total radiation, or with regard to directional and spectral effects.

The fact that absorptivity has a spectral (wavelength) dependence is significant to radiant heating. Recall that all radiant emitters produce waves of an infinite number of wavelengths. That is, any radiation emission is a continuous, nonuniform distribution of monochromatic (single-wavelength) components.[8] It is known that one can find the wavelength of maximum emission using Wien's displacement law. Certain materials will absorb more radiation of a given wavelength than they will other wavelengths. The most familiar example of this phenomenon is in the visual spectrum. An object that appears red has more affinity for light of the wavelengths associated with blue, green, and every other color, so those wavelengths are absorbed. For light in the red part of the spectrum, absorptivity is low and reflectance is correspondingly high. Thus, the object appears as red. The same principle applies for thermal radiation. Materials whose absorptivity favor a certain wavelength will become warmer when exposed to that wavelength. Therefore, it is important to select the wavelength of the radiant energy source according to the preference of the materials being heated. The American Gas Association and others have published values for absorptivity for various materials for given wavelengths.[*] Examination of those values reveals that materials commonly found in infrared radiant heated space (concrete, wood, etc.) tend to absorb wavelengths associated with a 900 °F (482 °C) emitter (about 3 to 6 μm) better than other parts of the infrared range. Therefore, low intensity infrared heaters are well matched by wavelength for most of space heating applications. Industrial processes or some space heating applications that feature a preponderance of materials with maximum absorptivity at different wavelengths will require a different radiant heating source. Another important fact about absorptivity is that air is a poor absorber of infrared radiation. Therefore, the effect of direct radiant transfer of energy to the air is negligible.

Reflectivity also has spectral properties. For infrared energy, the spectral effects for reflectivity are negligible. Infrared energy, like other long-waved energy, is called "colorblind" to reflect this fact.

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[8] Ronald H. Howell, *A Study to Determine Methods for Designing Radiant Heating and Cooling Systems*, ASHRAE Report RP-394 (ASHRAE, 1987), p 18.

[*] Tables of absorbtivity values are widely published in textbooks and technical manuals on thermal radiation; also see DeWerth.

Recall that radiant heat energy behaves like other electromagnetic waves in that it travels line-of-sight. For heat exchange to occur between two surfaces, one surface must be able to "see" the other. The discipline of heat transfer employs the quantitative factor known as the *view factor* or *configuration* or *shape factor* to describe this behavior. The view factor is a geometrical quantity that indicates the amount of radiation that leaves one surface and reaches another. One important property of view factors is that of reciprocity, given by the *reciprocity relation*:

$$A_iF_{ij} = A_jF_{ji} \tag{Eq 6}$$

where A_i is the surface area of object i and F_{ij} is the view factor from object i to object j, etc. Eq 6 and Eq 2 show that the radiant heat transfer between two black surfaces is given by:

$$q_{ij} = A_iF_{ij}\sigma(T_i^4 - T_j^4) \tag{Eq 7}$$

However, actual surfaces are not blackbodies; they require a more complex calculation. Since the design of an infrared heating system does not require such detailed calculations, further development of those equations will be deferred to the heat transfer texts. The development of Eq 7 shows the major considerations in applying radiant heat exchange.

Another basic concept that must be developed before addressing comfort issues in radiant heating is mean radiant temperature. The *mean radiant temperature* (MRT) is a theoretical temperature at which an occupant contained in a black enclosure would exchange the same amount of heat by radiation as in an actual nonuniform surface temperature environment. MRT can be calculated by using Eq 8:

$$MRT^4 = T_1^4F_{o-1} + T_2^4F_{o-2} + \ldots + T_n^4F_{o-n} \tag{Eq 8}$$

where F_{o-y} denotes the view factor from the occupant to surface y, and T_x implies the temperature of surface x. The mean radiant temperature is a conceptual abstraction that has proven to be useful when trying to quantify comfort considerations.

Related to MRT is another conceptual temperature, the *operative temperature* (T_o). The operative temperature is a theoretical temperature at which an occupant contained in an enclosure would exchange the same amount of heat by radiation *and* convection as in an actual nonuniform surface temperature environment. Operative temperature is found using Eq 9:

$$T_o = \frac{[(h_c \times T_a) + (h_r \times MRT)]}{(h_c + h_r)} \tag{Eq 9}$$

where h_c and h_r are the convective and radiant heat transfer coefficients for the occupant, and T_a is the ambient air temperature. Operative temperature is an indicator of the total heat sensation due to both convective and radiative effects. An alternate definition of operative temperature is the average of the ambient temperature and MRT, weighted by the convective and radiant heat transfer coefficients, respectively.

As is the goal with any space heating system, infrared radiant heating systems seek to provide comfort. How to quantify comfort is still somewhat of an open question in facility engineering to date. The Fanger Comfort Equations[9] are based upon the notion that comfort is defined by a state of neutral temperature sensation. Four principal environmental parameters help determine comfort conditions: (1) the ambient air temperature (T_a), (2) relative humidity (RH), (3) relative air velocity (V), and (4) MRT. Two other comfort parameters relate to the occupant as well: the metabolic rate for persons at their given activity level (MET), and the thermal resistance of the clothing they are wearing (CLO). Comfort models and their applications are not straightforward. In general, for a given activity level and clothing weight, the air temperature (T_a) required for comfort goes down as the MRT increases.[10] This relation is of particular interest when considering radiant heating options.

[9] P.O. Fanger, *Thermal Comfort* (McGraw-Hill, New York, 1972).
[10] ASHRAE Handbook of Fundamentals (ASHRAE, 1989).

3 COMMERCIAL INFRARED HEATERS

Claims Arising From Principles of Operation

It is readily apparent that radiant heating systems operate on a different set of principles from convective heating systems. Manufacturers use these differences to highlight purported advantages of radiant heating over conventional heating systems. Typical manufacturer's sales literature might tout the following:

- Energy savings
- Lack of stratification
- Immediate warmth
- Quiet operation
- Low maintenance
- Uniform heating
- Comfort
- Less heat loss
- No dirt and dust particles
- Comfort at lower temperatures
- Easy installation
- Space efficiency.

These sales claims are supported by the principles that govern radiant heat transfer. The most popular claim (and sales point) is that of reduced energy consumption over convection systems. Advertising for radiant heating claims as much as a 75 percent savings in energy consumption over convective systems. One reason for this claim is that radiant heat can maintain space at comfortable conditions at lower air temperatures. Recall that to have comfortable conditions with convective heating systems, the air temperature and MRT are generally the same.[11] For a sedentary person wearing medium weight clothing, if the MRT is 80.6 °F (27 °C) then the air temperature should actually be lowered to 72 °F (22 °C) to maintain comfort (p 31). The corresponding temperature for comfort when air temperature equals the MRT is 76.5 °F (24.7 °C). As the MRT is increased, the corresponding air temperature required for comfort is further reduced. Figure 3 illustrates this relationship. Lower interior air temperatures imply a lower temperature difference between the conditioned space and the ambient air, and thus lower energy losses through the building envelope. That is, transmission losses through the walls are reduced. Another reason that less heat should be lost through the walls is that radiant energy is directed, and will heat only objects within the path of the radiation. Properly installed tube-type infrared heaters are equipped with reflectors (and/or deflectors) that prevent direct radiation to the walls. These claims of lower heat loss form the basis for claims of energy savings.

Another common claim is that radiant systems eliminate thermal stratification problems. Thermal stratification refers to the situation where the warmest air is at the top of the building near the ceiling, while cooler air is found at the occupied levels. The argument goes that since warm air rises, convection systems are prone to stratification problems. Radiant heater manufacturers claim their systems are much less prone to this problem because infrared radiation does not heat the air, but rather, the objects at which the rays are directed. Since the air is not directly heated, warm air will not rise to the ceiling to cause the stratification effect. There are two direct benefits to reducing stratification. First, the heat remains where needed, at the occupant level, making the heating system more effective. Second, the temperature at the roof level is lower, thus reducing losses through the roof. One would expect these claims to be true to some extent, but it should be remembered that the heated objects in the space will release heat via convection, therefore the air in the space *is* heated by the radiant system, although to a lesser extent. Warm air rises regardless of heating system type. The stratification question is one of degree.

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[11] Ronald H. Howell, p 31.

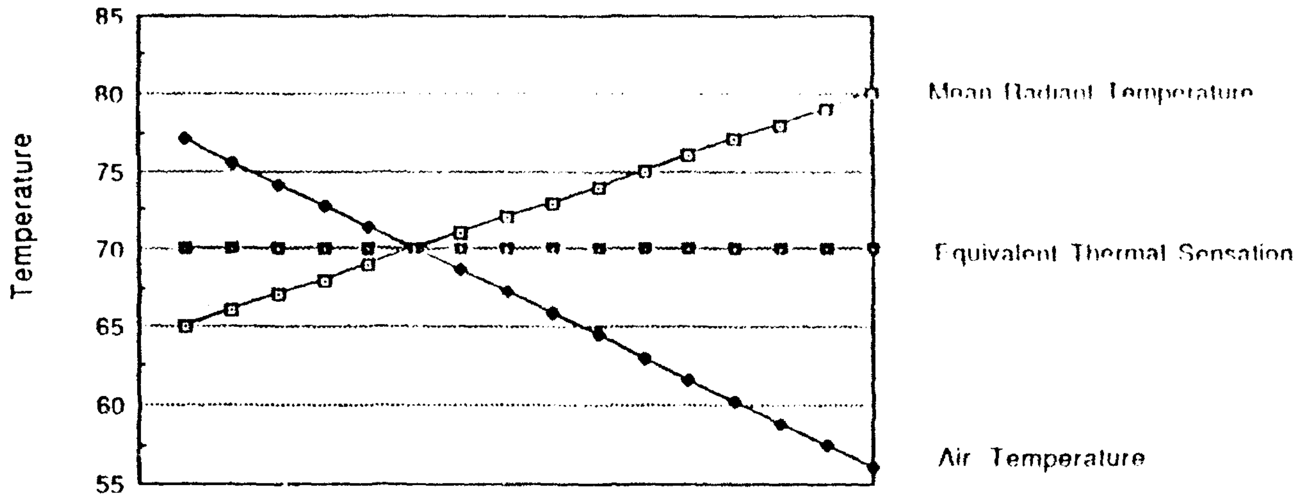


Figure 3. Relationship of MRT and Ambient Air Temperature for Comfort.

Vendors of radiant heating equipment claim their systems provide more immediate warmth than convection units. The claim goes something like this: When you use a convective system, you need to heat all of the air in the entire space before occupants become comfortable. With a radiant system, as soon as the unit is fired, occupants can feel the heat being transferred to them and are comfortable much sooner. The basis for this claim is the fact that radiant energy travels line of sight, and at the speed of light. Anyone who has ever walked under a running radiant heater has felt this sensation of warmth, even when the air temperature is relatively low. This is the same sensation one gets when walking in strong sunlight on a cool day. Whether this warm feeling caused by direct heat transfer from a radiant heater makes an occupant *completely* comfortable is an open question.

Four claimed advantages arise out of the fact that no mechanical ventilation is required, nor is it being provided, by the radiant system. First, absence of fans means that radiant units are quieter. There may be noise from the tube-type infrared system's eductor, but that noise is thought to be considerably less than that of conventional fans. Second, since there are no fans, there is no need to maintain fan motors, belts, bearings, and air filters. Third, the lack of forced convection in the space reduces the transport of airborne dirt and dust particles. Finally, radiant systems require no air-handling units. Thus, manufacturers claim radiant heaters save building space. A corollary claim is that the less bulky radiant heaters are easier to install than other types of unit heaters.

Theoretically, a radiant heating system will provide more uniform heat than alternative systems since the transfer of heat does not rely on air in the space. Therefore, the presence of warmer or colder air masses does not affect comfort to the same extent as it would with a convection system. Also, since heat transfer is quicker, there should be less fluctuation of comfort sensation. Both of these conditions depend on proper radiant coverage of the space, i.e., using an efficient radiant pattern. Note that these claims depend more on the design of the overall radiant heating system than on the appliance itself.

The first cost of a radiant system is less than the first cost of a convection system. Manufacturers claim that the lower operating and maintenance costs of radiant systems, combined with their low first costs enable radiant systems to pay for themselves in a shorter time than convection systems. On a purely cost basis, this claim may justify replacement of an existing convection system.

Most manufacturers' claims are based on the theory of heat transfer. As with any advertising claims, potential buyers must be wary of overstated claims. Most manufacturers can substantiate some of their claims with experience and data. Such substantiated data must be separated from the sales presentation for use in a sound scientific comparison of heating methods. This report will include examples of unbiased data and experience from a multiyear field test.

Current U.S. Manufacturers of Radiant Heating Equipment

Relatively few manufacturers make gas-fired, tube-type, low-intensity infrared heaters. Table 1 lists 10 manufacturers compiled from a search of the Thomas Register, correspondence with Underwriters Laboratories, Inc., and references to the "1991/92 HPAC Info-dex."[12] Each of these sources compiled a list of gas-fired, tube-type, low-intensity infrared heater manufacturers. These lists were reconciled to produce the table presented here.

Although the number of firms that manufacture these heaters is relatively small, the number of firms that market them is sizable. Manufacturers establish distributors in different locations throughout the United States. One manufacturer can have as many as 40 distributors, who are responsible for advertising, marketing, and possibly installing the products. One distributor may market and distribute one or more lines of tube-type infrared heaters for a given area. The manufacture of this product line, however, is left to one or more of the manufacturers listed in Table 1. Moreover, one manufacturer's equipment may be sold under several different names, creating the appearance of a larger industry than really exists.

Table 1

Gas-Fired Infrared Tube Heating Appliance Manufacturers

Manufacturer	Address	Products
Ambi-Rad, Inc.	Columbus, OH	Ambi-Rad Infrared Heaters
Combustion Research Corporation	Rochester Hills, MI	Reflect-O-Ray, Alpha, Omega II
Detroit Radiant Company	Warren, MI	Re-Verber-Ray
Gas-Fired Products, Inc.	Charlotte, NC	Space-Ray
Lambert Industries, Inc.	Parkville, MN	Infrared
Perfection Schwanck, Inc.	Waynesboro, GA	Perfection Schwanck
Roberts-Gordon	Buffalo, NY	Co-Ray-Vac, Vantage II, Gordon-Ray
Solaronics	Rochester, MI	Sun Tube
Sterling Gas-Fired Heating Equipment	Westfield, MA	Infra-Pak
Sun Technology Corporation	Shelby TWP, MI	Ray-Tec

[12] Thomas Register of American Manufacturers (Thomas Publishing Co., New York, NY, 1991); the "HPAC Info-dex" is a yearly index published in *Heating, Piping, Air Conditioning* (Cleveland, OH).

These relatively few manufacturers of gas-fired tube-type infrared radiant heaters produce m..., superficially similar products. While the details of the design and implementation of the various appliances vary widely, infrared heating systems can be classified as either positive- or negative-pressure systems, as determined by type of eductor used, either a blower assembly or a vacuum pump, respectively. Positive-pressure systems "blow" the products of combustion through the radiant tubes whereas negative-pressure systems "pull" the combustion products through the heat exchanger tubes. Both types of systems include vented and unvented applications. Generally, unvented applications are more likely to be positive-pressure systems. A single vacuum pump or blower may be sized to carry the combustion products through the entire network of radiant tubes, or multiple units may be used (as when several factory-assembled units are connected to a common exhaust). An advantage of negative-pressure systems is that since they maintain the radiant tube at less than atmospheric pressures, they are less likely to leak if the tube is damaged. Positive-pressure units have the advantage that they handle only combustion air, and not the products of combustion.

Another way to classify radiant heating systems is as condensing or noncondensing. Systems with sufficient tube runs to allow the combustion gases to cool to a point where water begins to condense in the combustion products make relatively efficient use of their fuel. Since this condition is predominantly dependent upon the length of the tube run, the question of a condensing or noncondensing system is largely implementation specific. That is, a radiant heating contractor installing a field assembled system may achieve a condensing system at one site, but not at another even though the same manufacturer's equipment is installed on both jobs. Factory assembled units, which tend to be relatively smaller than field-assembled units, are generally noncondensing.

Other differences in commercial units include the thickness of the radiant tube, shielding options, fuel options, and burner configurations. Typically, radiant tubes are steel. (One manufacturer offers a cast iron radiant tube designed to be more durable than the steel tubes, at a higher cost.) Different manufacturers offer different styles, shapes, and materials for the shielding placed over the radiant tubing. Some provide end caps for the shields, while others leave them open. Some manufacturers use side deflectors to keep radiant energy from hitting the walls, while others will instruct the installer to tilt the shield. Typical fuel options are propane and natural gas. Most units use one burner per radiant tube, while some are built with multiple, in-line burners. Units with multiple burners offer a more uniform tube temperature throughout the system than single-burner units.

Note that the many types of radiant units are simply variations on a common theme. Even so, these variations can tremendously impact the quality and efficiency of the final product. Nearly all the manufacturers' equipment will have most or all of the following components: (1) some type of eductor-- either a vacuum pump or blower assembly; (2) a tubular heat exchanger surface (radiant tube); (3) a burner assembly; (4) an air supply system; (5) a reflector assembly; (6) suspension brackets; (7) gas piping/connectors; and (8) a control apparatus.

These basic components are assembled into marketable, competitive infrared heating systems. Manufacturers vary the size, structure, and combination of these components to differentiate their products from those of their competitors. Appendix A provides a list of the systems produced by the manufacturers referenced in Table 1.

Experimental Setup

A demonstration project for gas-fired, infrared radiant tube heaters was undertaken beginning in 1988 at Fort Riley, KS. Two buildings were selected for a side by side comparison of infrared heaters versus hydronic unit convection heaters. Both buildings chosen were vehicle maintenance shops. The first building is the control building, heated with hydronic convection unit heaters, sometimes referred to as the convection building. This building is Fort Riley building number 8390 and has a gross area of 24,755 sq ft (2300 m^2). The second building is the test building, Fort Riley building number 8370, sometimes known as the radiant building. Building 8370 has a gross area of 26,876 sq ft (2496 m^2). This particular building type was selected for the large amount of such space in use by the Army. According to the Red Book,[13] the Army has 76.2 million sq ft (7.1 million m^2) of maintenance and production facilities in the continental United States, and 29.3 million sq ft (2.7 million m^2) outside the continental United States for a total of 105.5 million sq ft (98 million m^2) of such facilities. Therefore, a successful demonstration for these facilities would have a large potential for application.

Both buildings are slab-on-grade construction with a vehicle maintenance area comprised of service bays, which are accessed by insulated metal overhead doors located on opposite sides of the buildings. The side walls consist almost entirely of the bay doors separated by structural steel columns with translucent panels over the doors to provide natural lighting. Both ends of the bay area are concrete block walls, one being an exterior wall and the other separating the maintenance bays from conditioned office space. This study is concerned only with the maintenance bay portions of the buildings. Furthermore, only the six bays on the north end of building 8390 were studied. This building has additional bays on its south end with conditioned space in between these bays and the study bays. The roofs of both buildings are insulated double metal. Table 2 shows the appropriate overall heat transfer coefficient (U) values for the various components of the building.

The two buildings chosen for the study are located in the Custer Hill area of Fort Riley. This area of the Fort has rolling hills and little vegetation. The buildings are both in the center of large parking areas with small outlying buildings. No outlying buildings shade or shield the study buildings (Figures 4 and 5).

There are two major differences between the two buildings, the heating systems and their size. Building 8370 has eight maintenance bays comprising about 8500 sq ft (790 m^2) while the portion of

Table 2

U-Values of Building Components

Item	U Btu/hrft^2×°F	(W/m^2×°C
Walls	0.05	(0.28)
Roofs	0.07	(0.40)
Doors	0.10	(0.57)

[13] Facilities Engineering and Housing Annual Summary of Operations (Office of the Assistant Chief of Engineers [OACE], 1988), pp 2, 5, 50.

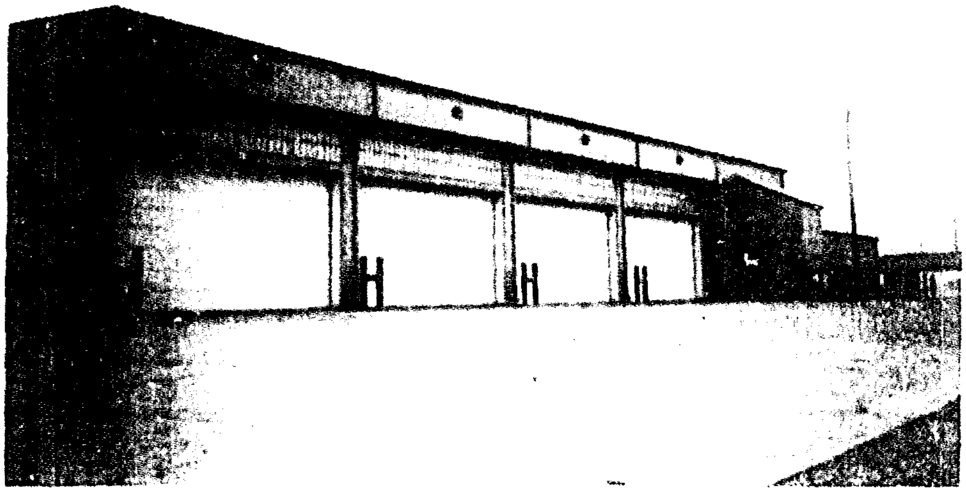


Figure 4. Building 8370, the Radiant Building.

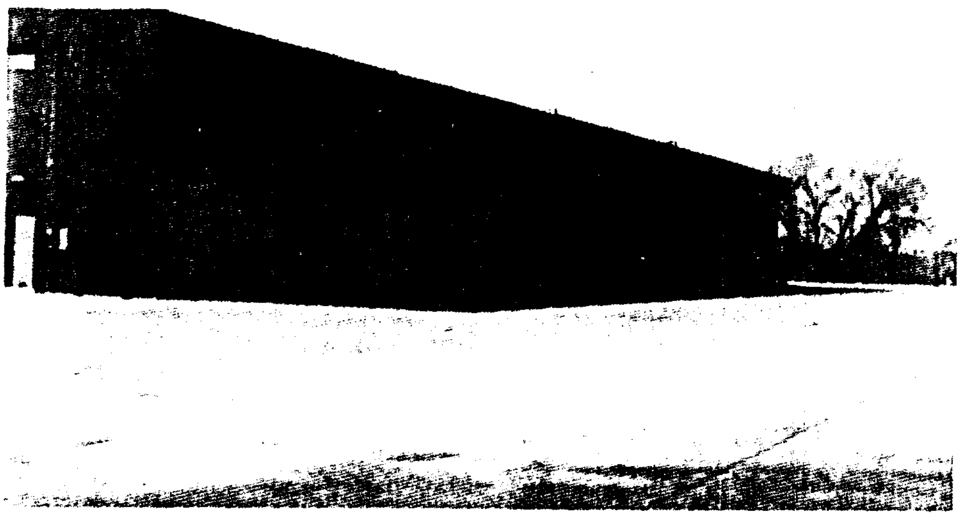


Figure 5. Building 8390, the Convection Building.

building 8390 studied has only six bays totaling about 6400 sq ft (595 m^2). Both buildings were relatively new at the time of the study. (Building 8370 was completed in the fall of 1987 and building 8390 was completed approximately 1 year earlier.) Building 8370 is used by a Military Intelligence Battalion to maintain a variety of wheeled and tracked vehicles, while the portion of building 8390 studied is occupied by an Armor Battalion and is used almost exclusively to maintain wheeled vehicles. Plans and elevations for the two buildings are shown in Figures 6 and 7.

The heating system for building 8370 consists of five separate Perfection-Schwank Model JP125 DSAN indirect, gas-fired, tube-type radiant heaters. These units are rated at 125 kBtu/hr (36.6 kW)

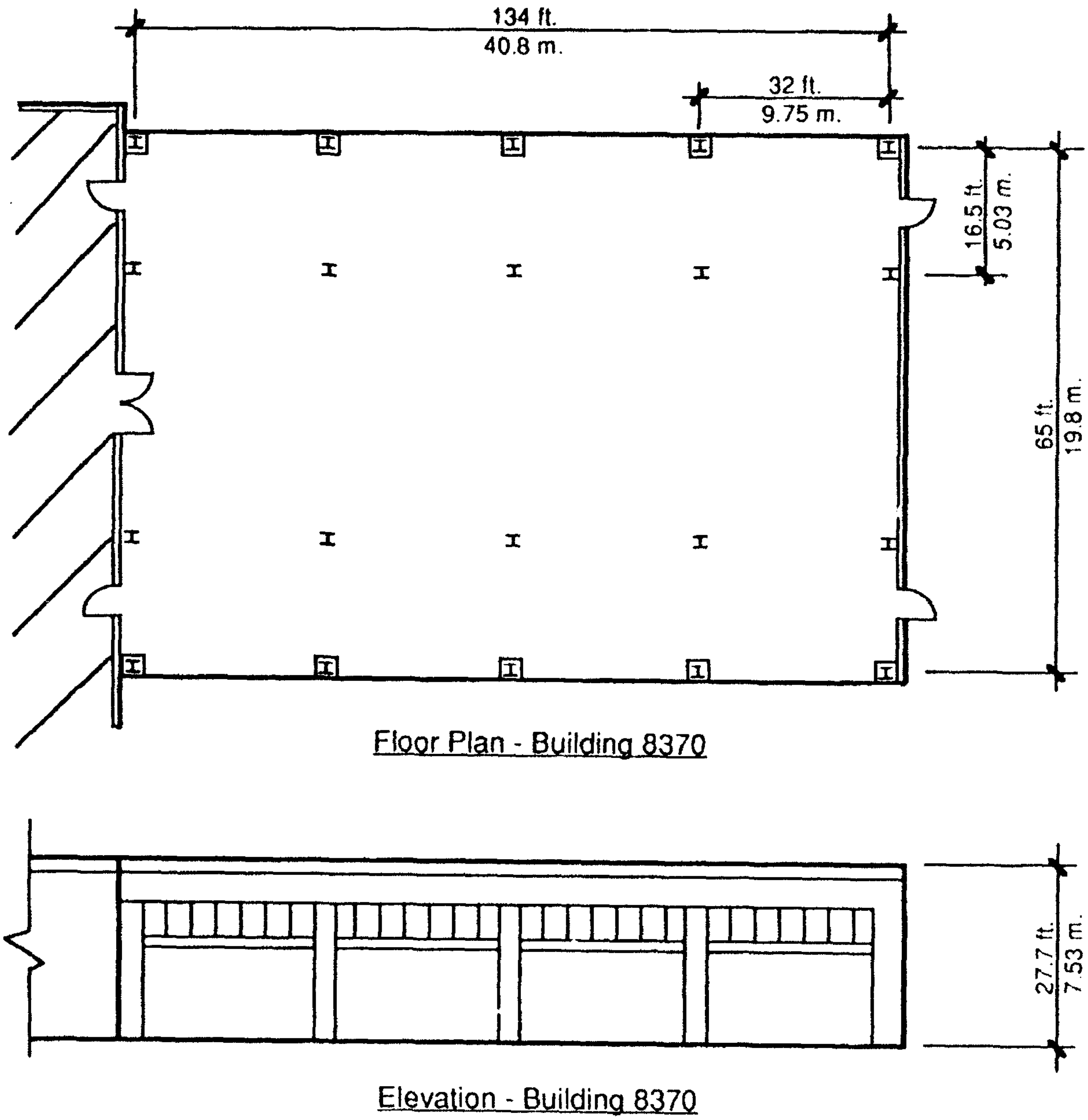
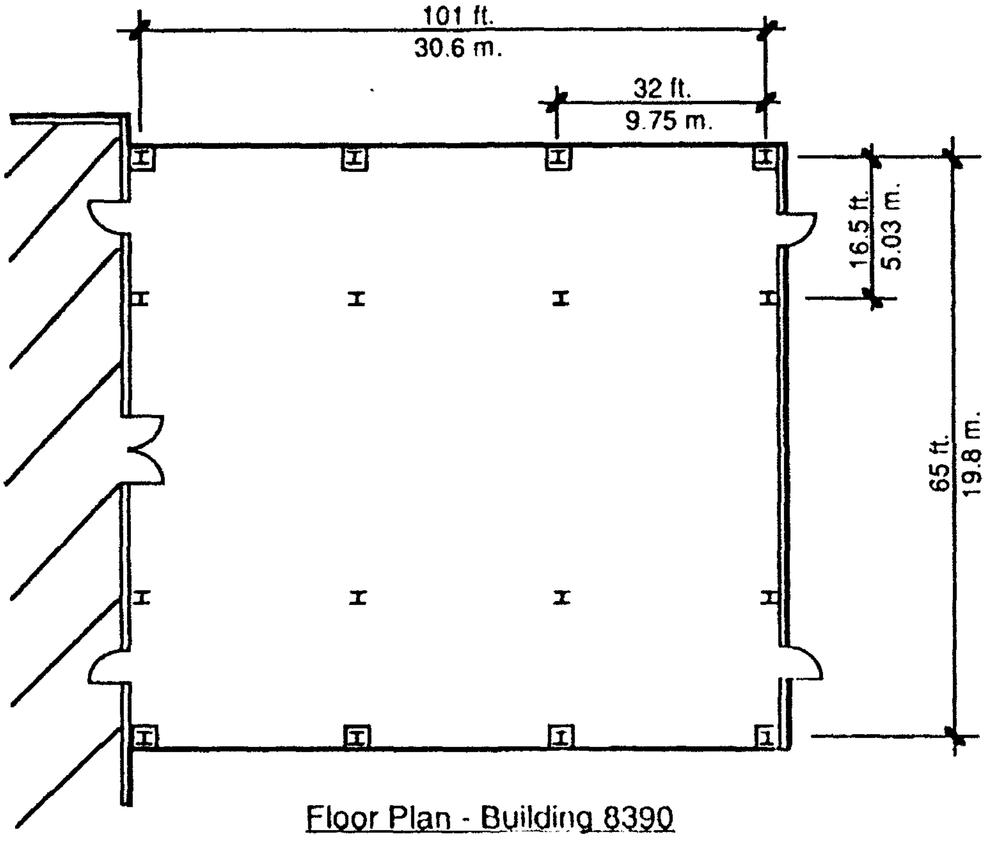
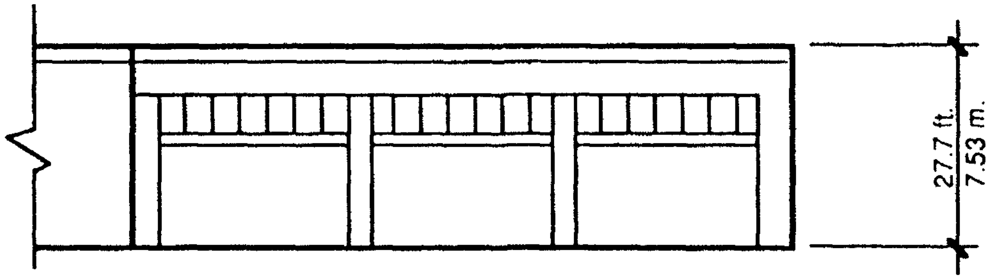


Figure 6. Plan and Elevation, Building 8370.



Floor Plan - Building 8390



Elevation - Building 8390

Figure 7. Plan and Elevation, Building 8390.

each, for a total heating capacity of 625 kBtu/hr (183 kW). Construction of these units is typical of factory assembled (Type 1[c]) units, with a single forced draft burner, 4 in. (10 cm) diameter lineal tube and reflector. Operating temperatures for the radiant tube are 800 °F (426 °C) or greater near the burner end of the tube and 250 °F (121 °C) or less at the exhaust end. Each heater is mounted at a height of 20 ft (6 m) and is exhausted through the roof. Combustion air is also drawn through the roof. Figure 8 shows, from left to right, the exhaust of a unit, and the intake, burner, and radiant tube of another unit. Figure 9 shows the layout of the radiant heating system. Control is facilitated by four thermostats mounted 5 ft above the floor on structural columns. Heating units 2 and 3 are controlled by a single thermostat, and all other heaters have individual thermostats. Figure 10 shows the structural column with the thermostat mounted on the right. A globe thermometer used for this experiment is located below the thermostat, and a radiant tube heater can be seen at the top of the picture on the left side of the column. The thermostats operate on 120 volts AC (VAC) and provide on/off control. Each heater operates at full capacity when it is on since there is no provision for modulation.

A makeup air unit (MAU) is also used in this building to temper fresh air brought into the building. This unit is a gas-fired forced air furnace rated at 550 kBtu/hr (161 kW) at 5000 cubic feet per minute (cfm) (142 m^3/min). This unit has a modulated burner and is supposed to provide 55 °F (13 °C) air to the space. Measurement of the actual supplied air temperature showed that it was usually between 70 and 75 °F (21 and 24 °C). The MAU was operated manually by the building occupants from controls mounted on the end wall of the bay.

Additional environmental control devices installed in the building consist of two types of fans. Four three-bladed ceiling fans (Figure 11) are mounted at a height of 22 ft (6.7 m). A separate wall switch controls each fan. Also, there are two banks of vehicle exhaust fans controlled by separate wall switches, one on each side of the bay.

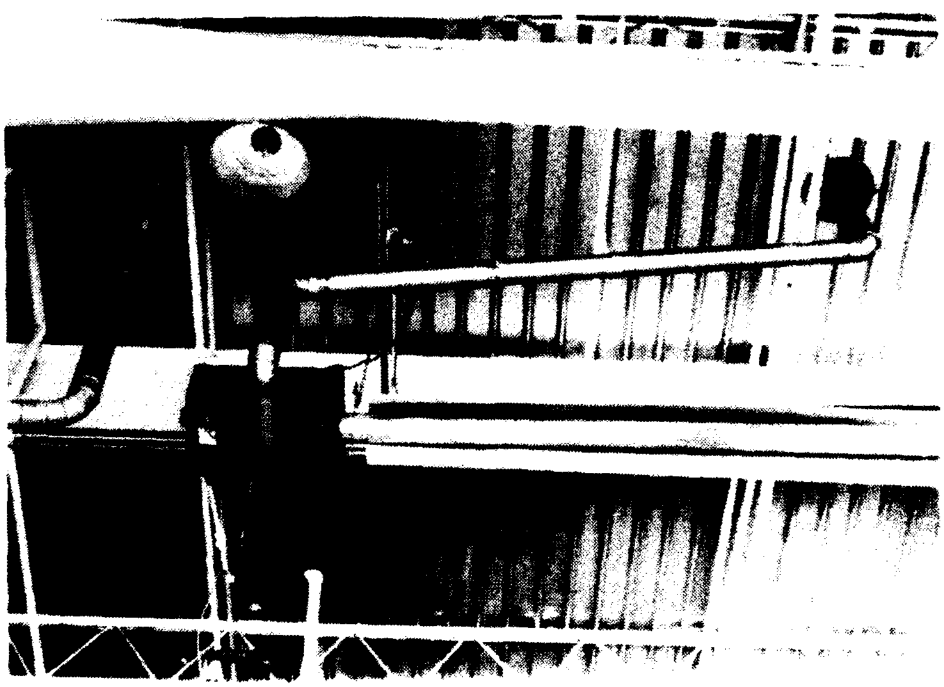


Figure 8. Exhaust and Intake Arrangement.

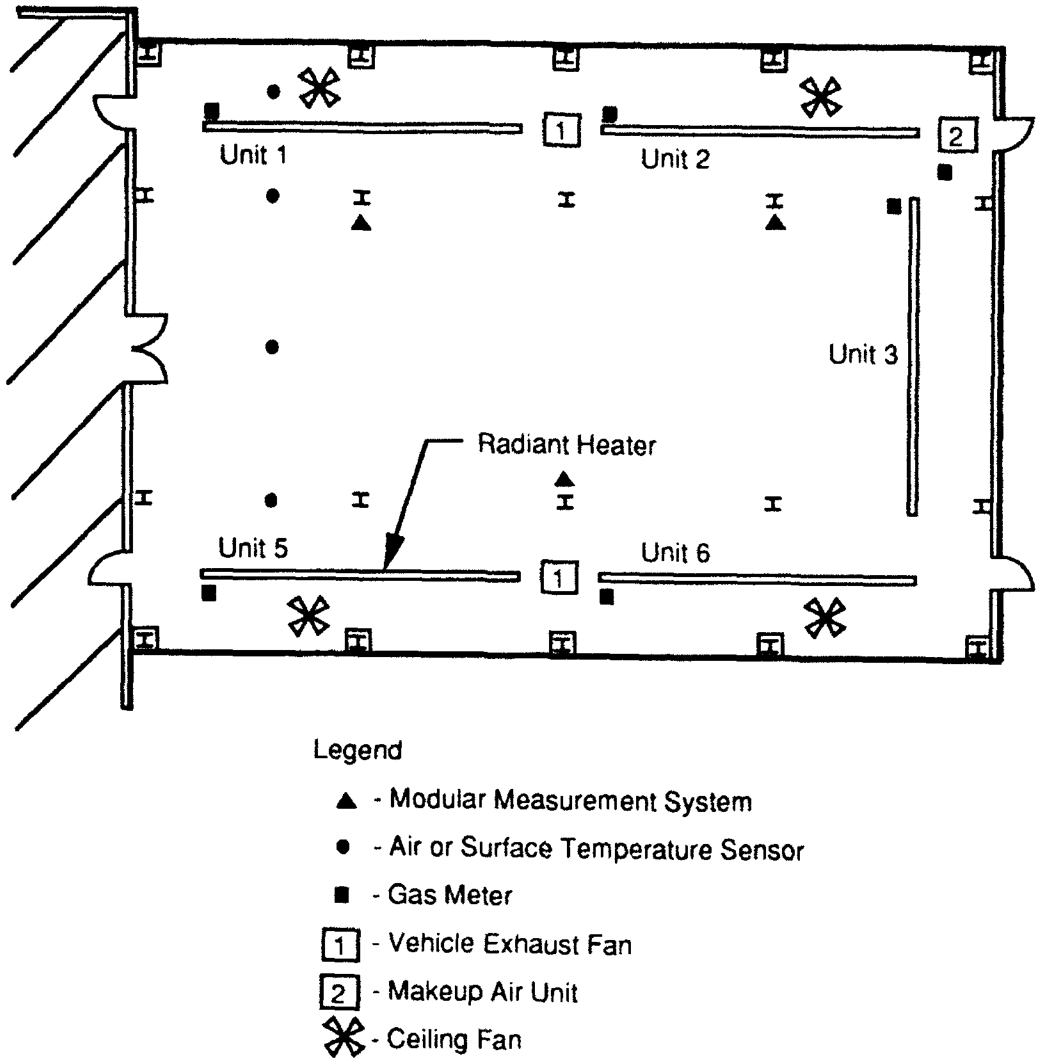


Figure 9. Heater Layout, Building 8370.

The heating system in building 8390 is composed of six unit heaters which are supplied a hot mixture of equal parts of water and glycol. Each heater is comprised of a finned-tube heat exchanger and a fan, which forces air from the space downward through the heat exchanger. The hot water supplied to these units and to the rest of the building is controlled by a single outdoor thermostat that activates the pump when the outdoor temperature falls below 65 °F (18 °C). The fans in each unit are controlled by thermostats on structural poles in the space. These thermostats sit inside metal electrical boxes, each with a day and a night thermostat. There are two thermostat pairs, each of which controls one side of the building, or three heaters. There are two heaters in each bay, each mounted at a height of 18 ft (5.5 m), and rated at 88, kBtu/hr (25.7 kW) (Figure 12).

Building 8390 also has a makeup air unit to temper fresh air brought into the building. This MAU operates on the same hot water loop as the unit heaters, and has a rated capacity of 288 kBtu/hr (66.8 kW). The on/off operating scheme of this unit was unavailable, but it was observed to remain "on" most of the time during the heating season, as opposed to the MAU in 8370 which operated little during the heating season.

Figure 10. Radiant Heater, Structural Column, and Thermostat.

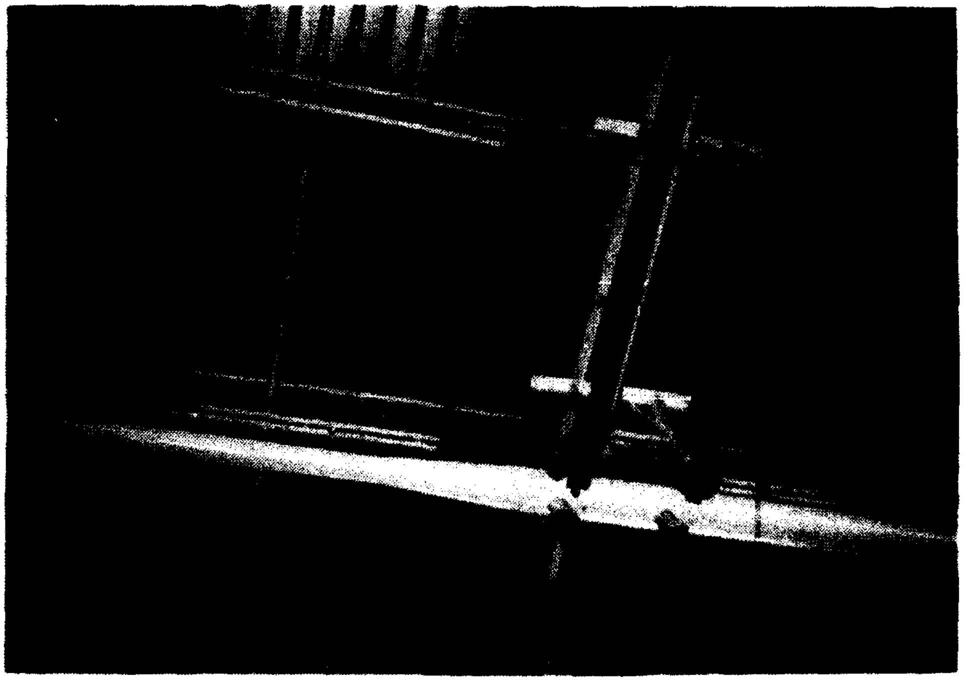


Figure 11. Typical Ceiling Fan in Building 8370.

There are also vehicle exhaust fans installed in building 8390, similar to those in 8370. Four air recirculation devices to reduce thermal stratification are also employed. Each of these devices is a centrifugal fan mounted near the ceiling with an 8-in. (20-cm) duct that hangs down to about 2 ft (0.6 m) above the floor. Each of these units is controlled by a separate wall switch.

The data collected for this demonstration fall into two time categories, data taken every 3 minutes and data taken every hour. The data taken every 3 minutes can be further subdivided into three categories: (1) thermal comfort data, (2) building dynamics data, and (3) heater controls data. Data collected to ascertain thermal comfort include globe thermometer temperature, air velocity, ambient temperature, and dew point temperature. Data collected to track building dynamics include ceiling and vehicle exhaust fan status, and door status. Heater controls data consist of heater status and temperature at the thermostat.

The data taken every hour have two subcategories, averages and totals. The averages category includes air stratification temperatures taken at eight elevations, component directions of the globe

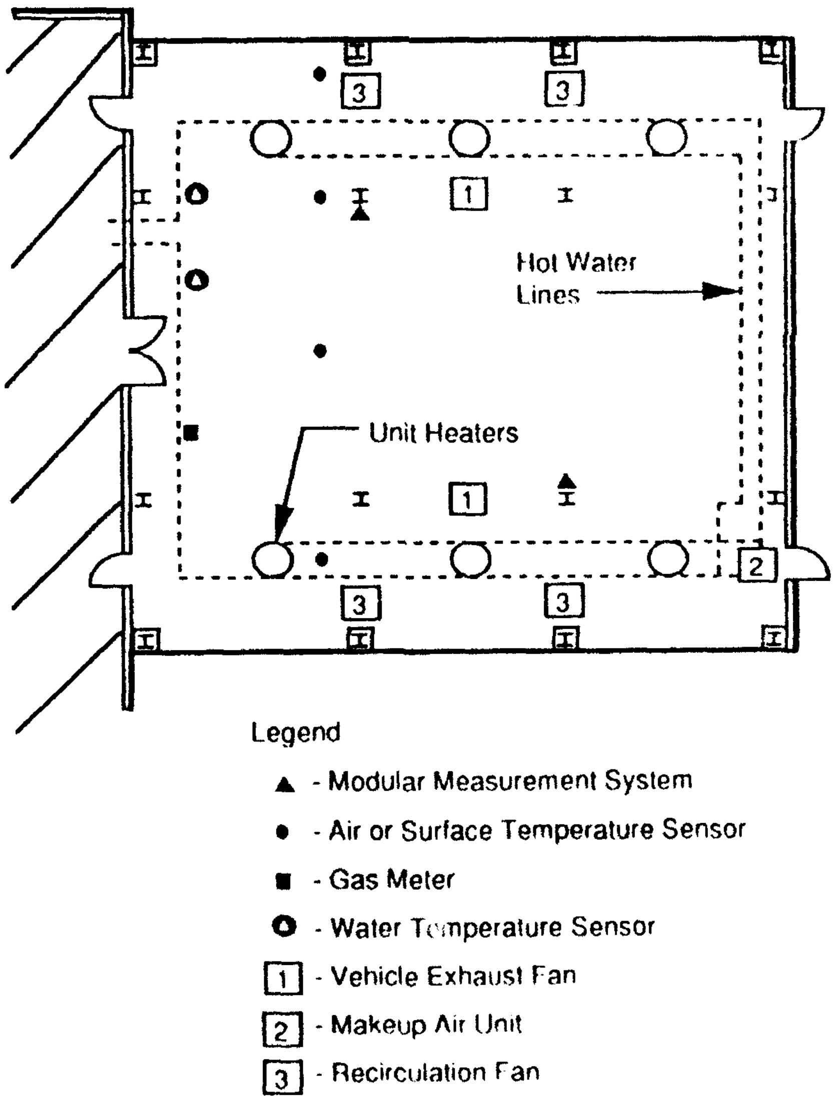


Figure 12. Heater Layout, Building 8390.

thermometers (six components per globe), and ceiling temperature. The only total item kept was energy consumption, either gas consumption for the radiant building or hot water flow and temperature differences for the convection building.

These data were collected using several "Modular Measurement Systems" (MMSs). The design of these systems was the result of considering several factors. For one, the systems must be able to monitor not only the energy consumption but also the thermal comfort and building dynamics, that is, all of the data items mentioned above. Another consideration was obtrusiveness: If the instrumentation would interfere with the building occupants' normal work habits, its chances for survival would be nil. Also along those lines, the instrumentation needed to be rugged. A certain amount of abuse was assumed, and the MMS needed to be able to withstand such abuse.

Each MMS has three main components: (1) a vertical string of eight thermocouples, (2) an omnidirectional anemometer, and (3) a segmented black globe thermometer. Figure 13 shows the makeup of a typical MMS. The type "T" copper-constantan thermocouple strings are protected by 1/2-in. (1-cm)

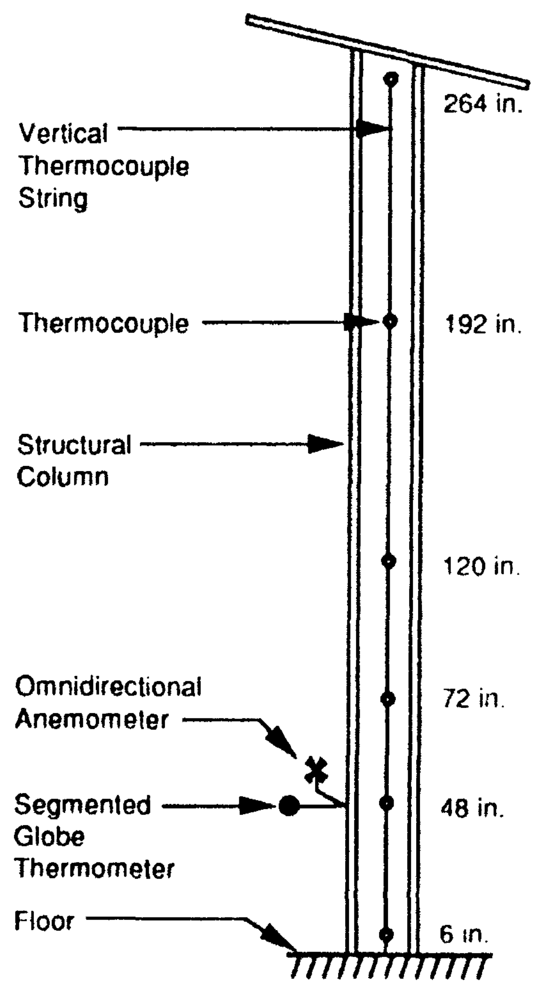


Figure 13. Modular Measurement System.

metal conduit with the dissimilar metal junctions exposed to the air. The omnidirectional anemometer and segmented globe thermometer are mounted inside a protective cage constructed of 1/2-in. (1-cm) hail screen. Each globe thermometer is a 6-in. (15-cm) copper sphere painted matte black, with six segments arranged according to the six cartesian directions. A thermocouple was attached to each segment and the globes were filled with fiberglass insulation to preclude radiant heat exchange between segments. Unpublished research by Jones and Tao indicates that the average of the six measurements from each segment is essentially the same as the measurement of an unsegmented globe thermometer.[14] Segmented globes were used in this case to enable measurement of radiant asymmetry. The globe thermometer/anemometer pairs are mounted at a height of about 48 in. (122 cm), with the tip of the anemometer positioned approximately 6 in. (15 cm) above the globe thermometer. Figure 14 shows a globe thermometer in a Modular Measurement System.

Monitoring of on-off status of ceiling fans and exhaust fans was accomplished using relay circuits that closed when the fans were in use. Bay door status was monitored by using infrared beam sensors of the type used with automatic garage door openers, to reverse direction when the infrared beam is broken, and a custom circuit was used to translate the square wave signal to an on-off type of signal. These sensors were placed such that the door must be opened 12 in. (30 cm) or more to break the beam. Figure 15 shows one of these sensors.

Energy usage in building 8370 was monitored by measuring natural gas flow into each radiant heater and the makeup air unit using commercial gas meters (Figure 16). The gas meters were equipped with pulse counters that sent a pulse to the data logger for each cubic foot (.028 m^3) of gas consumed. The data logger then recorded a cumulative total for each hour. Energy consumption was calculated

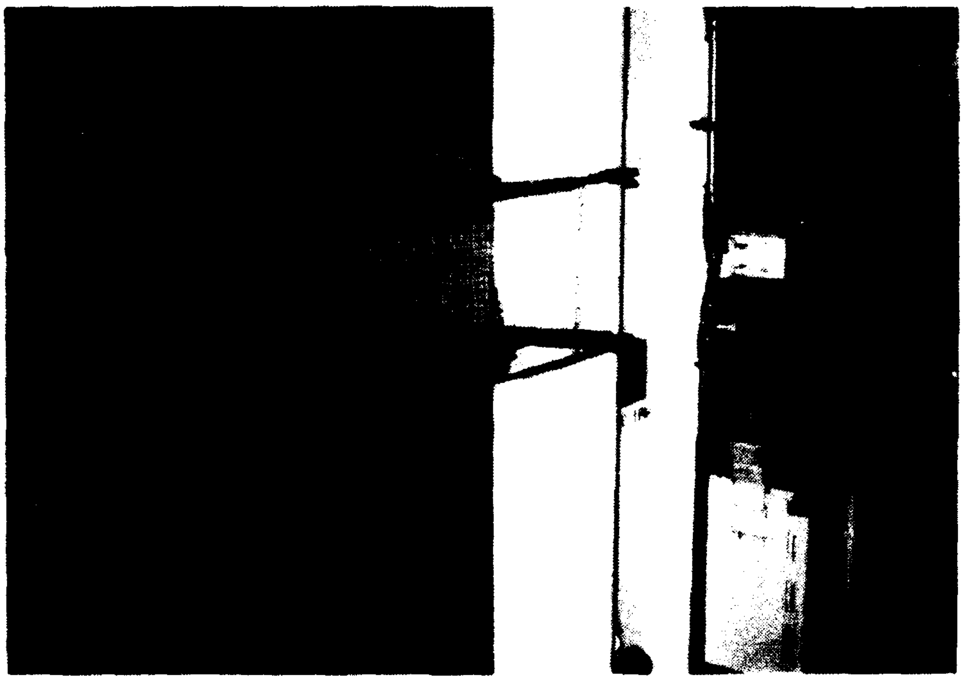


Figure 14. Globe Thermometer/Anemometer Set.

[14] Cited in William F. Niedringhaus, *A Field Comparison of Radiant and Convective Heating Systems in Army Maintenance Facilities, a Master's Thesis* (Department of Mechanical Engineering, Kansas State University, Manhattan, KS, 1988), p 19.

Figure 15. Typical Door Open Sensor.

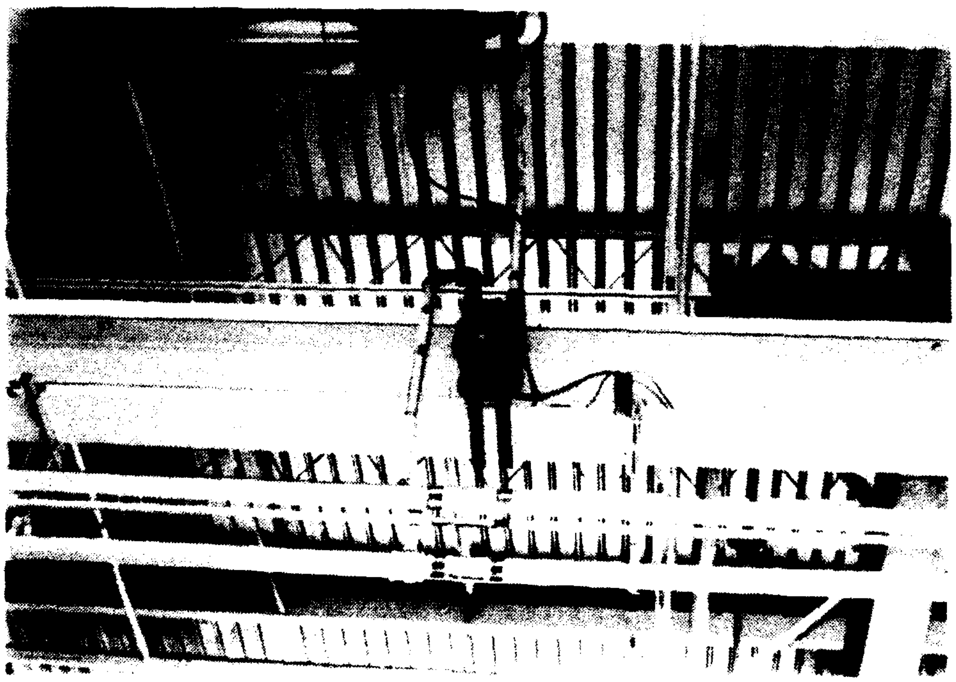


Figure 16. Typical Gas Meter for Building 8370.

based on the conversion of 9 kBtu (1055.04 W·s) per cubic foot (0.028 m^3). Each radiant heater and the MAU were also monitored for on-time, using relays.

Energy usage in building 8390 could not be monitored as straightforwardly as in building 8370, because a single boiler for the building provides circulating hot water for the entire building. To measure only the energy used in the north maintenance bays, the water flow rate and the temperature difference between the supply and return water was measured. The temperatures were measured using resistance temperature detectors (RTDs) and the flow rates were measured with paddlewheel flowmeters. The RTDs were calibrated once a month to ensure accuracy. Figure 17 shows a typical heating unit for building 8390 with its supply and return line. Each individual unit was not instrumented, only each water loop. The energy use for building 8390 may then be calculated using Eq 10:

$$dQ = 0.436 \times dV \times \Delta T \qquad \text{[Eq 10]}$$

where dQ is the heat flow rate in kBtu/hr, dV is the water flow rate in gallons per minute (GPM) and ΔT is the difference in temperature between the supply and return water. The constant 0.436 makes the necessary unit conversions and includes a factor of 0.85 for the specific heat of the circulating water/glycol mixture. The combined average heat flow rates for 1 hour is then the energy use in kBtu.

All data from each building were collected by Acurex Autocalc Data Acquisition Systems.[15] The Acurexes are mounted in cabinets that reside in offices adjacent to the maintenance bays. The circuitry for the bay door sensors and the power supplies required for the anemometers, dew point temperature

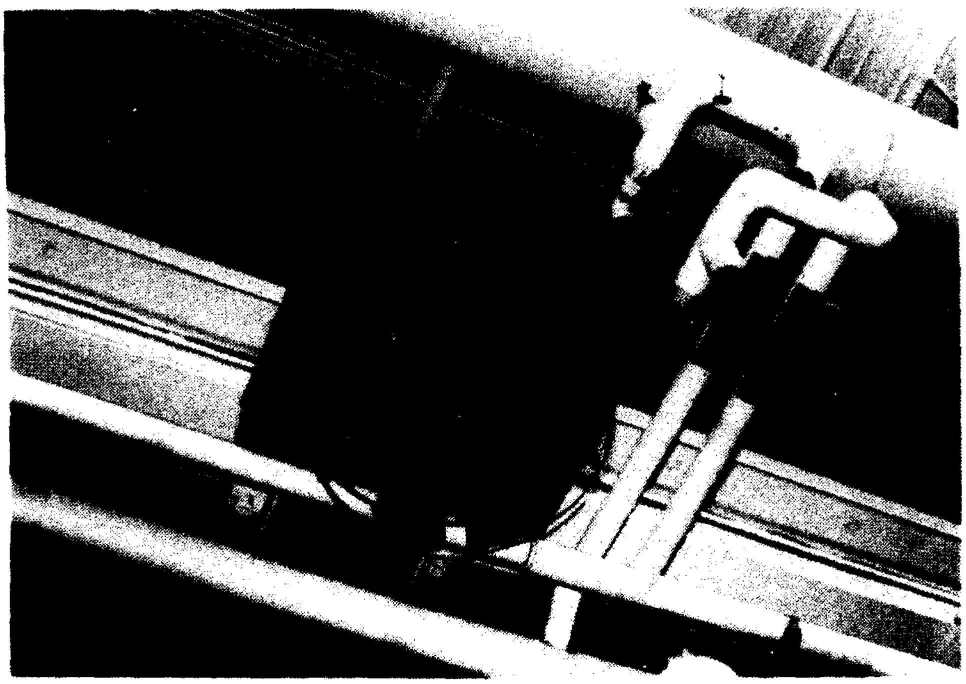


Figure 17. Hydronic Convection Unit, Building 8390.

[15] Acurex Environmental System Division, 485-T Clyde Ave., Mountain View, CA 94039.

sensors, door sensors, RTDs, and flow meters are also mounted in these cabinets. Telephone lines are connected to each unit to allow remote downloading of the data to a personal computer. Figure 18 shows an Acurex cabinet in one of the buildings.

Weather data were provided by a Climatronics Meteorological Monitoring System[16] located on a 30-ft (9-m) tower on Custer Hill, about 1 mile (1.6 km) from building 8370 and 2 miles (3.2 km) from building 8390. Backup outdoor temperature data were available from a sensor located at building 7108, also on Custer Hill. A separate document written as part of this demonstration project discusses the relative error for the energy measurements taken (Appendix B).

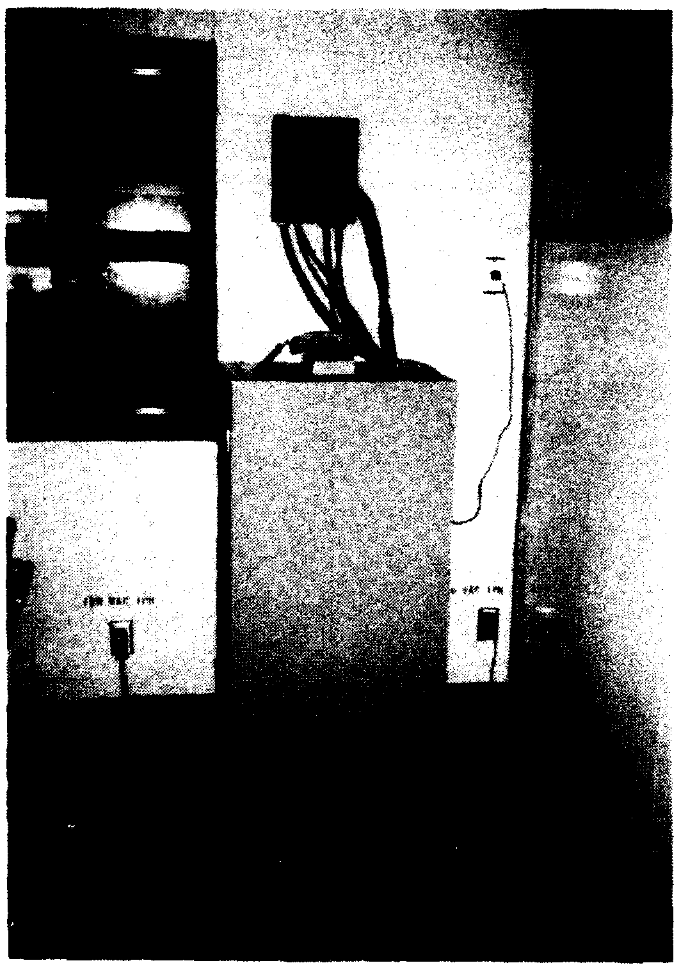


Figure 18. Acurex Cabinet in Office Adjacent to Maintenance Bays.

[16] Climatronics, Inc., 140-T Wilbur Place, Bohemia, NY 11716.

The data collected were analyzed to compare the performance of the two building heating systems with respect to three major concerns: (1) energy consumption, (2) thermal comfort, and (3) stratification. These three aspects of heating are indicators of the attainment or nonattainment of the bulk of the radiant heater manufacturers' claims. First, however, a methodology for making valid comparisons needed to be developed.

Energy Consumption

To compare the two heating systems studied, the differences in the physical characteristics of the two buildings and the character of the data collected needed to be considered. In terms of floor area, building 8370 is 33 percent larger than the studied portion of building 8390. To approximate a comparison of two equally sized buildings, the energy use data from building 8390 were scaled by a factor of 1.33. Second, energy use was monitored in two different ways between the two buildings. In building 8370 gas usage (fuel input) was metered. However, in building 8390, energy input to the hydronic units was measured, since they received hot water from a boiler in common with the rest of the building. Therefore, the energy figures for building 8390 need to be adjusted to account for the efficiency of the boiler.

Boiler efficiency is expressed in two ways, in combustion efficiency and in overall efficiency. Combustion efficiency is calculated by subtracting the stack loss from the fuel input and then dividing this quantity by the fuel input. According to ASHRAE, combustion efficiency for a noncondensing boiler ranges from 75 to 86 percent.[17] For this analysis, a rather optimistic combustion efficiency of 85 percent was assumed for the building 8390 boiler. Overall efficiency is defined as simply the gross output divided by the input. Overall efficiency is always lower than combustion efficiency, due to heat losses through the walls of the boiler (usually called radiation loss). For this study, a radiation loss of 10 percent was assumed indicating that the overall efficiency for the building 8390 boiler would be taken to be 75 percent. The energy figures for building 8390 were adjusted accordingly, so that energy consumption from both buildings could be compared in terms of fuel input.

Since it is difficult to make generalizations and conclusions from 3-minute snips in time, the data scans were processed into daily averages to make these comparisons. This conversion was done using computer programs written for this project at USACERL to transform the data files from the data loggers into a format easily readable by spreadsheet software. The data were then uploaded into spreadsheets and further processed. Figure 19 shows the results of such processing.

Figure 19 represents the overall energy usage for the studied portions of both buildings in February 1988. Figures 20 and 21 show similar compilations for March and April. There are noticeable peaks in the energy use for 11 February, which is attributable to subzero outdoor temperatures on that date. It can be seen that building 8370 used substantially more energy than building 8390 from 1 February through 24 February. After that period, the difference between the two buildings is less pronounced, until the first 6 days of March when 8370 again used much more energy than did building 8390. Disregarding the period from 23 March through 27 March, when the heaters in building 8370 were turned off, the rest of March shows no clear difference in consumption between the buildings. The consumption plot for April shows a widely varying pattern, reflecting the wide variance in outside air temperature during the month. Note that the hot water pump for building 8390 shut down on April 16, while the radiant heaters in building 8370 continued to operate through the end of the month.

[17] ASHRAE (1988), p 23.3.

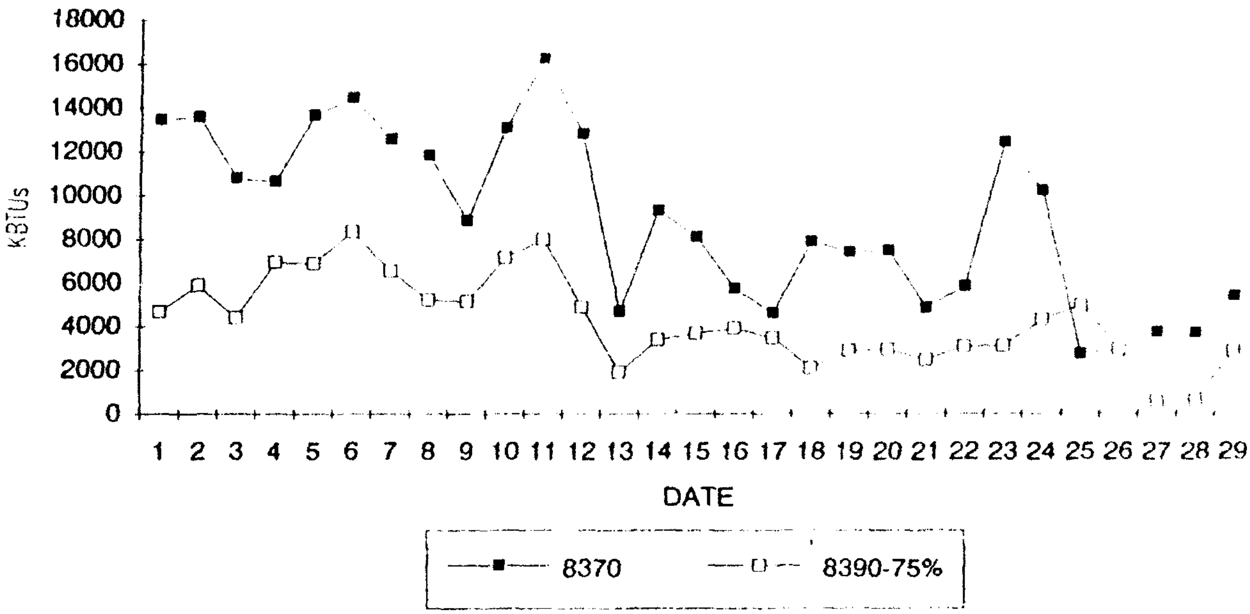


Figure 19. Daily Energy Use for February 1988.

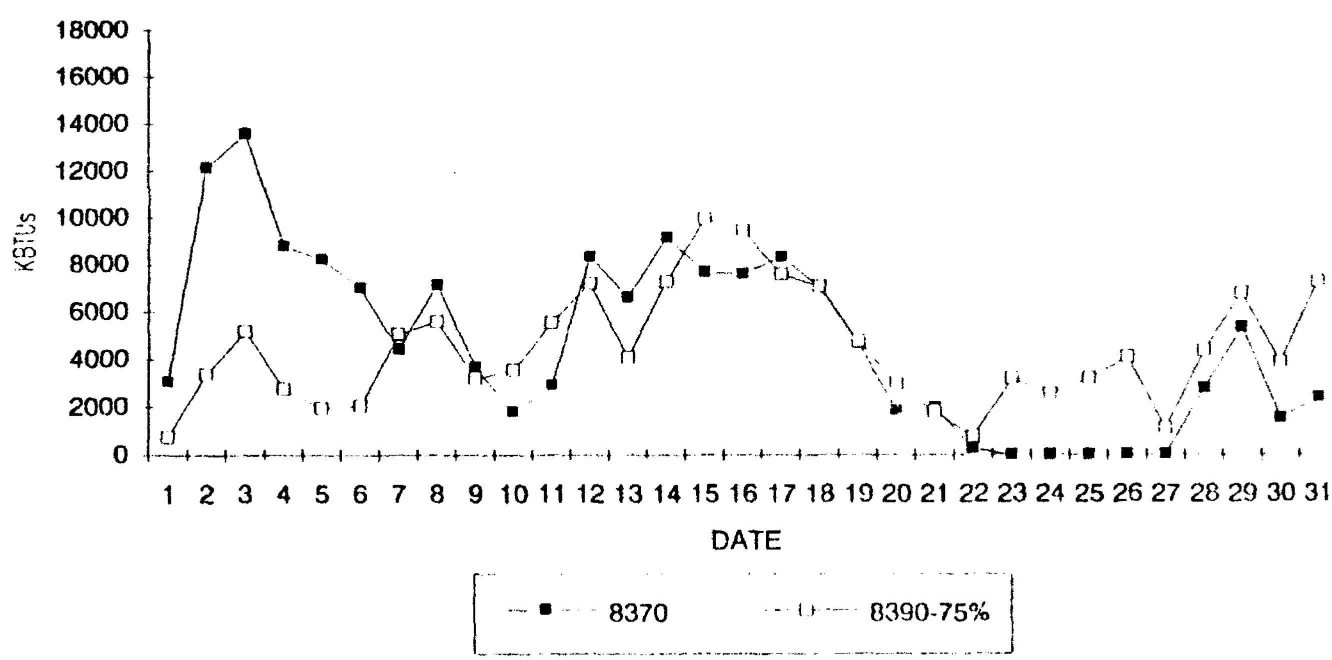


Figure 20. Daily Energy Use for March 1988.

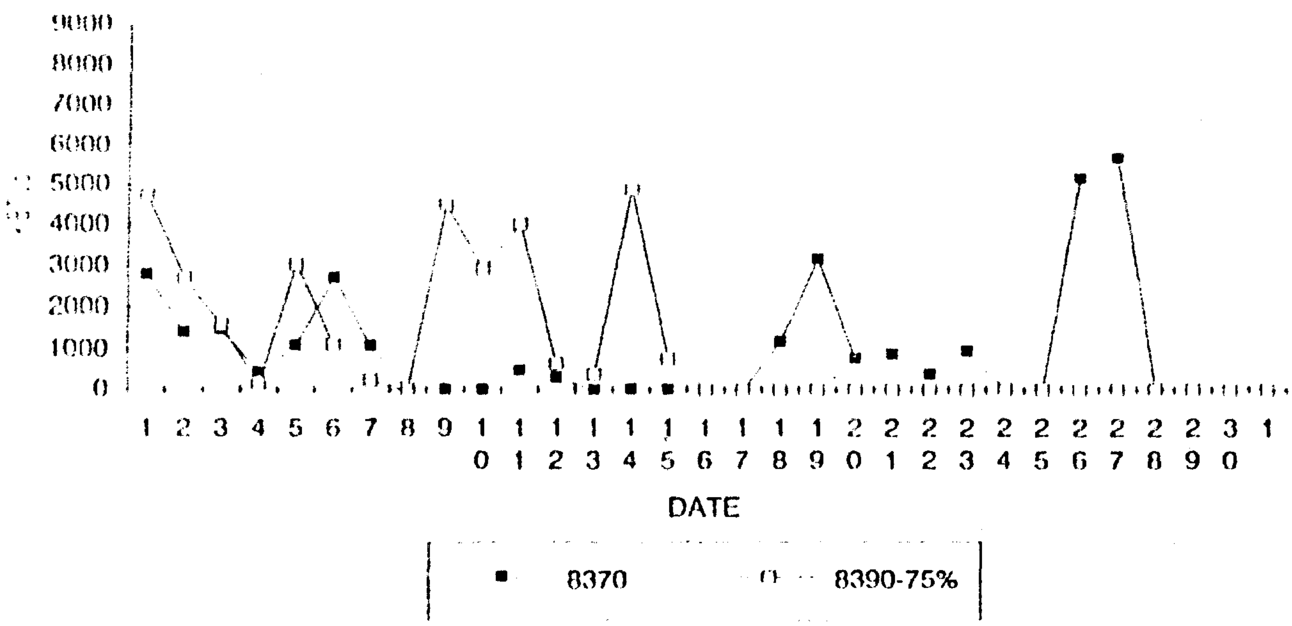


Figure 21. Daily Energy Use for April 1988.

As expected, energy consumption in the two buildings varied inversely with outside temperature. However, the rate at which the energy use changes with outside temperature provides some insight into the relative performance of the two buildings. Figures 22 and 23 show plots of energy usage versus outside air temperature for 8370 and 8390, respectively. The plots show the daily energy usage and regression lines (calculated using only nonzero data) with confidence bands, which show large standard errors for both buildings. The two regression bands are shown superimposed on Figure 24. Note that the bands overlap for all but the lowest temperatures, where the indication is that building 8390 is more energy efficient at lower temperatures. The main reason for this difference and the steeper slope of the building 8370 regression line is the surprisingly high energy consumption for building 8370 in February.

Table 3 shows the monthly and grand totals for energy usage in both buildings. Over the February through April 1988 period, building 8370 used 43 percent more energy than did building 8390. This certainly was not the expected result, since the type of building being studied would appear to be ideal for application of low-intensity infrared radiant heating.

There are a number of reasons why building 8370 showed unexpectedly high energy usage for the period in question. Most notably, the occupants of 8370 used the radiant heating system controls as on/off switches, rather than as thermostatic controls. That is, the occupants would set the thermostats at a high temperature to run continuously without ever cycling off. In addition, since there were no provisions for automatic setback, the thermostats apparently were left at these high temperatures even at night. Figures 25 through 30 show that the temperature in building 8390 dropped sharply at night, while the temperature in building 8370 remained constant or increased during the same unoccupied time. Note that the temperatures shown in the figures for 8390 have been reduced by 20 °F (11 °C) to improve the clarity of the graph. The overheating problem in 8370 was not overcome until the fourth week of February when the supervisory personnel in the building became more familiar with the heating system

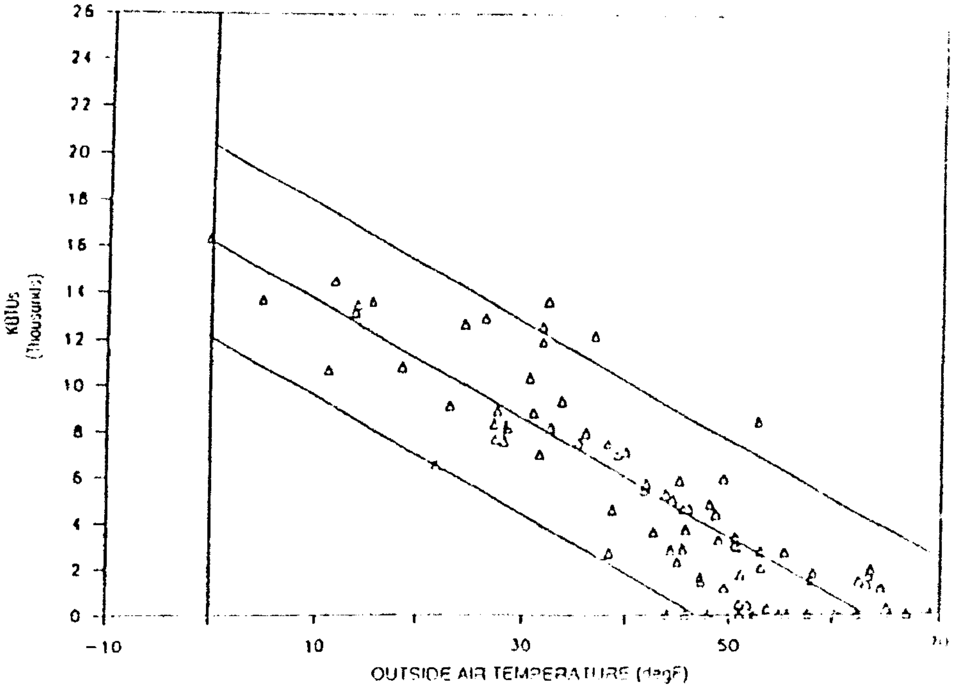


Figure 22. Relationship Between Outside Temperature and Energy Use for Building 8370.

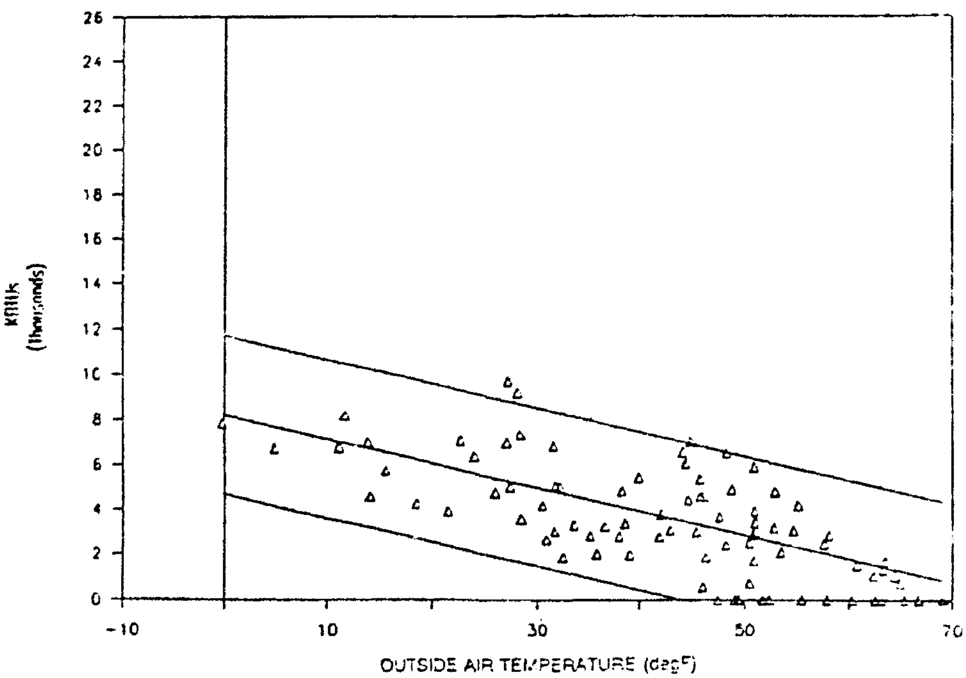


Figure 23. Relationship Between Outside Temperature and Energy Use for Building 8390.

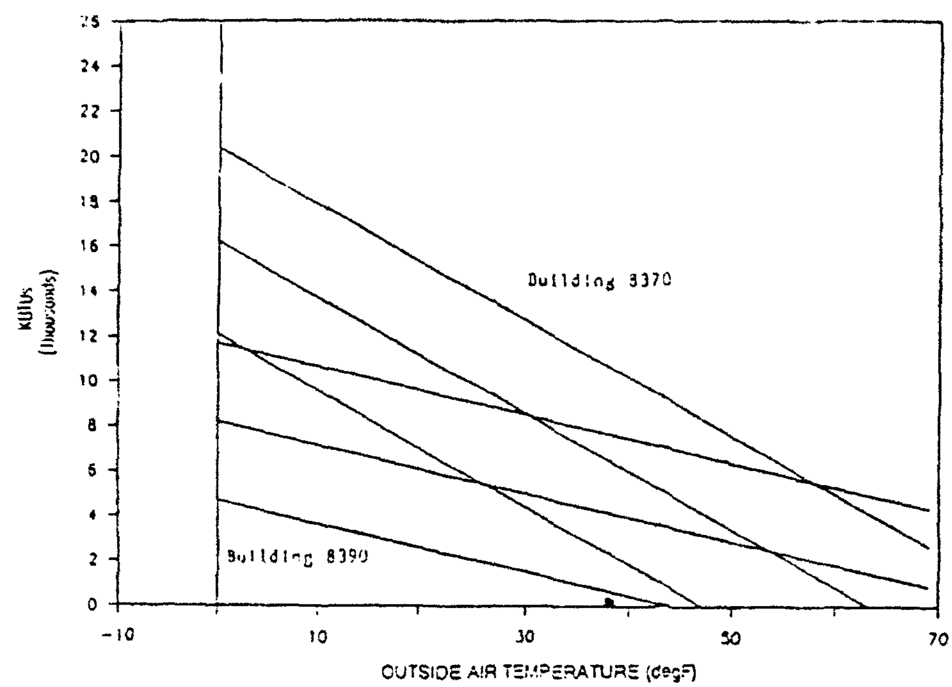


Figure 24. Comparison of Response in Energy Use to Variance in Outside Temperature.

Table 3

Total 1988 Heating Energy Use in kBtu (kWh)

Month	Bldg 8370	Bldg 8390
February	260,000 (76,179)	123,000 (36,039)
March	147,000 (43,071)	137,000 (40,141)
April	45,000 (13,185)	54,000 (15,822)
Total	452,000 (132,435)	315,000 (92,294)

and began to turn the thermostats down at night. This learning process helped to improve performance for building 8370 in March and April.

The discrepancy between daytime energy usage (6 a.m. to 6 p.m.) and nighttime (6 p.m. to 6 a.m.) is clearly shown in Table 4. Building 8390 consistently used less energy during unoccupied hours than did building 8370, with 8370 using 132 percent more energy than building 8390 overnight from February through March. During March and April, building 8370 actually used 2 percent less energy than building 8390 during the day, even though the heaters were running almost continuously during the day. Table 5 illustrates the lack of cycling, particularly in February where average cycles were over 1 day long. Thermostat number three in that table is the only thermostat cycling near normally, probably due to its proximity to two of the radiant heaters and the outlet of the MAU. The lack of cycling and

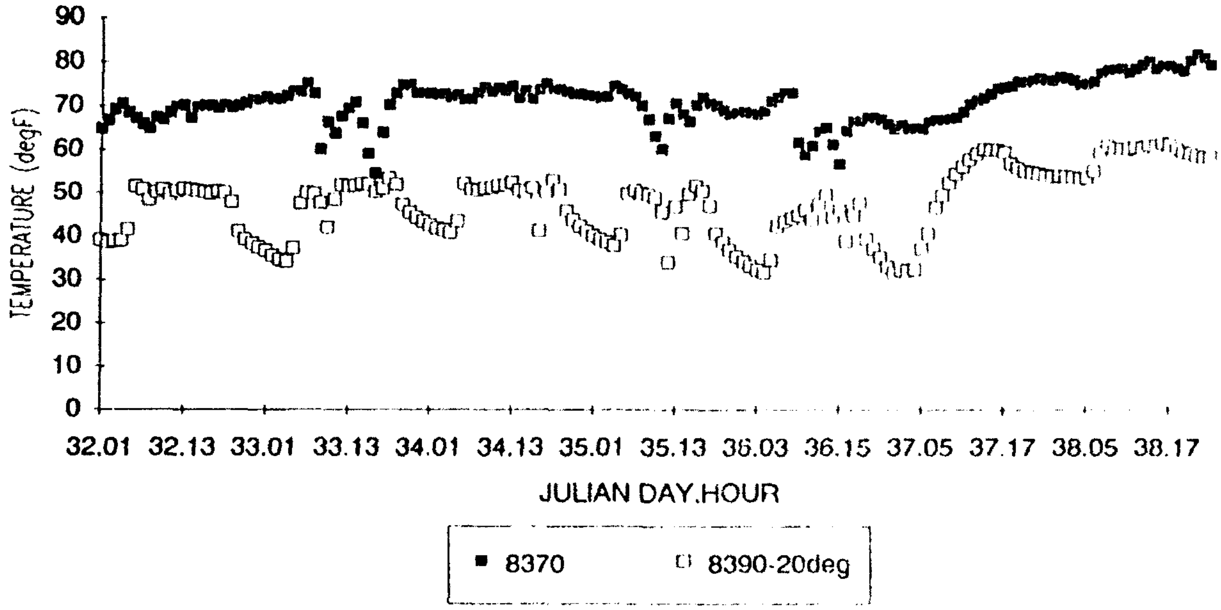


Figure 25. Week 1 Average Space Temperatures.

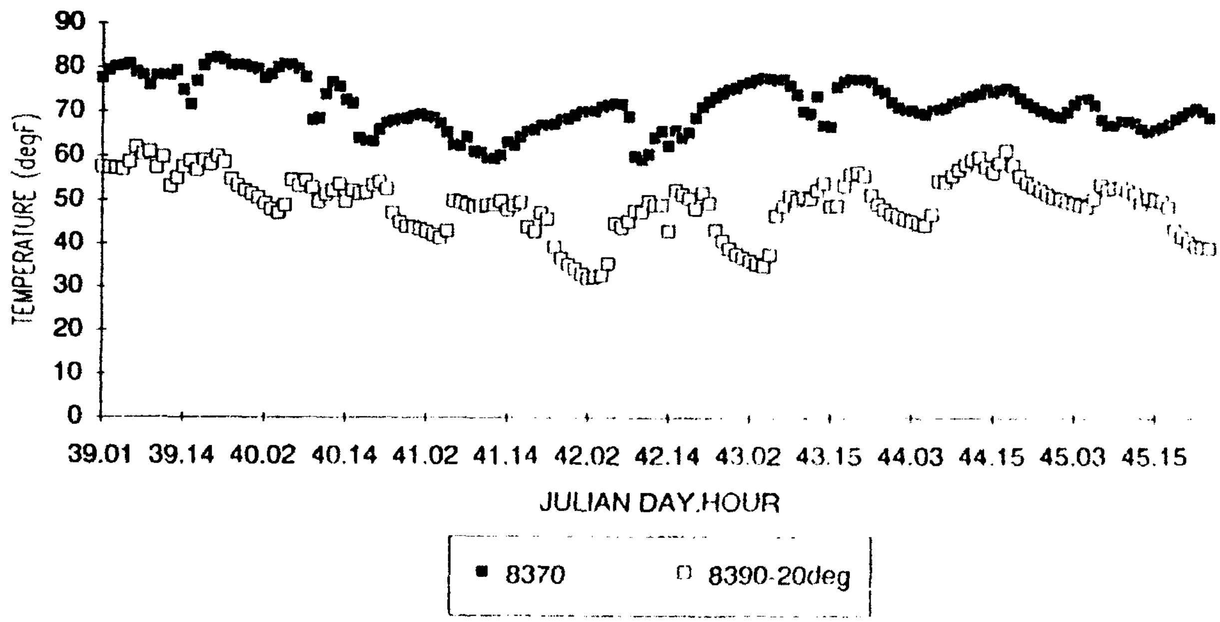


Figure 26. Week 2 Average Space Temperatures.

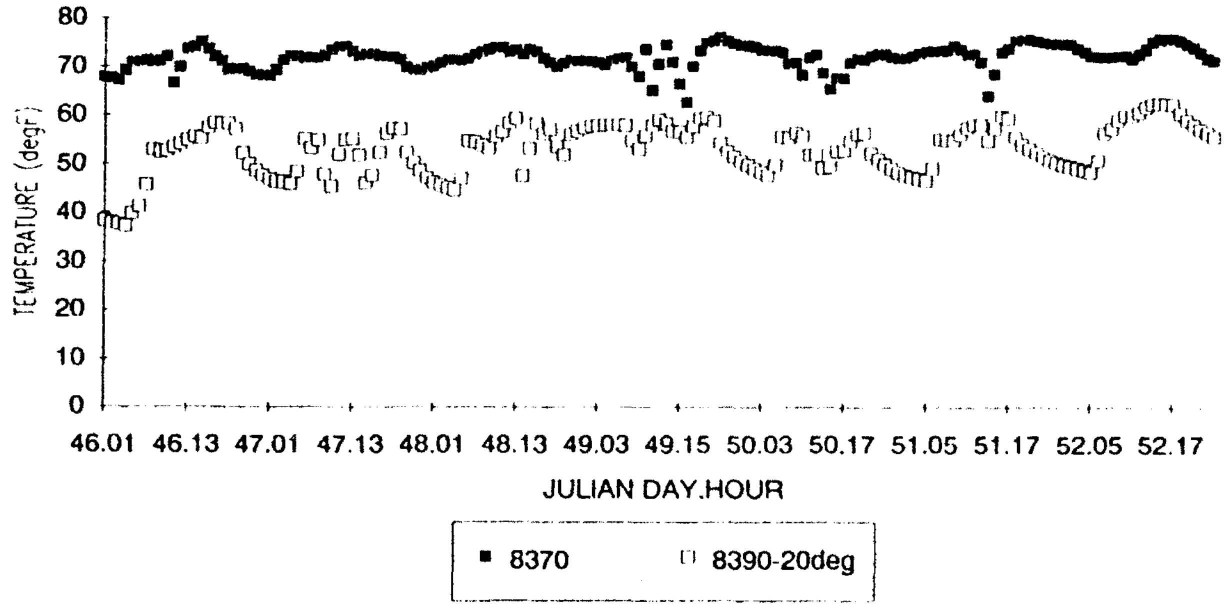


Figure 27. Week 3 Average Space Temperatures.

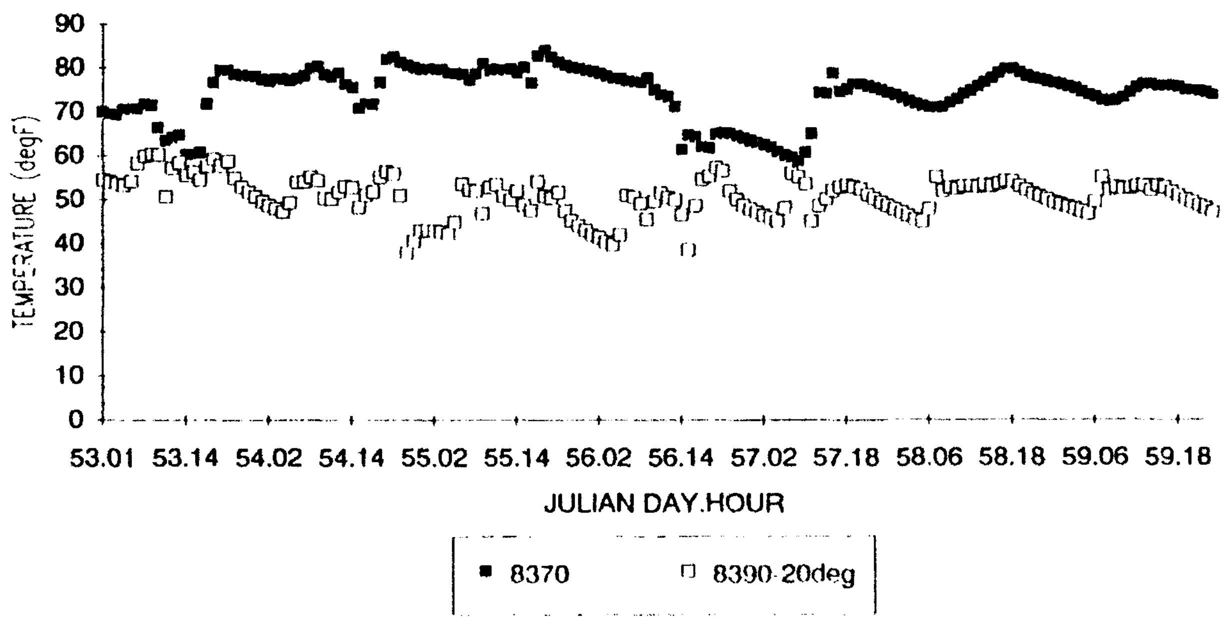


Figure 28. Week 4 Average Space Temperatures.

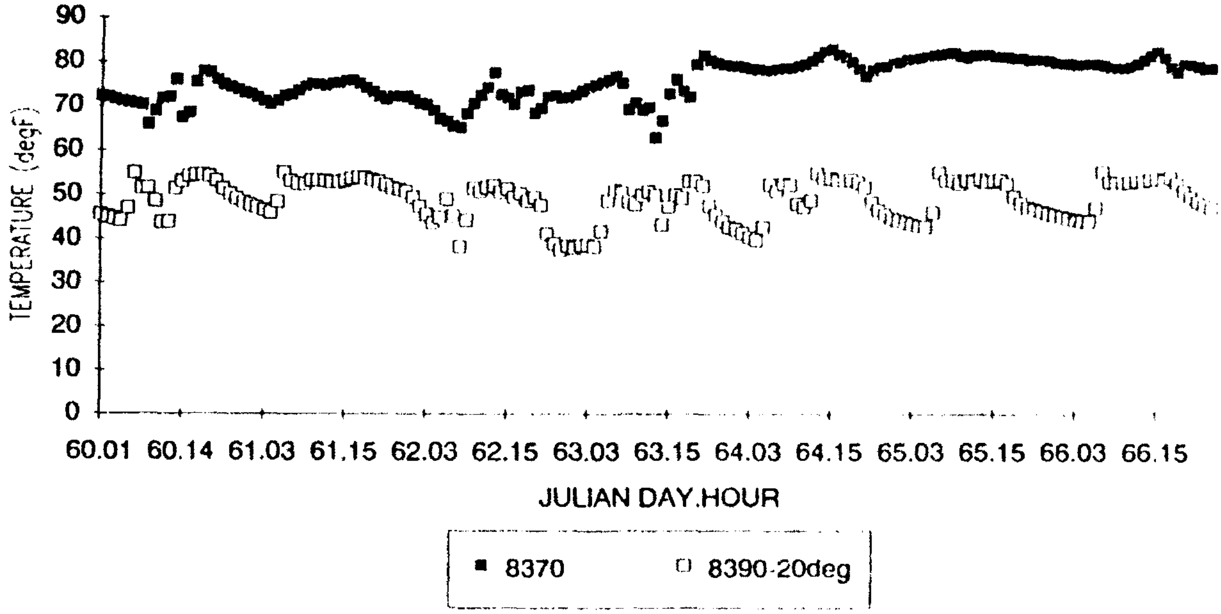


Figure 29. Week 5 Average Space Temperatures.

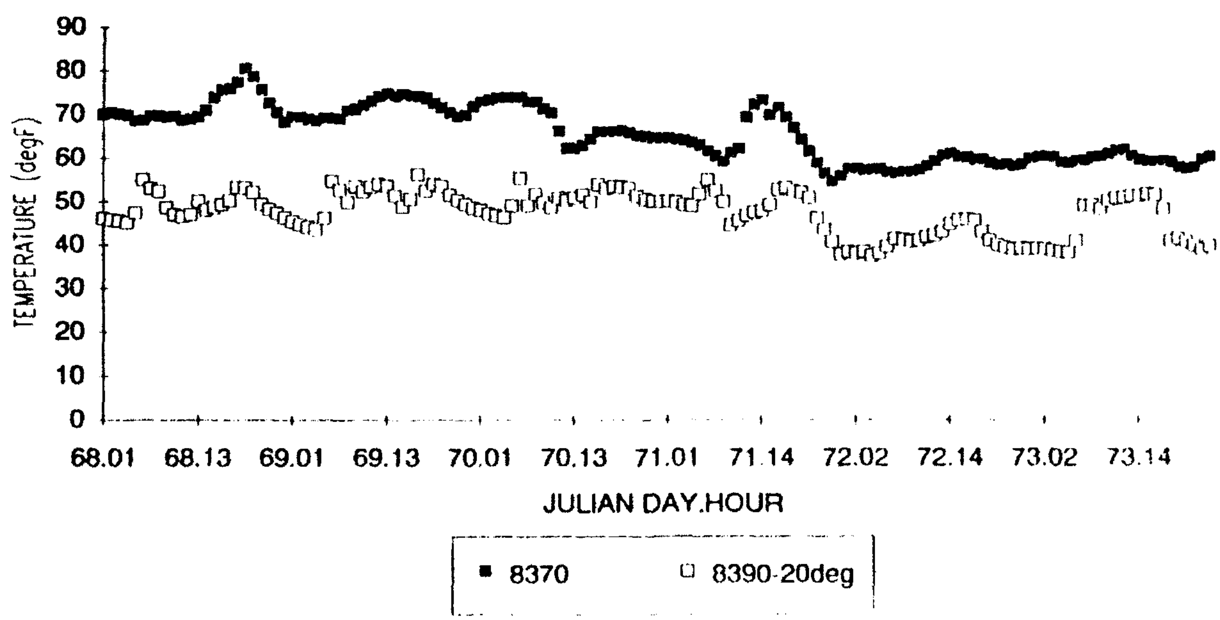


Figure 30. Week 6 Average Space Temperatures.

Table 4

Daytime Versus Nighttime Energy Use in kBtu (kWh)

	Day		Night	
Month	**Bldg 8370**	**Bldg 8390**	**Bldg 8370**	**Bldg 8390**
February	123,000 (36,039)	90,000 (26,370)	137,000 (40,141)	34,000 (9,962)
March	70,000 (20,510)	88,000 (25,784)	77,000 (22,561)	49,000 (14,357)
April	15,000 (4,395)	32,000 (9,376)	30,000 (8,790)	22,000 (6,446)
Total	208,000 (60,943)	210,000 (61,529)	244,000 (71,491)	105,000 (30,765)

Table 5

Radiant Heater Operation - Building 8370

Thermostat	1	2	3	4
February				
Total on time (hrs)	526	527	219	482
Average cycle time (hrs)	35.8	29.3	7.1	26.8
March				
Total on time (hrs)	242	348	138	297
Average cycle time (hrs)	13.5	16.6	4.9	12.4
April				
Total on time (hrs)	48	85	36	168
Average cycle time (hrs)	4.8	5.3	3.6	12.9

the fact that building occupants had to manually reset the thermostats for unoccupied periods pointed out a weakness in the control setup of the radiant building. This problem was later corrected with some controls modifications, which will be discussed shortly.

Three other factors that have potential for affecting energy usage in the buildings include the number and length of bay door openings, and the operation of ceiling and exhaust fans. To try to measure the effect of the bay doors, the 3-minute scans were analyzed and percentage of time the doors were open was calculated. The results of these calculations are plotted in Figures 31 through 33. It was assumed that if a door's status was open when the 3-minute scan was taken, it was open the entire 3 minutes. The percentage time open is then calculated as the ratio of the total time open for all doors to the possible time open. In other words, a score of 100 percent would mean that all of the bay doors were open for the entire hour. Note that the high figures for early February plotted for building 8390 are due to a faulty sensor and should be ignored. In general, open-door time increased with warmer weather. Also, building 8390 usually had more open-door time than building 8370, and was observed to

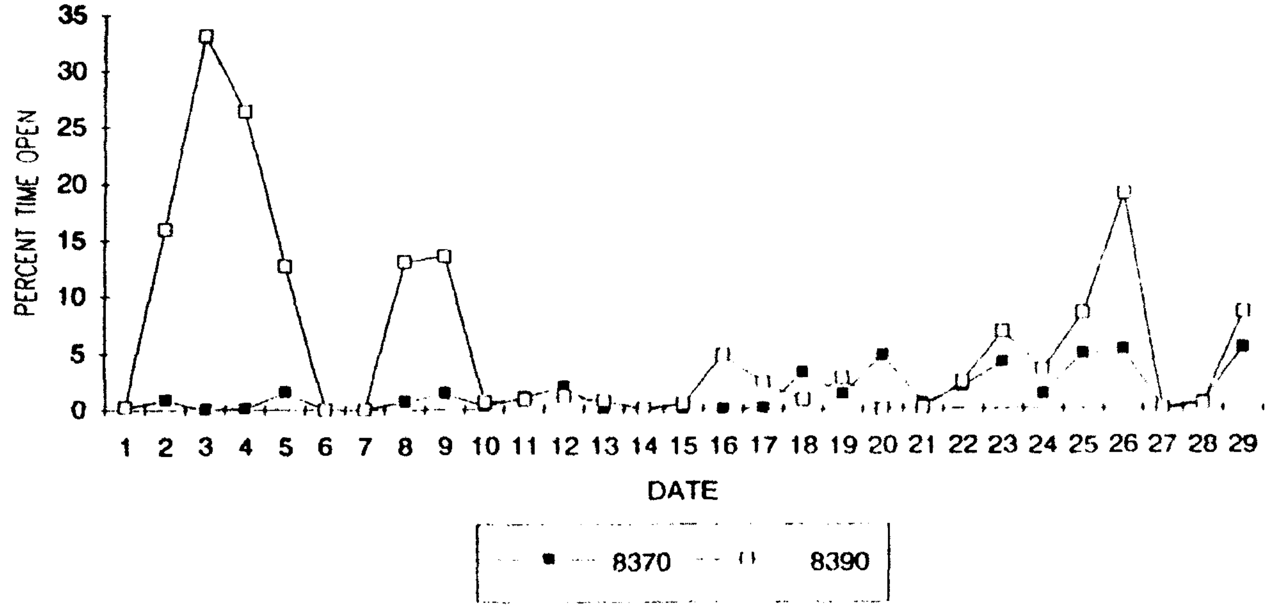


Figure 31. Bay Doors Percentage Time Open, February 1988.

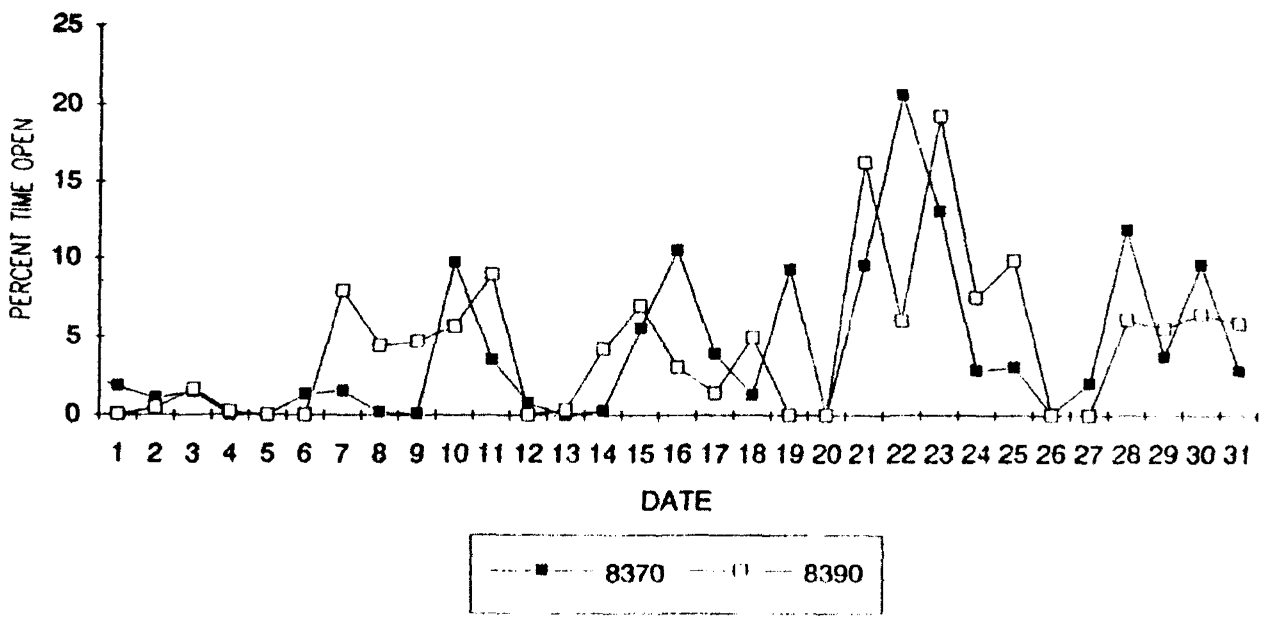


Figure 32. Bay Doors Percentage Time Open, March 1988.

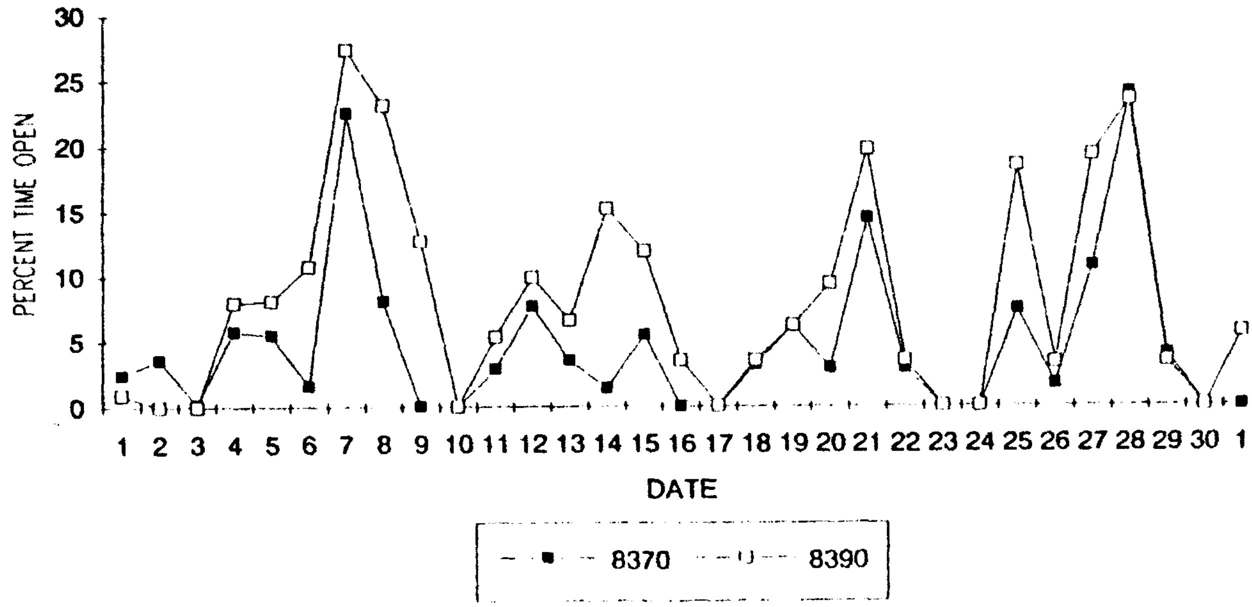


Figure 33. Bay Doors Percentage Time Open, April 1988.

be the busier of the two buildings. Apparently, opening of the bay doors was not a factor in 8370's excessive energy consumption.

Similarly, on-time percentages for the ceiling fans in both buildings were examined. However, no correlation was found between ceiling fan use and energy consumption. Ceiling fan (or recirculation fans in the case of building 8390) usage was high during both low and high energy consumption periods. Conversely, the exhaust fans were used only sporadically in both buildings. Again, no correlation is evident. Table 6 shows the daily average percentages of ceiling and exhaust fan use.

On 14 January 1989, a new control system was implemented in building 8370. This system made the provision for automatic night setback of the radiant heaters. Conventional wisdom for radiant heating is to not set back, because of the time required to heat all of the mass in the space so that it can re-radiate. However, it was postulated that a moderate setback of about 10 °F (6 °C) could achieve an energy savings without letting the objects in the building cool enough to require an excessive amount of energy input to reach comfort conditions. Since the building in question was not particularly massive, the chances for success were deemed especially high. This control system allowed for override of the setback position in the event that the building were to be used beyond its normal schedule. The override was initiated by the occupants pressing a momentary contact switch that would tell the control system to return to its *daytime* setting for a specified period of time. This contrasts with other override schemes where the override turns the heaters fully on for the entire time period. The relative merits of these two approaches will be discussed in Chapter 5.

Figure 34 is a plot of energy consumption for the period from 30 January to 11 March of 1989. This period represents some of the best data taken for the entire experiment, in terms of accuracy and completeness. January and February of 1989 experienced more severe outside temperatures than did the same period in 1988. However, by mid-March, the weather became quite mild and no heating was

Table 6

Daily Average Percentage Time of Ceiling and Exhaust Fan Use

	Bldg 8370		Bldg 8390	
Month	**Ceiling**	**Exhaust**	**Recirc**	**Exhaust**
February	33.6	4.0	35.0	N/A
March	27.6	2.3	2.7	34.0
April	1.3	1.7	15.1	8.2

required. Thus the period shown provides a good comparison between the two buildings *after* the controls were modified. Apparently, the radiant system did not always outperform the convection system, or vice versa. The radiant system consistently outperformed the convection system during the warmer parts of the comparison period, but the opposite was true for colder periods. Regression models of the relationship for building 8370 between outside temperature (or HDD) and energy consumption showed strong straight line correlations. For the winter of 1988, this regression had an R^2 of 0.73, which for the winter of 89 improved to 0.79. The radiant system also used slightly less energy than the convection system for the entire period, as evidenced by the data in Table 7.

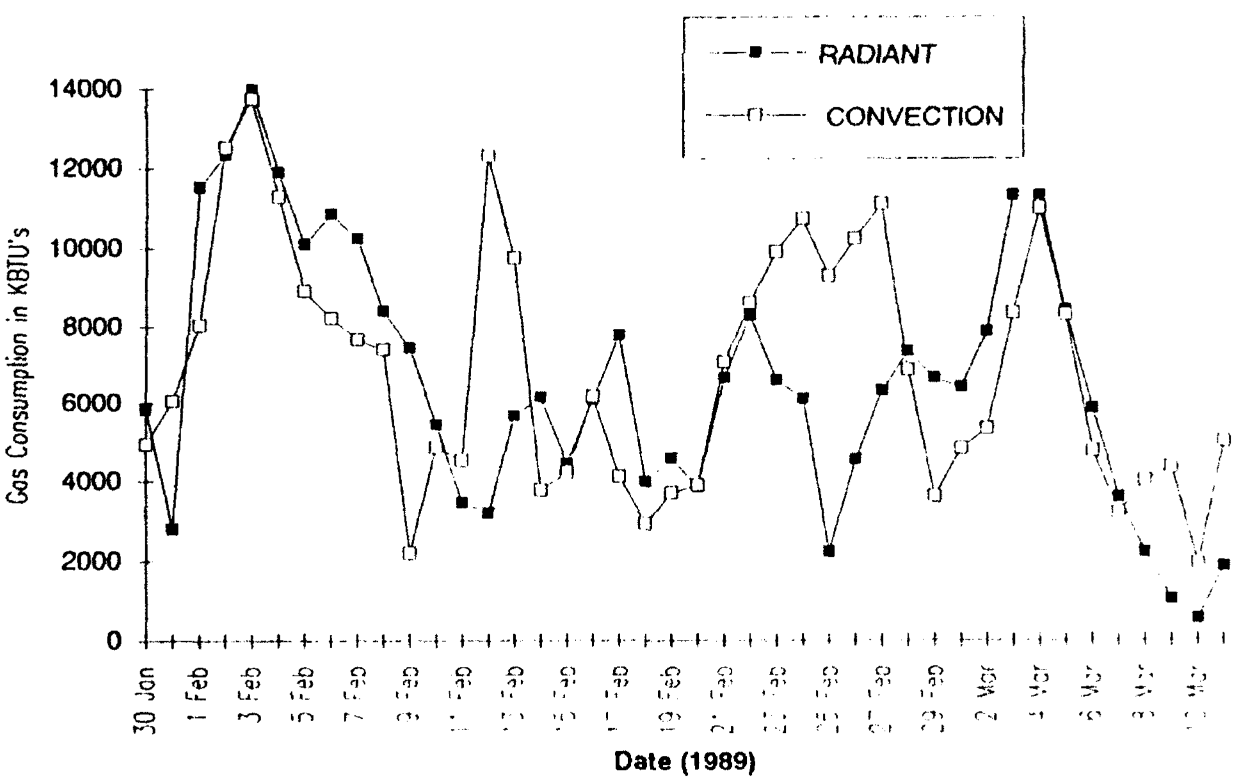


Figure 34. Gas Consumption Comparison After Control Modification.

Table 7

1989 Heating Energy Use in ktu (kWh)

Month	Bldg 8370		Bldg 8390	
January (30-31)	8,623	(2,527)	11,004	(3,224)
February	205,841	(60,311)	217,557	(63,744)
March (1-11)	60,246	(17,652)	60,960	(17,681)
Total	274,710	(80,489)	289,521	(84,829)

Over the entire period shown in Table 7, building 8370 consumed 5 percent less energy than did building 8390. Though this is far from the savings claimed by radiant heating manufacturers, it is a marked improvement over the 43 percent of excess energy consumed by the radiant building for the winter of the previous year. Since February is the only complete month in the 1989 study period, comparison of building 8370's energy consumption in February 1989 to that in February of 1988 further demonstrates the value of the controls retrofit. It has already been pointed out that February of 1989 was colder than that of February 1988. Accordingly, building 8390 used 77 percent *more* energy in 89 than for the same period in 88. However, building 8370 used 21 percent *less* energy than it did for the same period the previous year. The conclusion to be drawn is that proper control is just as important for radiant heating systems as it is for other systems, if not more so. The control modifications made for this project showed a significant savings over the earlier control method. However, total energy savings when compared to the convectively heated building were still less than expected, for several possible reasons.

The experimental setup itself may have affected the measured results. The study's purpose was to do a side-by-side comparison of two similar buildings with similar missions, and to compare results. However, differences in the buildings' usage may have made this comparison more difficult than anticipated. The energy consumption patterns of building 8390 as a whole indicate this fact. Building 8390 actually has two maintenance areas, one on its north end and the other on the south end, with conditioned space in between. Thus far this report has dealt only with the north maintenance bays of building 8390, since this was the intended area of study and was fully instrumented. However, the south bays of 8390 were instrumented *for energy use only*. During the same 30 January through 11 March time period that the north bays used 289,521 kBtu (84,829 kWh) of energy, the south bays of the same building with similar floor space and mission used 479,591 kBtu (140,519 kWh) of gas-equivalent heating energy, or about 65 percent more than the north bays. Comparing the south bays to the 274,710 kBtu (80,489 kWh) used by building 8370, the radiant system would show a 43 percent *savings* over the convection system in that part of 8390. Why there was such a large difference between the north and south bays of 8390 is difficult to determine. One reason may be that the north side of the building was used for maintenance of wheeled vehicles, while the south side was used for tracked vehicles. Maintenance activities on some of the tracked vehicles require the doors to remain partially open for ventilation, so greater infiltration losses would account for some of the difference. Also, the tracked vehicles tend to be larger, resulting in more cold mass moving into the space to be heated. The fact that building 8370 services a mixture of wheeled and tracked vehicles, together with the observed differences within building 8390 due to vehicle mixture, may partially account for the less than expected savings from the radiant system. If the equivalent gas consumption from the north and south bays of building 8390 for the 30 January through 11 March period were averaged and compared to that of building 8370, the radiant building would show about a 29 percent savings, much more according to expectations. However, these savings are not based on a nonrigorous comparison method; these numbers are presented here to give the reader a fuller picture of the nature of the side-by-side experiment, and some insight into the causes for the unexpected results.

Another reason the radiant heating system did not post the expected savings may be that the system itself was not as efficient as hoped. The Perfection-Schwanck heaters used in this experiment were unitary heaters, which are not necessarily the most efficient radiant heaters. Also, the layout chosen for the radiant heaters may have been less than optimal. Various aspects of radiant heating efficiency are discussed in **Design Parameters**, in Chapter 5.

Thermal Environment

Energy consumption alone does not tell the whole story. One can easily save energy by heating less, to the point where occupants become uncomfortable. In the thesis associated with this project, Niedringhaus applied the statistical method of a two-sided t-test to the parameters indicative of the thermal environments in both buildings. The discussion here is centered upon that work, which was done for the winter of 1988. It is reasonable to assume that the controls changes made during the winter of 1989 did not make a significant difference to the comfort of the occupants, since the change to the control profile was for unoccupied hours. The null hypothesis for the test was equality of the means, that is, the mean value of the parameter analyzed for building 8370 equals that of the same parameter for building 8390. The critical t value for the test was 2.00 ($t_{crit} = 2.00$), corresponding to 60 degrees of freedom, about the number of data points from both buildings for a month. For the particulars of the calculations made, see Appendix C. Table 8 summarizes this analysis.

Table 8

Thermal Environment Analysis

		Bldg 8370		Bldg 8390		
Parameter	**Month**	**Mean**	**σ**	**Mean**	**σ**	**t**
Occupied zone	February	68.2 (20.1)	4.45	67.6 (19.7)	4.56	0.52
Temp °F (°C)	March	66.8 (19.3)	5.78	67.5 (19.7)	3.71	0.49 (-)
	April	65.0 (18.3)	4.10	67.4 (19.7)	4.40	2.29†
Globe minus	February	2.94 (1.63)	1.53	0.65 (0.36)	0.40	7.77†
Occupied	March	1.67 (0.93)	0.95	0.68 (0.37)	0.54	5.05†
Zone °F (°C)	April	0.95 (0.53)	0.58	0.50 (0.28)	0.29	3.81†
Globe minus	February	-1.59 (-0.88)	1.37	-2.30 (-1.27)	0.65	2.51†
Space °F (°C)	March	-0.56 (-0.31)	0.58	-2.00 (-1.11)	1.28	5.66
	April	-0.63 (-0.35)	0.73	-0.58 (-0.32)	0.68	0.24 (-)
Thermal	February	13.13 (7.29)	7.15	5.63 (3.13)	1.28	5.57†
Stratification	March	6.94 (3.86)	4.30	5.25 (2.92)	1.67	2.04†
°F (°C)	April	4.42 (2.46)	3.65	2.46 (1.37)	1.47	2.78†

†Indicates a statistically significant difference.

One of the primary considerations in thermal comfort is the air temperature in the occupied area of the building (i.e., near the floor). Table 8 (adapted from Niedringhaus) shows that there was no significant difference for this temperature between the two buildings for February or March. In fact, the building temperatures generally followed the same trends. The single difference, in April, is likely due to higher ambient temperatures.

Another temperature that is a good indicator of the level of comfort in the space is the globe (or operative) temperature, which is an indicator of MRT. In Table 8, the difference between the operative temperature and the occupied zone temperature is given for the two buildings. The results indicate a significant difference, with building 8370 providing a greater difference between operative and air temperatures, as would be expected. Note that there was no significant difference in the occupied zone air temperature for the buildings. Therefore, building 8370 would have felt warmer than building 8390. Assuming building 8390 was adequately comfortable, the air temperature in building 8370 could have been reduced due to the higher MRT being provided by the radiant heaters. Since the air temperature was not reduced to take advantage of the higher MRT, some of the potential energy savings were lost.

Comparing the difference between the globe temperatures and the average of the entire space (as opposed to only the occupied portion), yields some unexpected results. The negative numbers shown in Table 8 indicate that the globe temperatures were less than the average space temperature. Since the globes were located in the lower (occupied) region of the building, these numbers would indicate a stratification problem. Note that a problem is apparent for the entire heating season.

Stratification

Figures 35 through 40 show plots of the air temperatures at three different levels in the building. While the amount of stratification varies, the plots show that the ceiling temperatures are consistently higher than the occupied zone or 6-inch levels. The largest difference is on 5 February 1988 for building 8370, where there is 35 °F (19 °C) difference between the ceiling temperature and the temperature at the 6-inch level. High stratification for building 8370 appears to coincide with periods of high heater use, i.e., continuous operation of the heaters and attendant high energy usage. The statistical analysis was done using the difference between the ceiling temperature and the temperature at the 6-inch level. Building 8370 exhibited greater stratification for the entire period.

The fact that the radiant building had higher stratification was counter to radiant heating appliance manufacturers' claims, and thus was an unexpected result. There are several explanations for the radiant system's exhibited high stratification. One possible contributing factor is the shield shape of the heating appliances. Some radiant heating appliances use "end caps" at the end of the tube runs, or on corners. Figure 41 shows such a cap on the corner of a Type 1(b) unit. The end caps and the shape of the shield help to contain the warm air around the radiant tube and diminish stratification. The heating units in building 8370 did not include end caps. The positioning of the shields on the radiant heaters also can contribute to this effect. Some of the units had their shields tilted to avoid exposing the wall to the radiant pattern. This adjustment makes it easier for the warm air near the radiant tube to escape. Also, the long cycle times experienced in the winter of 1988 may have contributed to the stratification effect. Since the units were on for extended periods of time, there may have been excessive buildup of warm air in the vicinity of the radiant tubes. The fact that the building air temperature was not reduced to take advantage of the higher MRT offered by the radiant heaters also nullified the chance for less stratification to some extent. Warm air will always rise, regardless of the heat source. Much of the claim for reduced stratification is based on the idea that the air in the space *will not* be as warm. A final factor that may have contributed to the high ceiling temperatures in both buildings is that the roofs were well

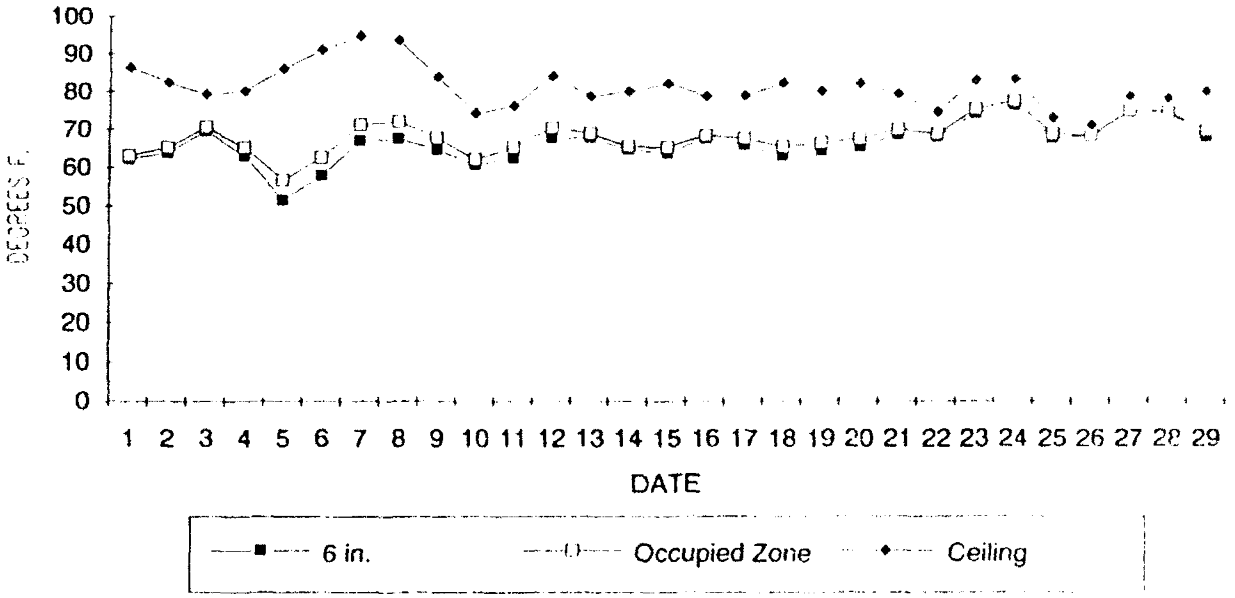


Figure 35. Air Stratification for Building 8370, February 1988.

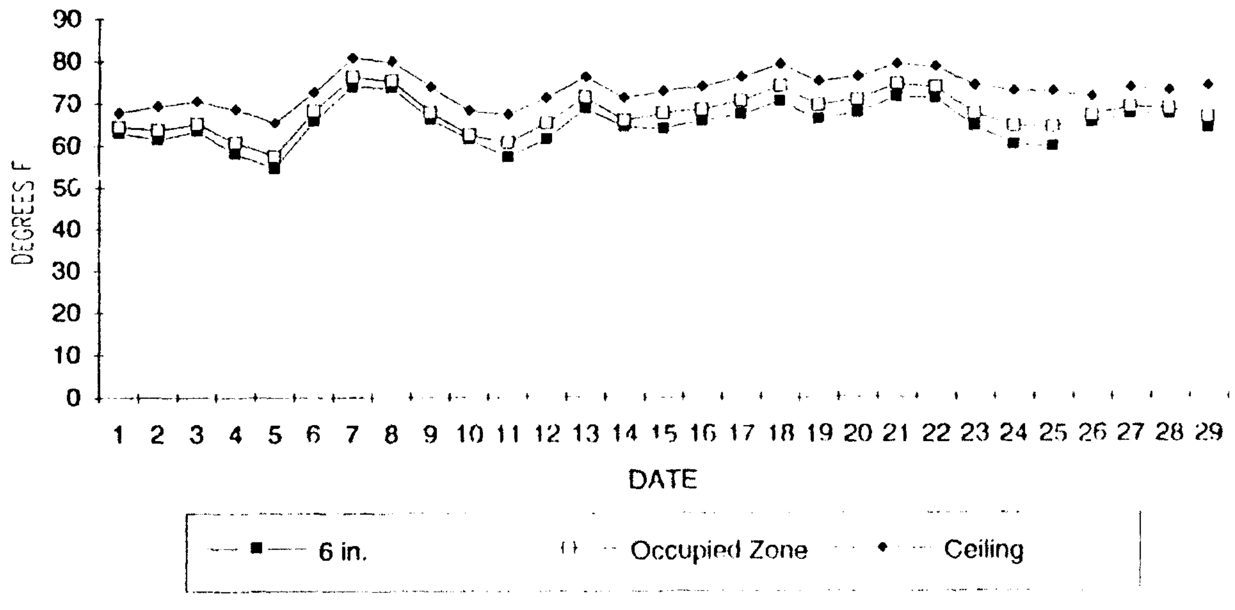


Figure 36. Air Stratification for Building 8370, March 1988.

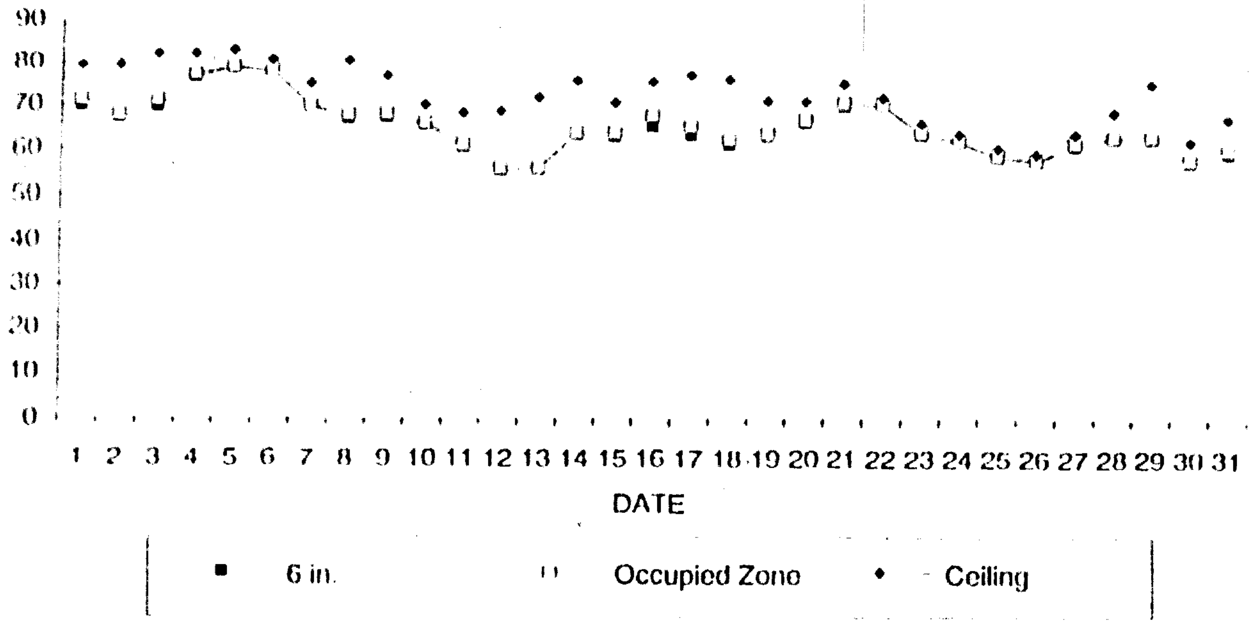


Figure 37. Air Stratification for Building 8370, April 1988.

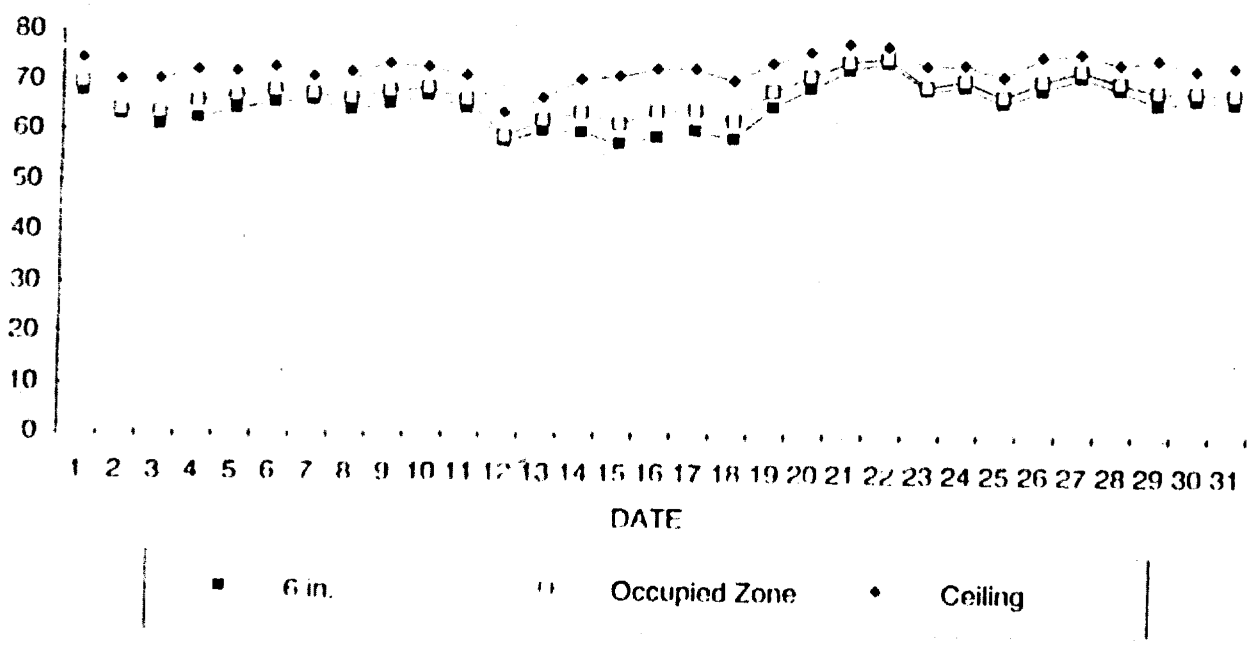


Figure 38. Air Stratification for Building 8390, February 1988.

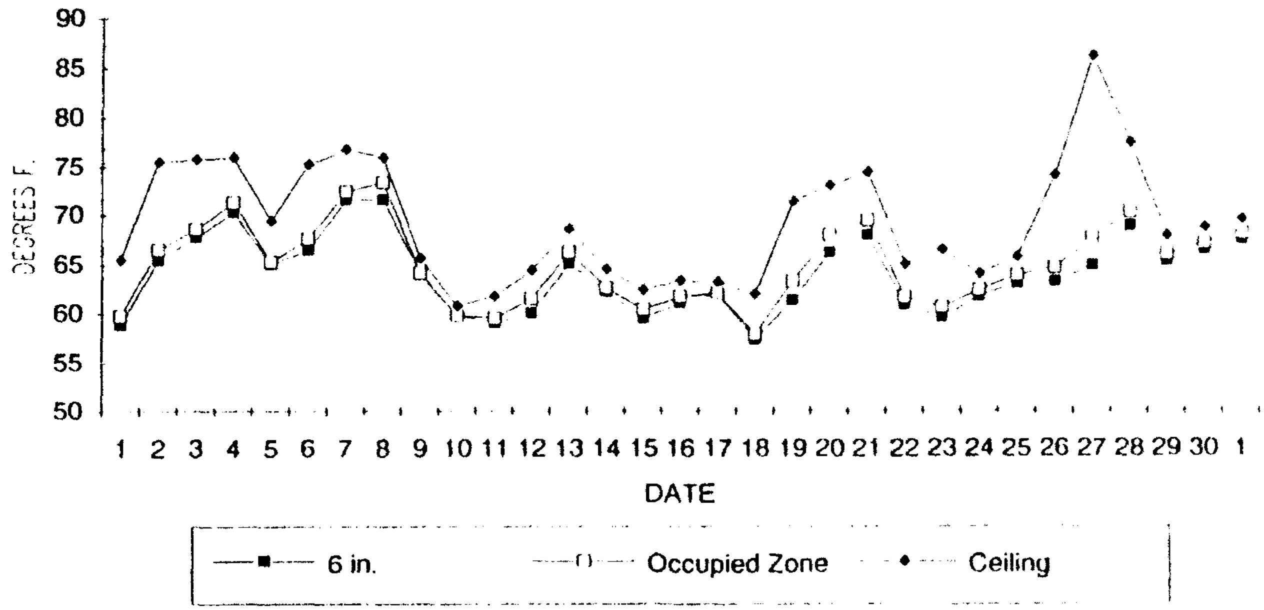


Figure 39. Air Stratification for Building 8390, March 1988.

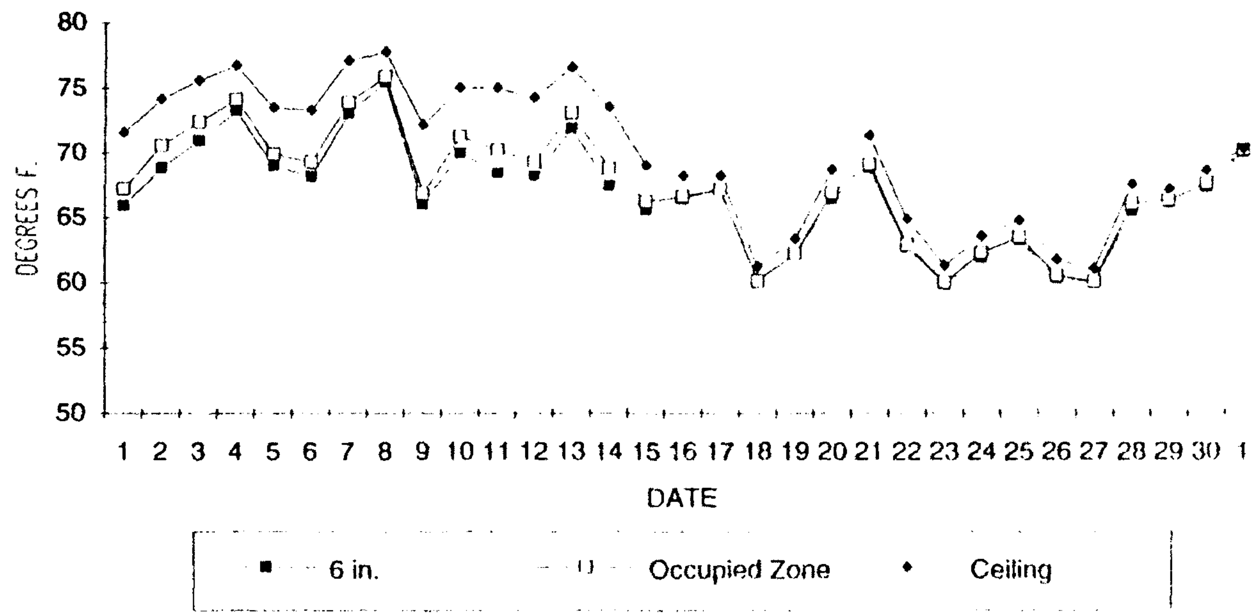


Figure 40. Air Stratification for Building 8390, April 1988.

Figure 41. Shield End Cap on a Type 1(b) Radiant Heating Appliance.

insulated. In older buildings with less well insulated roofs, the ceiling temperature would have been lower due to a higher rate of heat loss through the roof.

Figures 42 and 43 show the effect the ceiling fans and recirculation fans in buildings 8370 and 8390, respectively, had on thermal stratification. Though no strong trends are readily evident, the higher usage of ceiling fans does correspond with lower stratification in building 8370. The recirculating fans in building 8390 seem to have little to no effect, ostensibly because the hydronic unit heaters directly blow their warm air toward the floor. That is, the recirculating fans reproduce the effect of the fans in the convection heating units themselves. Figure 44 shows the effect of the ceiling fans in building 8370 most dramatically. The graph shows temperatures at various levels versus time. The temperature at the 22-ft (6.7 m) level is quite high until 7 a.m. At that time the ceiling fans are switched on and a dramatic reduction in stratification takes place. It appears that ceiling fans help to control stratification in buildings with gas-fired, tube-type radiant heaters.

This demonstration provides some insight into the operation of infrared radiant heaters. Lessons learned about such systems, including those found in the data presented in this chapter will be discussed in **Lessons Learned in Infrared Heating Design** (p 64).

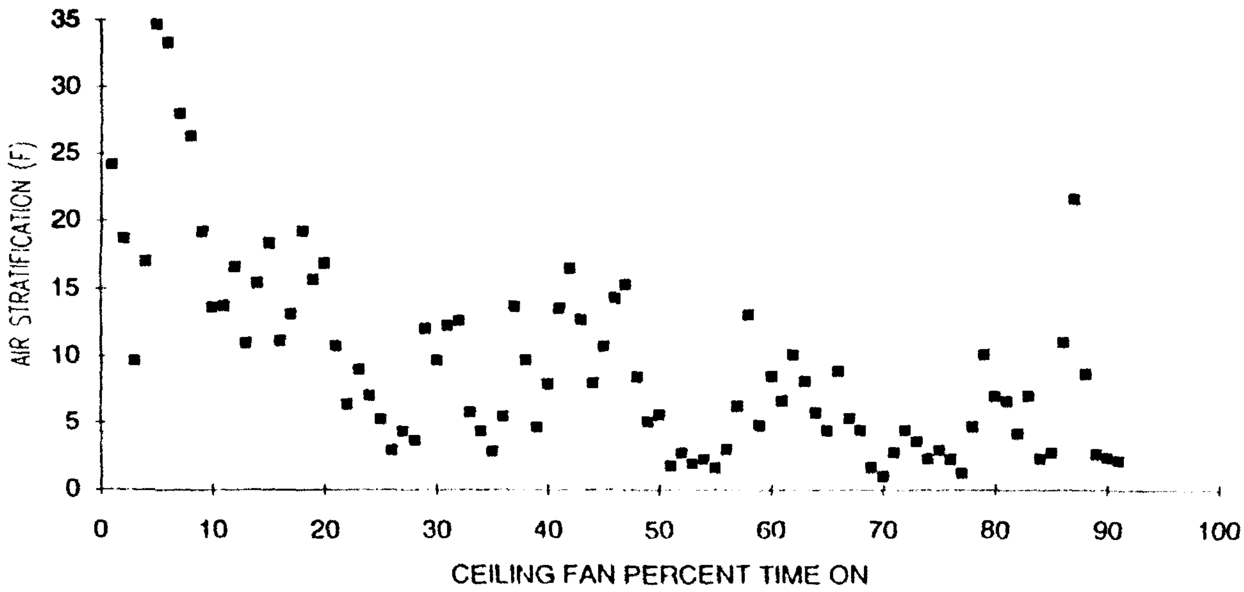


Figure 42. Effect of Switching on Ceiling Fans on Stratification in Building 8370.

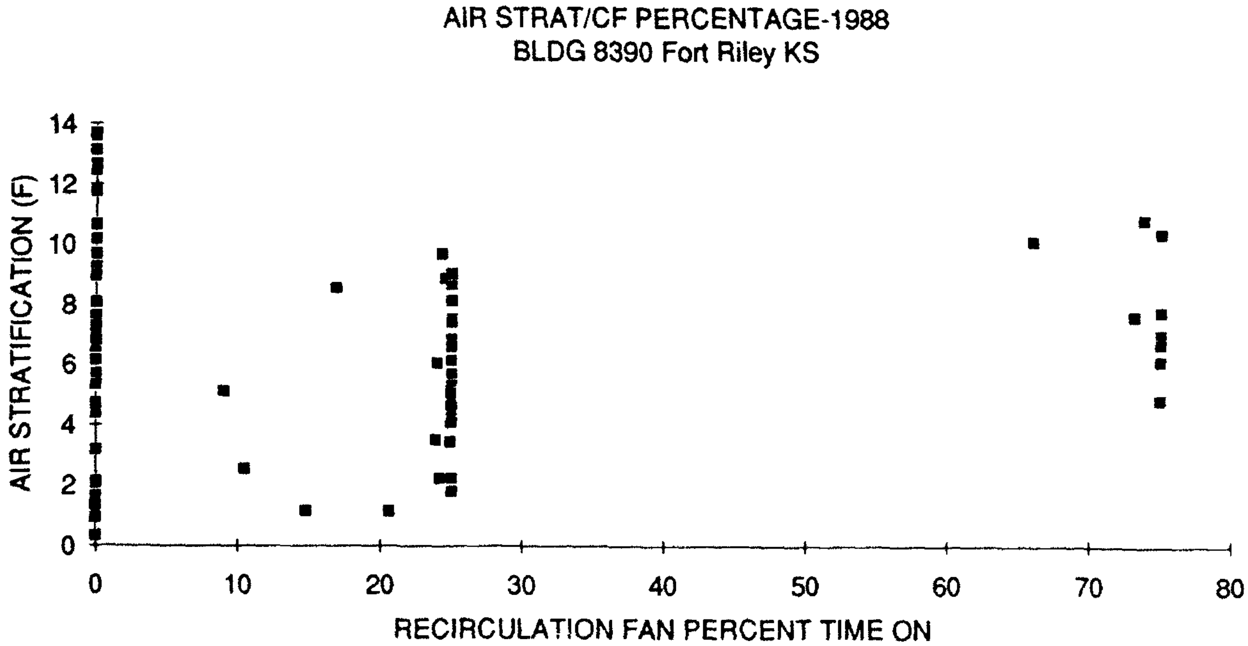


Figure 43. Effect of Recirculation Fans on Stratification for Building 8390.

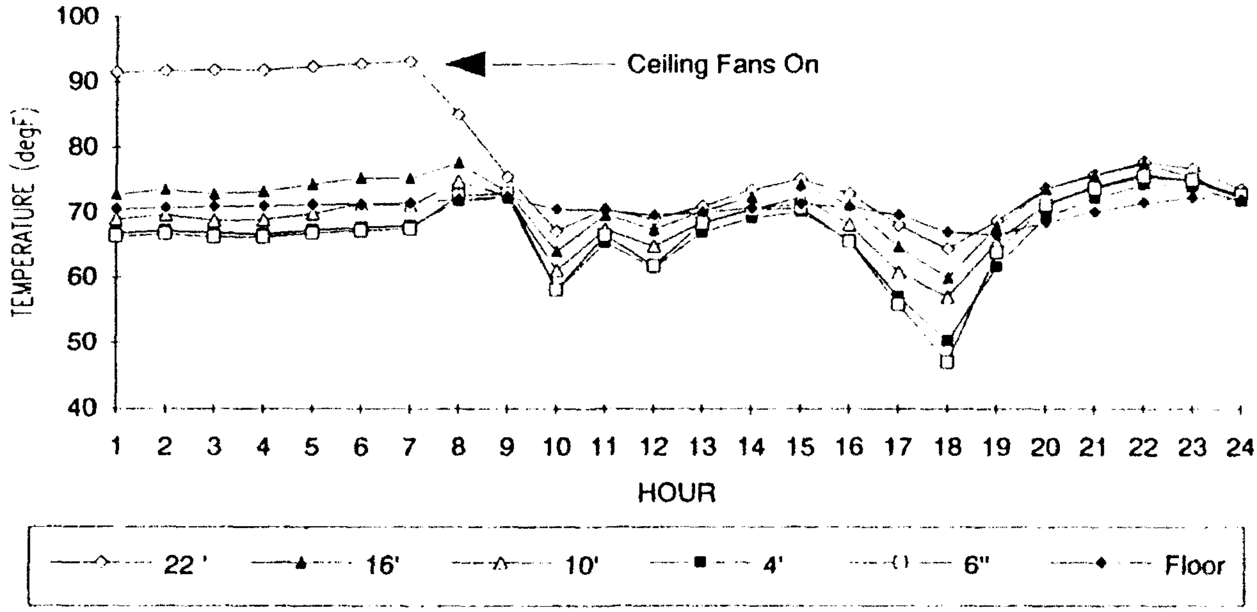


Figure 44. Effect of Switching on Ceiling Fans on Stratification in Building 8370.

5 ISSUES IN INFRARED RADIANT HEATING DESIGN

Design Parameters

Key issues in the design and application of gas-fired infrared radiant tube heaters have been divided into six basic categories: (1) sizing, (2) layout, (3) control, (4) efficiency, (5) safety, and (6) specification. After introducing these concepts, this chapter will outline current design practice gathered from an informal survey conducted as part of this project. Then, types of design guidance currently available for infrared radiant tube heater applications will be given. Finally, this chapter will review the lessons learned in this project with respect to the six basic concerns for radiant heating design.

Like all heating systems, the primary issue for infrared radiant tube heating systems is one of *sizing*. That is, how much heating capacity should be installed for a given building? Two considerations are generally taken into account when sizing radiant heating appliances. The first is the building heat loss, just as it is for a conventional system. The most recommended practice with regards to heat loss is to calculate the loss for a radiant system just as if a conventional system were being installed, and then to multiply by a factor that varies from 0.8 to 0.85, depending on the efficiency of the radiant system being employed. Generally the ASHRAE building heat loss calculation is employed, then multiplied by 0.85 for unitary heaters or 0.8 for more efficient units. This factor is called the *radiant adjustment to heat loss*, and is justified by the various "advantages" of radiant heating discussed earlier. Another rationale for making this adjustment is that the ASHRAE load calculations were developed for convection systems, so some adjustment is necessary. The practice of making this adjustment is discussed later in this chapter. Suffice it to say that the current practice is based on 25 years' experience of the manufacturers. Another consideration is the mounting height of the radiant appliance. Since the intensity of the radiant energy varies inversely with the square of the distance from its source, units mounted particularly high need to be oversized to assure a sufficient intensity to heat the floor and other objects in the occupied portion of the space. Generally manufacturers will recommend upsizing a unit a certain percentage for every foot over a given height it is to be mounted. For example, 1 percent per foot of mounting height over 20 ft (6 m), to a height of 50 to 60 ft (15-18 m) would be a typical recommendation.

Also like other heating systems, the question of uniform heat distribution is important to infrared radiant tube systems. However, since the means by which heat is distributed to the space is different than that of convection systems, the factors to consider for achieving a uniform distribution are different as well. Radiant tube systems have different considerations than do low temperature, low intensity (heated slab) systems, or high intensity spot heating systems. For example, spot heating systems can sometimes still provide comfort with asymmetric radiant fields, much as it is comfortable to stand in front of a warm fire on a cold evening. The degree of asymmetry that is tolerable has yet to be systematically described. Radiant tube heaters are most typically used for total space heating, rather than spot heating. Since a great deal of a radiant tube system's ability to provide comfort is based on a thermal reserve being built up in the floor (and, to a lesser extent, in other objects in the space) rather than solely relying on heating the occupants directly, the question of proper *coverage* is much more important. Thus the layout of the radiant heaters must take maximum advantage of the pattern of radiation produced by the heater. That is, one must strive to maximize the *pattern efficiency* for the system, which is a measure of the system's ability to deliver heat consistent with the need for heat in the space. Therefore, two major factors determine the layout of a radiant heating system: the radiant pattern of the heating appliance used, and the use (occupancy, etc.) of the space being heated. The goal for the radiant tube heater layout is to provide sufficient radiant intensity to meet the requirements of the space being heated as uniformly as practicable. It is common practice to concentrate most of the heating capacity around the perimeter of the building at a mounting height of 10 to 16 ft (3-5 m).[18] Other units may then be placed to meet special needs within the space. Determining radiant heating system layouts is a complex activity, and designers must use their own judgment in the absence of rigorous procedures. The distributors of radiant heating appliances are usually experienced with heater placement issues, and are the most often used resource for determining layouts in new radiant heating applications.

Control for full building heating applications is similar to that for convective systems. All control elements except the thermostat are within the radiant tube heating appliance. A standard thermostat provides on-off control of the appliances. Other control methods based upon operative temperature attempt to account for the effects of a higher MRT when controlling the heating system. Some radiant control panels now available with globe thermometers are designed specifically for radiant heating applications. The relative value of such units was not evaluated as part of this project

Efficiency is a key issue in any heating system. Efficiency is simply the ratio of energy output of a process to the energy input. Three types of efficiency are relevant to infrared radiant tube heaters. *Pattern efficiency* is related to the implementation of the heating system in a given building. *Thermal efficiency* is defined as the fuel input minus the stack loss, all divided by the fuel input, just as it is for convective systems. Thermal efficiency is primarily a property of the heating appliance, though how the appliance is installed in a particular heating system implementation may affect its thermal efficiency. A distinction is made between two types of radiant heating appliances, condensing ("wet") systems and noncondensing ("dry") systems. Condensing systems are so named because they will produce condensate after reaching steady state operations (though not continuously). The presence of condensate is an indicator of operation at a high level of thermal efficiency. Specifically, condensing appliances are recognized as those that operate continuously at thermal efficiencies above 83 percent. The presence of this condensate necessitates design considerations to prevent corrosion of the appliance.

Radiant efficiency is a measurement index that seeks to compare the radiant energy output of the appliance to its fuel energy input. ANSI standard Z83.6a-1989 specifies how to test for radiant efficiency for gas-fired infrared heaters. Radiant efficiency taken together with other factors can be used to describe *fixture or appliance efficiency.* Fixture efficiency is a measurement index of the radiant heating appliances ability to release available radiant energy to the space. For any radiant heating appliance, some of the radiant energy is absorbed by the appliance itself and is then convected away. High convection losses, coupled with the inability to properly control the direction and distribution of radiant energy will result in a low fixture efficiency. High emitter temperature, high tube emissivity, and high reflectivity for the reflector material will contribute to a higher fixture efficiency. However, tube length and reflector shape must also be considered.[19] There currently are no standards for measuring fixture efficiency.

Safety is a concern in all building systems, and is of particular concern with infrared radiant appliances, due to the high temperatures involved. Obviously, one of the primary concerns is fire safety. As with other heating apparatuses, clearances to combustibles are established for infrared radiant tube heaters by all certifying laboratories. Consideration of combustibles goes beyond installation and into the operational phase for infrared radiant heaters. Stacking stored materials too close to the radiant heater can cause hot spots to develop, and should always be avoided. Strict adherence to manufacturer's recommendations is advised, in addition to compliance with all national and local fire codes. The fire codes will also provide the designer with information as to the suitability of a radiant device for a particular environment. Some buildings harbor hazardous environments where flammable or otherwise

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[18] ASHRAE, *1987 HVAC Handbook* (ASHRAE, 1987), p 16.8.
[19] Roberts-Gordon, Inc., pp 37-38.

potentially hazardous vapors may be present. Radiant heaters are not applicable in most environments where the atmosphere contains ignitable dust, gases, or vapors in sufficient concentrations to present a hazard. In addition, vapors that form lethal or otherwise potentially dangerous compounds when heated should be avoided unless special attention has been paid to remove them from the space. For example, trichlorethylene is used in degreasing operations, but when heated forms toxic phosgene and corrosive hydrogen chloride.[20] Less dangerous vapors can contribute to corrosion of the heating appliance. For example, mere traces of fluoro/chloro-hydrocarbons can cause accelerated corrosion of the heat exchanger surface.[21] While not an immediate safety hazard, the corrosion of the unit will lead to its eventual failure with possible safety consequences. Sufficient ventilation is important for all infrared heating devices. If unvented devices (those that exhaust to the space) are employed, sufficient ventilation must be provided to assure that the combustion products are diluted to an acceptable level. Ventilation and other humidity control methods are also important for unvented units to prevent condensate from the products of combustion from forming on the colder interior surfaces of the building, such as the underside of the roof. If vented appliances are used, these latter problems are not of concern, but ventilation air is still required to make up any combustion air that is being drawn from the space. If the appliance is vented and draws its combustion air from the outdoors, then the usual requirements for ventilation for the type of space being considered are employed. The standards that apply to infrared radiant tube heating in a given building will vary with the building type and locality. However, some standards apply generally to gas-fired radiant heaters, and will be discussed later in this chapter in **Currently Available Design Guidance** (p 59).

Specifications are another issue in infrared radiant tube heating application. The Corps' current guide specifications allow the use of radiant heaters, but are not specifically geared toward them. Since the guide specifications were written with conventional (convection) heating systems in mind, they do not cover all of the specifics for radiant systems. As a result, the design engineer is required to devise his own radiant specifications. There are two major potential pitfalls in specifying radiant systems. One, mentioned earlier, is that lower efficiency units than those that the designer intended could be substituted. This generally means lower first costs (and/or greater profits for the contractor), but may also mean that either excessive energy will be consumed or the space will not be adequately heated, or both. A second pitfall is that the designer will need to work more closely with a radiant heating appliance vendor to develop the specification, which could lead to potential procurement problems with competitive bids. (The government may not get the best price for the required equipment.) The specification problem may be one of the largest barriers to designers wanting to use radiant heating. More time and effort is required, and when projects are short-dated, radiant heating may be overlooked because of the extra work involved, even though the potential for substantial energy savings may exist.

Current Design Practice

An informal survey was conducted as part of this project to further review current design practices for radiant heating within the Corps. This survey included all forms of radiant heating that the respondents were familiar with. Appendix D includes a list of the persons contacted, questions used while querying interviewees, and a synopsis of the responses. The phone interviews were a rather

[20] ASHRAE (1988), p 29.5.
[21] Roberts-Gordon, Inc., p 72.

informal query of mechanical engineers throughout various Corps elements around the country. Many of the responses were similar. Of greatest importance were the common beliefs that:

1. Radiant heat was the only way possible to maintain productive thermal comfort conditions within large volumes such as aircraft hangars, tactical shops, warehouses, etc., that typically had large volumes and infiltration rates.

2. Radiant heaters saved energy and outperformed convection systems in the above-mentioned building types.

3. Design of radiant heaters was usually based on proprietary manufacturers' design guidance literature.

4. Although heating loads are calculated just as they would be for conventional systems, a reduction factor is applied to these loads to size the radiant system (per manufacturers' recommendations). Thus the installed capacity of the radiant systems is often only two-thirds the capacity of a convection system.

The types of systems used and their associated nuances differed greatly between respondents. Some installations used interior air for combustion, while others drew in air from the exterior. The control of radiant heaters varied from just letting them run 24 hours per day to controlling them with programmable thermostats, which were primarily used for nighttime setbacks.

The general consensus of the interviewees was that radiant heaters filled a need in heating applications for certain facility types. Energy conservation and occupant comfort were the primary driving forces for specifying these systems.

Most respondents indicated they relied most heavily on the manufacturers of radiant heating systems for their system design guidance. This reliance sometimes has pitfalls, as discussed earlier, and may not always result in the best system design. Radiant manufacturers will usually use their own hardware items to meet the design criteria. If other manufacturers are to bid successfully on the same job, they will be confined to using similar equipment, even though they may have a different market approach and hardware that would be better suited to the job. It is difficult for the designer to "genericize" the design if he/she must rely on proprietary information or equipment to do the initial design. Ideally, designers should be able to design and specify "generic" radiant systems with all of the features needed for successful implementations before looking at some specific manufacturer's literature. However, to do so requires the designer to have access to some type of design guidance, since many will not necessarily be familiar with radiant heating.

Currently Available Design Guidance

An exhaustive search for guidance available to Corps designers on gas-fired infrared radiant tube heating system design included government and these private sources: manufacturers (not limited to heating equipment manufacturers), professional societies, and standards and testing organizations.

Typical government guidance for doing Corps design work includes Army regulations (ARs), Air Force regulations (AFRs), etc., technical manuals (TMs), Corps of Engineers guide specifications

(CEGS), and the *Architectural and Engineering Instructions: Design Criteria*.[22] Additional government resources may include technical reports from laboratories or other government agencies, engineering technical letters and notes (ETLs and TNs), and various other bulletins. Respondents to the survey specifically referred to only two such documents, AFR 88-15 and TM 5-810.[23] The search for additional government resources revealed very little additional available information.

AR 420-49 pertains to heating systems, and prescribes policy and criteria for operation, maintenance, and repair of boiler plants and heating systems, selection of energy sources for conversions and new construction, quality control for solid fuels and maintenance, and repair of fixed petroleum storage and dispensing facilities.[24] AR 420-49 focuses on central heating plants, and contains no specifics on building heating system selection beyond standards for space heating temperatures and temperature controls. No mention is made of specific building heating system, including radiant heaters.

Some survey respondents cited AFR 88-15, *Criteria and Standards for Air Force Construction*, which has more information on radiant systems. First, it defines five types of construction categories based on fire safety considerations (section C, page 1-20). Further guidance determines combustibility and explosive limits. The regulation also specifically refers to radiant heating under 15-126 Building Heating Systems: "(5) Unit heaters will generally be used in shop, warehousing, and other hi-bay type industrial areas. Infrared heaters will be considered where fuel supply can support them. Administrative, schools, offices, and other type administrative areas may use either convective or radiant heating."[25] AFR 88-15 later states the following for aircraft hangars: "(a) Floor type air handling units will not be provided for hangar areas except where building geometry dictates. Overhead or sidewall mounted heaters will be used. These heaters may be NFPA, UL, or AGA approved gas or oil fired radiant tube heating systems when installed in accordance with NFPA 409."[26] NFPa 409 is a standard on aircraft hangars, and is specific to the building type, not radiant heaters. The AFR gives no guidance on sizing, layout, or other design parameters for using radiant tube heaters. This document does, however, give the designer license to investigate and use infrared radiant heaters.

Another regulation not referenced by any of the survey respondents is Department of Energy regulation 10 CFR Part 435, *Energy Conservation Voluntary Standards for Commercial and Multi-Family High Rise Residential Buildings; Mandatory Rule for New Federal Buildings; Interim Rule*. This regulation has a small section on radiant heating, found in section 435.107, "Heating, Ventilation, and Air-Conditioning (HVAC) systems:"[27]

> 7.2.4.1 Radiant heating systems shall be considered in lieu of convective or all-air heating systems to heat areas which experience infiltration loads in excess of two (2) air changes per hour at design heating conditions.

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[22] *Architectural and Engineering Instructions: Design Criteria* (Headquarters, U.S. Army Corps of Engineers [HQUSACE], 1989).

[23] AFR 88-15, *Criteria and Standards for Air Force Construction*, Interim Draft Edition (Department of the Air Force [DAF], January 1986); Technical Manual (TM) 5-810-1, *Mechanical Design: Heating, Ventilation, and Air Conditioning* (Department of the Army [DA], 15 August 1983).

[24] AR 420-49, *Heating, Energy Selection and Fuel Storage, Distribution, and Dispensing Systems* (Department of the Army, April 1985), p 3.

[25] AFR 88-15, 15-126a(5).

[26] AFR 88-15, 15-126b(2).

[27] 10 CFR Part 435, "Energy Conservation Voluntary Performance Standards for Commercial and Multi-Family High Rise Residential Buildings; Mandatory for New Federal Buildings; Interim Rule," *Federal Register*, Vol. 54, No. 18, U.S Government Printing Office, Washington, DC, January 30, 1989), p 4668.

7.2.4.2 Radiant heating systems should be considered for areas with high ceilings, for spot heating, and for other applications where radiant heating may be more energy efficient than convective or all-air heating systems.

No specific provision for radiant heating system design is made in the "Calculation Procedures" section that follows these paragraphs.

A number of the survey respondents referenced TM 5-810-1, *Mechanical Design: Heating, Ventilating, and Air Conditioning*. Two paragraphs in Chapter 3, "Types of Systems,"[28] reference radiant and infrared heating:

"*d. Radiant heating.* Radiant heating will be considered for application in hangars and high bay spaces. Radiant panels are adaptable to solar heating. Refer to ASHRAE Handbooks.

e. Infrared heaters. In high bay areas or in outdoor applications infrared heaters using gas, oil or electricity and operating at surface temperatures from 500° to 5000° F can be used. refer to ASHRAE Handbooks."

No further information specific to infrared radiant heaters is provided, beyond reference to ASHRAE materials.

Another design manual not referenced by any of the survey respondents is the Naval Facilities Engineering Command Design Manual 3.03, *Heating, Ventilating, Air Conditioning, & Dehumidifying Systems*. This manual references radiant panel air systems, and infrared heating systems. The section on infrared heating systems[29] reads as follows:

3.12 Infrared Heating Systems. Infrared heating systems are suitable for use only where heating of the entire space is not required, for example, in loading docks, fabrication shops, aircraft hangars, and warehouses. Infrared heating systems are primarily used as spot heaters. These heating units can be electric, gas-fired or oil-fired. For the most efficient infrared system, consider the line of sight and distance between the occupant and the heater. Installation of these systems shall be in accordance with NFPA Standard No. 31. For equipment selection, see paragraph 4.14.4

3.12.1 Safety Features. Infrared heaters equipped with power burners shall have an automatic fuel shut-off switch for use when the blower is not operating. An example of this is a centrifugal or sail switch. Locate infrared units to avoid hot spots or the possibility of igniting surrounding materials.

3.12.2 Design Factors. Typical heating load calculations are based on heat losses associated with the indoor space air temperature. Because infrared heating systems are not designed to directly heat the space air, a typical heating load calculation will tend to inaccurately size the heating equipment required. Infrared heating systems raise the space air temperature only indirectly through the re-radiation of thermal energy from surfaces in direct sight of the heating system.

Carefully investigate all factors affecting the heating load and follow the design procedure described in the ASHRAE Systems Handbook, High Intensity Infrared Heating chapter.

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[28] TM 5-810-1, *Mechanical Design: Heating, Ventilating, and Air Conditioning* (Headquarters, Department of the Army [HQDA], April 1988), p 3-1.

[29] Design Manual 3.03, *Heating, Ventilating, Air Conditioning, & Dehumidifying Systems* (Naval Facilities Engineering Command, Alexandria, VA, January 1987), pp 3.03-113 - 3.03-114.

NFPA Standard 31, *Standard for the Installation of Oil Burning Equipment*, cited in TM 5-810-1, contains no information specifically geared to infrared heaters. This standard would not pertain at all to gas-fired infrared heating appliances. Paragraph 4.14.4 of NFPA Standard 31[30] reads as follows:

> 4.14.4 High-Intensity Infrared Heaters. High-intensity infrared heaters are used primarily for spot (local) heating. Use this equipment in loading docks, warehouses, hangars, gymnasiums, and similar applications where selective heating of occupants is desired. This equipment shall not be used in areas where it can ignite inflammable dusts or vapors, or can decompose vapors to form toxic gases. Unvented gas heaters in tight, poorly insulated spaces can cause excessive humidity and consequent condensation on cold surfaces. For more information, see paragraph 3.12.

This design manual has more information on infrared radiant heating than does the Army manual, but the information is geared specifically to high-intensity infrared "spot" heating. There is no information directly applicable to low-intensity infrared radiant tube heaters for whole space heating.

The guide specification that most directly relates to gas-fired infrared radiant tube systems is CEGS-15565 (March 1989). This specification incorporates American National Standards Institute (AMSI) Standard Z83.6, *Gas-Fired Infrared Heaters*, by inclusion. Section 2.3.5, "Infrared Heaters"[31] states:

> 2.3.5 Infrared Heaters
>
> NOTE: Unvented infrared heaters may be employed only in buildings with high ceilings such as shop buildings, industrial buildings, etc. Exhaust vents will not be located directly above infrared heaters. Where the units are used in metal buildings, the roof will be insulated and an adequate non-combustible vapor barrier will be provided. Unvented infrared heaters will not be used in hazardous areas. Select type of heater required and delete inapplicable type of ventilation. Capacity of the exhaust sytem must be a minimum of 4 cfm per 1,000 Btu per hour input to properly dilute the carbon dioxide produced. Provision will be made to provide air to the space in an amount equal to the exhaust.
>
> 2.3.5.1 Heaters
>
> Heaters shall conform to the requirements of \-ANSI Z83.6-\ and shall be [vented] [or] [unvented] type [as indicated]. [Vented heaters shall be vented to the outside atmosphere.] Heater style shall be [surface combustion] [catalytic] or [tubular] type [as indicated]. Reflector shape shall be [parabolic] [horizontal] [or] [standard] [as indicated].
>
> 2.3.5.2 Space Thermostats
>
> Space Thermostats shall have a 3-degree F differential and set point range of 40 to 75 degrees F. Thermostats shall control the burner. Thermostats located in the direct radiation pattern shall be covered with a metal shield.

As written, the guide specification allows a tube-type infrared heater to be specified. However, the designer must add to the template significantly to ensure that the ordered radiant tube appliance is appropriate (positive-pressure vs. negative-pressure, unitary vs. site-assembled, etc.). The designer will have to provide this information, or leave these decisions to the discretion of the contractors bidding on the job. Also note the specification for a shield over the thermostat. Work done by Buckley and Seel

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[30] National Fire Protection Association (NFPA) Standard 31, *Standard for the Installation of Oil Burning Equipment* (NFPA, Quincy, MA, 1987).

[31] CEGS-15565, *Guide Specification for Military Construction* (Department of the Army, March 1989), pp 6-7.

suggests that the shielding may cause inaccurate temperature readings due to the mass of the shield heating, re-radiating, and convecting to the thermostat.[32] Although this particular experiment was done using thermocouples, it does raise the question as to whether the same is true for conventional thermostats.

Other government sources of information for radiant heating design were found in two reports. TN 1684, *Design Guidelines for Heating Aircraft Hangars With Radiant Heaters*,[33] describes the use of high-intensity infrared heaters in hangars and provides some general recommendations for the specific application, but does not consider low-intensity infrared heaters. A second report, produced by EMC Ingenieure, GmbH for the Department of the Army Headquarters, U.S. Army Europe (USAREUR), and Seventh Army Office of the Deputy Chief of Staff, Engineer Facilities Engineering Division, *Radiant Heat Investigation*, develops a mathematical model for evaluating the economics of radiant heat, and evaluates some radiant heating systems in use in Army buildings in Germany. While this report is the most developed of all the government guidance found and looks specifically at gas-fired infrared radiant tube heaters, it was developed for European facilities and looks exclusively at European manufacturers of radiant heating equipment. The method used for energy consumption calculations is a Variable Base Degree Day method, which is the basis of the radiant heat model. The procedure outlined is less than straightforward, and the general applicability of the model is not verified. Though this report is the best resource found in terms of applicability to the subject at hand, it still is not a ready guide to a designer trying to apply infrared radiant tube heating to a building.

There are few government resources for radiant heating design. Many refer the reader to private sources, such as ASHRAE. The richest private sources of design procedures are those provided by the radiant heating manufacturers themselves. During the course of this investigation USACERL researchers reviewed the design literature of many manufacturers. Most manufacturers can provide design manuals to be used with their equipment. Worksheets or other forms are often included to aid in performing the calculations. Although the basic procedures used are much the same, the quality and completeness of the design guides vary widely. Each manufacturer develops a design guide for a proprietary product. In short, there is no "one-stop" source for radiant heating design information.

ASHRAE literature contains much specific radiant heating design information, which covers specific topics published separately over a long span of time. Available ASHRAE information spans from 1962 to the present, in the form of handbooks, articles, and reports. Some of these works focus on only one type of radiant heating, while others deal with all forms. To help designers interested in a specific type of radiant heater, an annotated bibliography of the ASHRAE resources is included in Appendix E. Many of these resources are referenced elsewhere in this report. As noted earlier, some of the dated references may not reflect recent experience with radiant heating. This selective bibliography contains the best references from ASHRAE on radiant tube heaters.

Other sources of information for radiant tube heating design consist largely of the publications of various certifying laboratories and standards organizations. Often many standards will apply to a single design feature of radiant heating systems, while others may apply to facility type and/or building locality. Some standards that are generally applicable to gas-fired low-intensity infrared radiant tube heaters are produced by four principal organizations: AGA (American Gas Association), ANSI (American National Standards Institute), NFPA (National Fire Protection Association), and UL (Underwriters Laboratories). A brief annotated list follows.

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[32] N.A. Buckley, P.E., and T.P. Seel, "Engineering Principles Support an Adjustment Factor When Sizing Gas-Fired Low-Intensity Infrared Equipment," *ASHRAE Transactions, Vol. 93, Pt. 1* (ASHRAE, 1987), p 5.

[33] Edward L. Correa, *Design Guidelines for Heating Aircraft Hangars With Radiant Heaters*, Technical Note N-1684 (Naval Civil Engineering Laboratory [NCEL], Hueneme, CA, 1983).

American Gas Association

D.W. DeWerth's *Literature Review of Infra-Red Energy Produced With Gas Burners*, Research Bulletin 83 (American Gas Association Laboratories, May 1960) is referenced by other publications on the subject (including this report) and is a good reference for all types of infrared heating applications. The American Gas Association is also a primary certifying body for infrared tube heating appliances, and manufacturers will often point out other AGA reports that relate to their equipment.

American National Standards Institute (ANSI)

ANSI Z83.6-1987, *Gas-Fired Infrared Heaters*, and two addenda to this standard with the same title, Z83.6a-1989 and Z83.6b-1989, specifically apply to radiant heating. The secretariat for all of these standards is the AGA. All three of these ANSI publications and later addenda should be reviewed before designing a gas-fired infrared heating system.

National Fire Protection Association (NFPA)

NFPA 54, *National Fuel Gas Code* (which is also ANSI Z223.1-1988), and NFPA 90B, *Standard for the Installation of Warm Air Heating and Air Conditioning Systems* are among many NFPA standards that relate to fire safety and are applicable to radiant heaters, even though they may not be directly aimed toward that end. Designers should review these standards for applicability when doing any radiant heat design, as well as any NFPA standards that pertain to the particular facility type where the system is to be employed (such as NFPA 88B, *Standard for Repair Garages*, and NFPA 409, *Standard on Aircraft Hangars*).

Underwriters Laboratories (UL)

UL795, *Commercial-Industrial Gas-Heating Equipment*, is a UL standard that applies to gas-fired radiant heaters.

Information about other standards and reports published by these four organizations is readily available from the organizations. The publications mentioned here are representative of some general resources that apply to gas-fired low-intensity infrared radiant tube heaters. The reader is cautioned to search for all applicable standards for particular applications to assure compliance.

Lessons Learned in Infrared Heating Design

In addition to the literature search, field demonstration, and informal survey, this study included visits to radiant equipment manufacturing facilities, to sites where such equipment had been installed, and interviews with dozens of people involved with various aspects of radiant heating. The collective experience of all of these people contribute to an understanding of the six areas of design concerns outlined earlier: sizing, layout, control, efficiency, safety, and specification.

Sizing a heating system is a basic part of building design. However, how to size radiant systems still seems to be somewhat of an open question. The most accepted practice is to use the standard ASHRAE heat loss calculation and multiply by a radiant adjustment factor, usually 0.8. Even this seemingly straightforward practice is subject to variations. Some practitioners will use normal indoor space air temperatures for calculating the heat loss, while others will use a lowered temperature to account for the higher operative temperature afforded by the radiant heating system. The adjustment factor is subjectively varied between 0.67 and 0.85. There is also work that suggests that the proper adjustment factor should depend on the air infiltration rate into the building.[34] As yet, there is not clear "best procedure"; the question of sizing method is the subject of ongoing research. Whether the radiant adjustment factor actually "adjusts" a calculation method to account for benefits of radiant heating, or just reduced some oversizing inherent in the initial load calculation, is uncertain.

There is also little consensus on the question of radiant heater layout. The perimeter layout method appears to be most used, but checkerboard and other layouts are also employed. Layout of the radiant heaters is an area where the designer must know how the space will be used and how patterns of radiant heaters can be varied to meet the needs of a particular space. The arrangement must avoid "shadowing" the radiant energy field by structural members and other obstructions that may prevent the heat energy from reaching the occupied areas. Common sense approaches to layout such as placing the heaters over the aisles in a warehouse appear to work for most applications. There are some points to keep in mind: (1) know how the space will be used and plan accordingly; (2) do not let the radiant pattern hit walls or roofs, which will cause excessive losses; (3) to avoid excessive losses, use side deflectors or shield extensions rather than tilting shields, which may cause the radiant pattern to hit the roof, and will almost always increase convection losses; (4) try to keep coverage as even as possible so occupants moving within the space do not experience sudden changes in temperature.

Probably the biggest lessons learned from the demonstration project had to do with controls. The Fort Riley demonstration showed that proper control is essential to efficient operation of an infrared heating system. Night set-back is beneficial for this type of system, provided it is done in moderation. Experience indicates that setbacks from 5 to 10 °F (3 to 6 °C) are beneficial and do not cause recovery problems once the space is re-occupied. Of course, the greater the setback, the greater the energy savings and the greater the chances for recovery problems. The way the setback is implemented is important. Any setback system must include a provision for override. The ultimate solution used at Fort Riley involved a momentary contact switch arrangement which overrides by returning the system to its daytime setting. Other override systems in other Fort Riley buildings experienced problems. First, any override system that turns the unit on continuously invites continuous use, so that the heaters never cycle. Second, controls other than the momentary contact switch may be tampered with to achieve this misuse. For example, a system with a rotary timer will normally turn the heaters full on for a limited period of time. Occupants were found to have "jammed" the rotary timers so that the system ran full blast all of the time. A contact switch prevents such tampering, and returning the system to a daytime setting rather than to a full on state removes the incentive to tamper.

In fact, controls tampering is a problem in general. With radiant heating, lower space temperatures should provide adequate comfort. Psychologically, however, when an occupant reads a lower than expected temperature on a thermostat or thermometer in the space, he may then decide he is cold. Some manufacturers try to circumvent this process by removing degree markings from their thermostats and providing a simple number scale instead. Experience at Fort Riley indicates that a better solution is to remove the thermostats from harms way by using remote temperature sensing elements in the space and placing the logic part of the controls in a secure area, such as a mechanical room. Such practices virtually eliminate tampering with thermostats.

Another question about control of radiant heating systems is what temperature to base control on. Recent work suggests that control based on operative temperature may provide better performance than control based on air temperature.[35] Few control systems in the marketplace attempt to do this, but

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[34] R.H. Howell and S. Suryanarayana, "Sizing of Radiant Heating Systems: Part II-Heated Floors and Infrared Units," *ASHRAE Transactions*, Vol. 96, Pt. 1 (ASHRAE, 1980), pp 666 675.

[35] A.K. Athienitis, and J.G. Shou, "Control of Radiant Heating Based on the Operative Temperature," *ASHRAE Transactions*, Vol. 97, pt. 2 (1991).

current literature and experience has not evaluated them. Perhaps the best advice is to take a "wait and see" approach as work in this area of radiant heating control continues.

Efficiency of radiant heating systems is another area where some important lessons were learned. The most important lesson is that infrared radiant tube heaters will not *automatically* provide large energy savings. Proper control and the ability to mitigate possible stratification problems is important. Properly applied radiant heating energy consumption may decline. Appendix E and the References to this report include bibliographic information on other studies that compare radiant heating to conventional systems. Note that radiant heating systems differ. Some operate more efficiently than others. Use of end caps on shields, reflector shield shape, length of radiant tube run, arrangement of burners, and other factors all determine which systems perform best. Unfortunately, objective overall efficiency ratings for radiant heating appliances do not yet exist as they do for other appliances.

Other efficiency related issues are the comfort of the occupants and maintenance. Overall, most people seem to feel that radiant heaters provided as much or more comfort than convection systems. The experimental results tend to support this conclusion. Agreement on comfort is not unanimous; therefore some complaints may arise in some situations. Generally, radiant heating systems require little maintenance; when infrared radiant tube heaters do require maintenance, their remote location near the roof of the building may make them hard to access. New facilities can be designed to help alleviate this problem (by providing or locating the heaters near catwalks, etc.). This problem did not seem to be an overwhelming concern among those using these heaters.

There was one particular lesson learned having to do with a new maintenance facility being designed for Fort Riley similar to those used in the study. The Fort Riley DEH preferred to install infrared heaters, if they were economically justifiable. However, the Kansas City District (which was doing the design) applied NFPA2 Standard 54, which includes the following in section 5.1.11 b:[36]

> **b. Repair Garages:** Gas utilization equipment may be installed in a repair garage (*see Section 1.7, Definitions*) when there is not dispensing or transferring of liquefied petroleum gas of Class I or II flammable liquids (as defined in the *Flammable and Combustible Liquids Code*, ANSI/NFPA 30), provided all burners, burner flames, and burner ignition devices are located not less than 18 inches above the floor, and provided continuous mechanical ventilation is supplied at a rate of not less than 0.75 cubic foot per minute per square foot of floor area....

This standard appears to specify continuous mechanical ventilation for radiant heaters, making such heaters relatively expensive. On the other hand, NFPA 88B, *Standard for Repair Garages*, section 3-2.3 "Suspended Unit Heaters" requires no such ventilation, other than by reference back to Standard 54. Headquarters, U.S. Army Corps of Engineers (HQUSACE) contacted NFPA and ruled that the ventilation would be unnecessary, as described in a memo signed by Mr. Byron E. Bircher, Chief, Design Branch, Kansas City District (CEMRK-ED-DM) dated 15 May 1990:

> HQUSACE contacted this office on 9 May 1990 with their decision to not require the interlocking of the infrared heaters with the ventilating units to provide 0.75 cfm per square foot floor area as indicated in NFPA 54. USACE has determined, in conversations with NFPA, that the interlock is not a critical requirement and can be waived. NFPA indicated that the ventilation requirement was intended to apply only to heating equipment with glowing elements or open flames mounted less than 8 feet above the floor. Since the infrared units in the subject project have sealed combustion chambers and are mounted well above the 8 feet level, no interlock is required. NFPA indicated,

[36] NFPA, *National Fuel Gas Code*, NFPA Standard 54-1988 (NFPA, 1988), p 54-29.

however, that the present wording of NFPA 54 and 88B does not accurately reflect this intention and both are currently being revised to eliminate the ambiguity.

This ruling is very important to designers attempting to apply radiant tube heaters to repair garages, as the ventilation requirements add significantly to the costs of such systems.

Designers must review all of the variations and plan for and stipulate the desired properties of radiant heaters in the specification. If a negative-pressure system is desired, state it in the specification. If unitary heaters are unsatisfactory, specify that the system will be interconnected in series. If in-line burners are required, state this as well. Other properties that make various units unique or superior include: type or thickness of radiant pipe used, reflector shield material or shape, emissivity/reflectivity factors for various components, thermal efficiency (condensing/noncondensing), safety/control features, and other features available from the local vendor. Many manufacturers will provide sample specifications that can be used in conjunction with one another and with guide specifications to create a sufficiently generic specification template that can be reused for other jobs. The goal of creating such specifications is to include the broadest number of competitive bids without sacrificing the system's most important features through poor substitutions.

In summary, there is no single comprehensive set of design guides for radiant heating systems. However, this review of current design practice and guidance, and of lessons learned should prove helpful in the design of infrared radiant tube heating systems. This information is not itself a design guidance, but may form the basis for preliminary design direction.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Although infrared radiant tube heating systems can potentially save significant amounts of energy, such savings are not automatic. The Fort Riley demonstration showed that radiant systems may potentially use more energy than convective systems if not properly designed, installed, controlled, and operated. The fact that radiant heating systems may heat the same space as higher-capacity convection systems does not mean that radiant systems necessarily save energy. Smaller systems running constantly can use more energy than larger systems running less frequently.

Manufacturers' claims for radiant heating devices were found to be partly true. The Fort Riley experience shows that actual energy savings are smaller than the radiant heating manufacturers' best projections. There does seem to be a basis for the industry claim that ambient temperatures can be lowered due to increased operative temperature (MRT). However, this study could not substantiate the claim that radiant heaters virtually eliminate stratification. The Fort Riley demonstration showed the same stratification problems for infrared systems as for convection systems. Also, since there is little reduction of ceiling temperatures due to the use of an infrared radiant tube heating system, it is unlikely that there is less transmission loss through the roof of the building with radiant heat. Energy savings from infrared radiant systems likely comes from reduced infiltration losses, less air movement over the inside walls, and lower wall temperatures. Finally, radiant heating devices have the potential to vary widely in their performance and efficiency. Unfortunately no energy efficiency ratings (EERs) or other similar objective rating criteria yet exist for radiant heating appliances.

The sizing of infrared heating devices to suit particular applications is an issue of special concern. Since infrared heating derives much of its comfort-providing capability from raising operative temperature, this parameter should play a greater role in calculating the size of the required infrared heating unit. Also, other work suggests that air infiltration and air movement around the occupants significantly affects the required size of the infrared heating unit. Standard heat loss calculation methods and adjustments factors are commonly used "best guess" methods for sizing radiant heat appliance size. The adjustment factors vary widely and have little scientific basis.

There is no good single source of guidance for infrared radiant tube heater system design. Most available relevant material is either outdated or contained in the manufacturers' manuals, whose primary interest is the commercial promotion of a product. The relevant guidance that does exist is scattered throughout many relatively inaccessible sources; much has been published in professional journals over a long span of time. Almost no usable information on infrared tube heaters exists within government design guidelines. There is a definite need of an objective, focused design guidance for low-intensity infrared radiant tube type heating applications.

Recommendations

To achieve energy savings from infrared radiant tube heating systems, the importance of proper control cannot be overstressed. It is recommended that users of radiant heat employ temperature setback during unoccupied hours to significantly increase energy savings. A moderate setback of 10 °F (6 °C) can save energy without performance penalties. It is also recommended that any override controls return the system to its "occupied" setting rather than to "full on" during override. All controls should be tamper-proofed, preferably with remote sensing elements being the only component in the heating space. Measures to control stratification, such as ceiling fans, are also recommended.

It is recommended that consistent standards and/or ratings to evaluate competing radiant heating units be developed. Better methods for calculating sizing for these units need to be developed. Currently designers are left to their common sense, experience, and creative imaginations to create radiant heating system designs. Experimental analysis of layout issues should be done to improve techniques for designing efficient radiant heating system layout.

It is recommended that current applicable guidance be updated and expanded to suit the needs of designers of infrared heating systems, especially for low-intensity infrared radiant tube type heating applications. A logical first step to filling this need would be to compile the best known current techniques for applying this technology. Such a compilation would both reduce the time spent in design, and encourage designers to consider the infrared radiant heating option. Increasing proper use of infrared radiant heating could significantly help reduce Army energy bills in the decades to come.

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APPENDIX A:

RADIANT HEATING EQUIPMENT DATABASE

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: CRV B-6
Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 60
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type:
Aluminum
Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See CRV-B2.

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: CRV B-10
Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type:
Aluminum
Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See CRV-B2.

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: CRV B-12
Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 120
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type:
Aluminum
Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See CRV-B2.

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: CRV B-4

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 40

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
Aluminum

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See CRV-B2.

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: CRV B-8

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 80

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
Aluminum

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See CRV-B2.

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-110(1)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 110

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
Non-condensing Vacuum System; Capability of heating up to four independent zones on one set-up; Stainless Steel burner cup; Reflector rotates 45 deg. End caps included.

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-110(2)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 220

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 80'

Miscellaneous notes:
See EV110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-110(4)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 440

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 160'

Miscellaneous notes:
See EV 110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-110(6)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 660

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 240'

Miscellaneous notes:
See EV 110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-140(1)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 140

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 50'

Miscellaneous notes:
See EV-110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-140(2)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 280

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 100'

Miscellaneous notes:
See EV 110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-140(4)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 560

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 200'

Miscellaneous notes:
See EV 110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-140(6)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 840

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 300'

Miscellaneous notes:
See EV 110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-170(1)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 170

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 60'

Miscellaneous notes:
See EV-110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-170(2)

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 340

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 120'

Miscellaneous notes:
See EV 110(1).

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-170(4)
Capacity (KBTU): 680
Unit Cost: -0-
Shield type: ALUMINUM
Miscellaneous notes: See EV 110(1).

Fuel: B (Gas, Propane, or Both)
Vented/Unvented: V
Positive/negative pressure: NEG
Tube diameter (in.): 4.
Tube length(s) (ft): [illegible]

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-200(1)
Capacity (KBTU): 200
Unit Cost: -0-
Shield type: ALUMINUM
Miscellaneous notes: See EV-110(1).

Fuel: B (Gas, Propane, or Both)
Vented/Unvented: V
Positive/negative pressure: NEG
Tube diameter (in.): 4.
Tube length(s) (ft): 70'

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-200(2)
Capacity (KBTU): 400
Unit Cost: -0-
Shield type: ALUMINUM
Miscellaneous notes: See EV 110(1).

Fuel: B (Gas, Propane, or Both)
Vented/Unvented: V
Positive/negative pressure: NEG
Tube diameter (in.): 4.
Tube length(s) (ft): 140'

Manufacturer Name: CO-RAY-VAC

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: EV-200(4) | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 800 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 280'

Miscellaneous notes:
See EV 110(1).

Manufacturer Name: CO-RAY-VAC

System Type: Site Assembled(SA)
(Unitary heater or Site Assembled unit)

Model Number: CRV 5-40 | Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 40 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
Combustion chambers are cast iron; various shapes available for sheild.

Manufacturer Name: CO-RAY-VAC

System Type: Site Assembled(SA)
(Unitary heater or Site Assembled unit)

Model Number: CRV-E2 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 20 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 20',25',35'

Miscellaneous notes:
Cast Iron combustion chamber; "Heavy Duty" applications; Sheild has perforation and extension options.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CRV-E 120

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 120

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Steel Cumbustion Chamber; Economical Model; Reflectors have end caps.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CRV-E 240

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 240

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See CRV-E 120

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CRV-E 300

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 300

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See CRV E-120.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CRV-E 360

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 360

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See CRV E-120.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CTH2-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS-40.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CTH2-125

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS- .

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CTH2-150

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS-40.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CTH2-40

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 40

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS-40.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CTH2-60

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS-40.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: CTH2-80

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 80

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS-40.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DS-40

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 40

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 12, 21.5

Miscellaneous notes:
Stainless Steel burner cup; Economical; Reflectors can be tilted 45 degrees; End caps available; Side Reflector option.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RTH-150B

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 140

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS-40.

Manufacturer Name: CO-RAY-VAC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RTH-75A

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See DS-40.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: INFA-RED HEATERS (LTH-SERIES)
(Unitary heater or Site Assembled unit)

Model Number: LTH-25-75 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 25'

Miscellaneous notes:
-0-

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-25-75 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 25'

Miscellaneous notes:
Water proof control box; Reflector Rotatable 0 to 45 deg.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-30-75 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 30'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-35-100 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 35'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-40-100 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-40-125 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-45-125 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 45'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-45-150 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 45'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: LTH-60-150 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 60'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: LAMBERT (GAS HEATERS)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: STG-50-150 N-P

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 50'

Miscellaneous notes:
See LTH 25.

Manufacturer Name: PERFERCTION SCHWANK

System Type: INFA-RED HEATERS (CENTURION)
(Unitary heater or Site Assembled unit)

Model Number: PRT-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: $1,428.00

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See PRT-60.

Manufacturer Name: PERFERCTION SCHWANK

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: JP-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: $1,678.00

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See JP 125

Manufacturer Name: PERFERCTION SCHWANK

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: JP-125

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: $1,899.00

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40 or 50

Miscellaneous notes:
Venting may be horizontal or vertical; Totally enclosed blower motor; Reflector rotation 0 to 30 deg.

Manufacturer Name: PERFERCTION SCHWANK

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: JP-60

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: $1,456.00

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 30'

Miscellaneous notes:
See JP 125.

Manufacturer Name: PERFERCTION SCHWANK

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: JP-85

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 85

Vented/Unvented: V

Unit Cost: $1,678.00

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 30'-40'

Miscellaneous notes:
See JP 125.

Manufacturer Name: PERFERCTION SCHWANK

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: PRT-60

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: $1,428.00

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
Burner designed especially for quiet operation; Totally enclosed Reflector.

Manufacturer Name: PERFERCTION SCHWANK

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: PRT-85

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 85

Vented/Unvented: V

Unit Cost: $1,428.00

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See PRT-60.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-2-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 200

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-2-125

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 250

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-2-75

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
Burner box is 16 gauge steel; No Condensation after operating temperature is reached; Reflector rotation 0 to 45 deg.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-3-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 300

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-3-125

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 375

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-3-75

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 225

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-4-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 400

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-4-125

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 500

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RV-4-75

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 300

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-40-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-40-125

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-40-75

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-50-100

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 50'

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-50-125

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 50'

Miscellaneous notes:
See Above.

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-50-75

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 50'

Miscellaneous notes:
See Above.

Radiant Heaters

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-60-125

Capacity (KBTU): 125

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See prior Raytec entries.

Fuel: B (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: NEG

Tube diameter (in.): 4.

Tube length(s) (ft): 60'

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-60-125

Capacity (KBTU): 125

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See Above.

Fuel: B (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: NEG

Tube diameter (in.): 4.

Tube length(s) (ft): 60'

Manufacturer Name: RAYTEC

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RVS-60-125

Capacity (KBTU): 125

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See prior entries.

Fuel: B (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: NEG

Tube diameter (in.): 4.

Tube length(s) (ft): 60'

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV2-150

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN,50' MAX.70'

Miscellaneous notes:
Straight-tube; Enclosed construction for burner; 0 to 45 deg. mounting angle.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV2-200

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.50' MAX.80'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV2-250

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.60' MAX.90'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV2-300

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.70'MAX.100'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV3-225

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.50' MAX.70'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV3-300

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.50' MAX.80'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV3-375

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.60' MAX.90'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV3-450

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.70'MAX.100'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV4-300

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN.50' MAX.70'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV4-400 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): MIN.50' MAX.80'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV4-500 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): MIN.60' MAX.90'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: DRV4-600 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): MIN.70'MAX.100'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 60'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 50

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 20'

Miscellaneous notes:
U-tubed; Enclosed construction for Blower Controls and Burner; 0 to 45 deg. mounting angle.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 20'

Miscellaneous notes:
See first entry in DTH Series.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Capacity (KBTU): 125

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See first entry.

Fuel: B (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: NEG

Tube diameter (in.): 4.

Tube length(s) (ft): 60'

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTH SERIES

Capacity (KBTU): 75

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See first entry.

Fuel: B (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: NEG

Tube diameter (in.): 4.

Tube length(s) (ft): 20'

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTHS SERIES

Capacity (KBTU): 50

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See first entry in DTHS series.

Fuel: B (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: POS

Tube diameter (in.): 4.

Tube length(s) (ft): 20'

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTHS SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTHS SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 20'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTHS SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 40

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 20'

Miscellaneous notes:
Straight tube; Blower controls and burner enclosed; 0 to 45 deg. mounting angle.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTHS SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTHS SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 20'

Miscellaneous notes:
See first entry.

Manufacturer Name: RE-VERBER-RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: DTHS SERIES

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 50

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 40'

Miscellaneous notes:
See first entry.

Manufacturer Name: REFLECT-O-RAY (3.5 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0910.LP(S/U)

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (3.5 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0910.NG(S/U)

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (3.5 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0915.LP(S/U)

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (3.5 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0915.NG(S/U)

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (3.5 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0920.LP(S/U)

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 50

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (3.5 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0920.NG(S/U)

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 50

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (4.0 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0930.LP(S/U) Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 125 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: POS

Shield type: ALUMINUM Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (4.0 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0930.NG(S/U) Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: POS

Shield type: ALUMINUM Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (4.0 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0935.LP(S/U) Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 150 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: POS

Shield type: ALUMINUM Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (4.0 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0935.NG(S/U)

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (4.0 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0940.LP(S/U)

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 175

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (4.0 OMEGA II)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: 0940.NG(S/U)

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 175

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Heater designed to operate in any position from 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2700-24-14

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 130

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Non-continuous condensing; Reflector rotation 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2700-24-15

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 120

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2700-24-16

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 130

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
See previous EDS 3.5 entries.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2700-24-17

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 120

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Non-Continuous Condensing; Reflector Rotation 0 to 30 deg.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2720-24-18

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2720-24-19

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2740-24-20

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 105

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 2740-24-21

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 105

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.075.N.S

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.075.N.U

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.075.P.S

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.075.P.U

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.105.N.S

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 105

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.105.N.U

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 105

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.105.P.S

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 105

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.105.P.U

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 105

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.130.N.S

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 130

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 3.5)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: OAL.130.N.U

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 130

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 3.5

Tube length(s) (ft): -0-

Miscellaneous notes:
Exhaust vents for roofs or walls.

Manufacturer Name: REFLECT-O-RAY (EDS 6.0)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 3000-24-02

Fuel: g (Gas, Propane, or Both)

Capacity (KBTU): 240

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 6.

Tube length(s) (ft): -0-

Miscellaneous notes:
High bay/large area applications.

Manufacturer Name: REFLECT-O-RAY (EDS 6.0)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 3000-24-03

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 240

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 6.

Tube length(s) (ft): -0-

Miscellaneous notes:
High bay/large area applications.

Manufacturer Name: REFLECT-O-RAY (EDS 6.0)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 3000-24-04

Fuel: g (Gas, Propane, or Both)

Capacity (KBTU): 360

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 6.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: REFLECT-O-RAY (EDS 6.0)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: 3000-24-05

Fuel: p (Gas, Propane, or Both)

Capacity (KBTU): 360

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 6.

Tube length(s) (ft): -0-

Miscellaneous notes:
See Above.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV2-150

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg. Handles large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV2-200

Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 200

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg. Handles large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV2-200
Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 250
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg;

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV2-200
Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 250
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV2-200
Fuel: p (Gas, Propane, or Both)

Capacity (KBTU): 230
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV3-225 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 225 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV3-300 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 300 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV3-345 | Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 345 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEC

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Radiant Heaters

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV3-375 Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 375 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV4-400 Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 300 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV4-400 Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 400 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV4-500
Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 500
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SV4-500
Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 460
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry-no condensation of flue products; Reflector rotatable 0 to 45 deg; Used for large applications.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-20-75
Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS \ -LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-30-100 Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-40-100 Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-40-125 Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-40-125 | Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 115 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-40-75 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-50-100 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-50-125
Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type:
ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-50-125
Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 115
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type:
ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-50-75
Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type:
ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-60-125
Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVS-60-125
Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 115
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVU-20-75
Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75
Vented/Unvented: V

Unit Cost: -0-
Positive/negative pressure: NEG

Shield type: ALUMINUM
Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVU-40-100 Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVU-40-125 Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVU-40-125 Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 115 Vented/Unvented: V

Unit Cost: -0- Positive/negative pressure: NEG

Shield type: ALUMINUM Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVU-40-75 | Fuel: B (Gas, Propane, or Both)

Capacity (KBTU): 75 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVU-60-125 | Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SO-LAR-VAC)

System Type: SA
(Unitary heater or Site Assembled unit)

Model Number: SVU-60-125 | Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 115 | Vented/Unvented: V

Unit Cost: -0- | Positive/negative pressure: NEG

Shield type: ALUMINUM | Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
Dry - no condensation of flue products; Reflector rotates 0 to 45 deg.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-100-30BL

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-100-30BN

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube lengtn(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-100-40BL

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-100-40BN

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-100-50BL

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-100-50BN

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-125-40BL

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first enrty.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-125-40BN

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-125-50BL

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-125-50BN

Capacity (KBTU): 125

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See first entry.

Fuel: G (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: POS

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-150-50BN

Capacity (KBTU): [illegible]

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See first entry.

Fuel: G (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: POS

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-75-20BL

Capacity (KBTU): 75

Unit Cost: -0-

Shield type:
ALUMINUM

Miscellaneous notes:
See first entry.

Fuel: P (Gas, Propane, or Both)

Vented/Unvented: V

Positive/negative pressure: POS

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-75-30BL

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-75-30BN

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-75-40BL

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SOLARONICS (SUNTUBE)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: STG-75-40BN

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: POS

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 10

Miscellaneous notes:
See first entry.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS100

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 30′ MAX 40′

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS110

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 110

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 30′ MAX 40′

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS120

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 120

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 30' MAX 40'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS125

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 125

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 30' MAX 50'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS130

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 130

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 30' MAX 50'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS140

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 140

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type: ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 40' MAX 50'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS150

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type: ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 40' MAX 50'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS160

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 160

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type: ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 40' MAX 50'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS40

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 40

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 20' MAX 30'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS50

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 50

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 20' MAX 30'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS60

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 20' MAX 30'

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS75

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 20′ MAX 30′

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS80

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 80

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 30′ MAX 40′

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTS90

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 90

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): MIN 30′ MAX 40′

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU40-L5

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 40

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See previous entry.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU40-N5

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 40

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
Cast Iron Burner; Can be vented 45 or 90 deg.; Reflector can be rotated 45 deg

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Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU50-L5

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 50

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU50-N5

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 50

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): 2

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU60-L5

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU60-N5

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 60

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See pricr entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU75-L5

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: LTU75-N5

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 75

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RSTP10-L5A

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RSTP10-N5A

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 100

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RSTP15C-N5D

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 150

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Manufacturer Name: SPACE RAY (U-SHAPED)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RSTP17C-L5D

Fuel: P (Gas, Propane, or Both)

Capacity (KBTU): 175

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

Radiant Heaters

Manufacturer Name: SPACE RAY (U-SHAPED)

System Type: U
(Unitary heater or Site Assembled unit)

Model Number: RSTP17C-N5D

Fuel: G (Gas, Propane, or Both)

Capacity (KBTU): 175

Vented/Unvented: V

Unit Cost: -0-

Positive/negative pressure: NEG

Shield type:
ALUMINUM

Tube diameter (in.): 4.

Tube length(s) (ft): -0-

Miscellaneous notes:
See prior entries.

APPENDIX B:

ERROR ANALYSIS FOR ENERGY MEASUREMENTS

Error Analysis for Energy Measurements[37]

Building 8370

The relative error of the energy measurements in Building 8370 is

$$e_Q = \sqrt{(e_V)^2 + (e_C)^2} \qquad (3.4)$$

where

e_V = relative error of volume measurement

e_C = relative error of conversion factor

The total error of the volume measurement is

$$E_V = \sqrt{(E_{meter})^2 + (E_{least\ count})^2} \qquad (3.5)$$

The accuracy of the gas meters is ± 0.01 , which leads to

E_{meter} = ± 0.01 x (volume measured) ft^3

$E_{least\ count}$ = ±1.0 ft^3

(3.5) thus becomes

$$E_V = \sqrt{(0.01 \times volume)^2 \quad + 1.0}$$

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[37] Excerpted from Niedringhaus, "A Field Comparison of Radiant and Convecitve Heating Systems in Army Maintenance Facilities, a Master's Thesis" (Department of Mechanical Engineering, Kansas State University, Manhattan, KS, 1988), pp 29-33)

For the highest volume measured (125 ft^3), this results in

$$E_V = 1.6 \text{ ft}^3$$

The relative error then is

$$e_V = 1.6/V \qquad (3.6)$$

Depending on conditions, the heat from 1 ft^3 of gas varies between 972 BTU and 988 BTU. A value of 980 BTU/ft^3 was used in this study. Therefore,

$$E_C = \pm 8 \text{ BTU/ft}^3$$

$$e_C = \pm 0.01 \qquad (3.7)$$

Combining (3.6) and (3.7) with (3.4) results in

$$e_Q = \sqrt{(1.6/V)^2 + (0.01)^2}$$

For V = 125 ft^3 this becomes

$$e_Q = 0.016$$

Building 8390

The relative error for energy measurements in Building 8390, based on (3.3), is

$$e_Q = \sqrt{(e_\rho)^2 + (e_C p)^2 + (e_V)^2 + (e_{\Delta T})^2} \quad (3.8)$$

For the small temperature range involved in this study, the density and specific heat are assumed to be constant.

$$E_V = \sqrt{(E_{meter})^2 + (E_{Acurex})^2 + (E_{cal})^2}$$

$$E_{meter} = \pm 0.005 \times (\text{current range})$$

$$= \pm 0.08 \text{ mA}$$

$$= \pm 1.0 \text{ gpm}$$

$$E_{Acurex} = 0.0008 \times (\text{input current})$$

For the highest input current (20 mA) this becomes

$$E_{Acurex} = \pm 0.016 \text{ mA}$$

$$= 0.2 \text{ gpm}$$

$$E_{calibration} = \pm 0.1 \text{ gpm}$$

Therefore

$$E_V = 1.025 \text{ gpm}$$

$$e_V = 1.025/V$$

The absolute error for each RTD is given by

$$E_T = \sqrt{(E_{trans})^2 + (E_{Acurex})^2 + (E_{cal})^2 + (E_{lc})^2}$$

$$E_{transmitter} = \pm 0.2 \text{ F}$$

$$E_{Acurex} = \pm 0.0008 \times (\text{input current})$$

$$= \pm 0.2 \text{ F}$$

$$E_{calibration} = \pm 0.1 \text{ F}$$

$$E_{least\ count} = \pm 0.05 \text{ F}$$

Combining these terms,

$$E_T = 0.3 \text{ F}$$

The error of the temperature difference is

$$E_{\Delta T} = \sqrt{2 \times (E_T)^2}$$

$$= 0.42 \text{ F}$$

$$e_{\Delta T} = 0.42 \text{ F}/ \quad T$$

Thus,

$$e_Q = \sqrt{(1.025/V)^2 + (0.42/\Delta T)^2}$$

When the system is operating, the flow rate $\dot{V}$ is generally constant at 95 gpm. Therefore, the relative error can be considered a function of T, or, using equation 3.3, a function of Q. Figure 3.5 shows this functional relationship. As can be seen, the relative error becomes extremely large for low values of Q, making these values suspect.

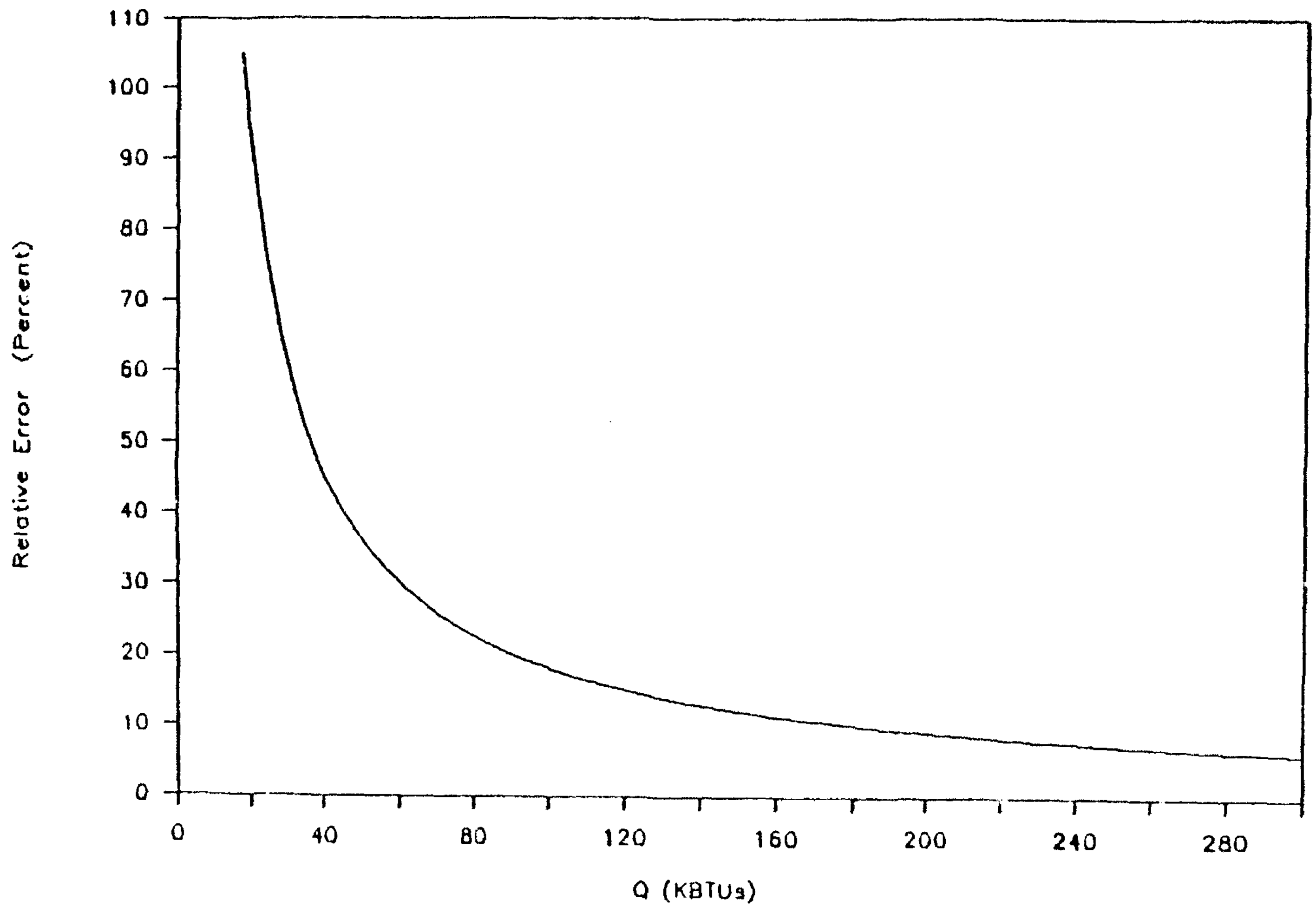

Fig 3.5 Relative Error In Energy Use Measurement - Building 8390

APPENDIX C:

T-TEST ANALYSIS METHOD

Analysis Method[38]

The method used to compare the thermal characteristics of the buildings was the two-sided t-test. The null hypothesis tested was $\bar{x}_1 = \bar{x}_2$, i.e., the mean of the value analyzed for Building 8370 equals that of Building 8390. The critical t value t_{crit} is 2.00, which corresponds to degrees of freedom approximately equal to 60, which approximates the total number of data points from both buildings during a month. The t value for the analysis was calculated using

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s_p \sqrt{2/n}} \qquad (4.1)$$

where
- t = comparison t value
- $\bar{x}_1$ = mean value for 8370
- $\bar{x}_2$ = mean value for 8390
- n = number of measurements (days/month)

$$s_p = \sqrt{\frac{(s_1)^2 + (s_2)^2}{2}} \qquad (4.2)$$

where
- S_1 = standard deviation for 8370
- S_2 = standard deviation for 8390

If the absolute value of the comparison t value $t < t_{crit}$, then the null hypothesis is accepted and it can be concluded that there is no statistically significant difference between the two buildings.

[38] Excerpted from Niedringhaus, "A Field Comparison of Radiant and Convective Heating Systems in Army Maintenance Facilities, a Master's Thesis" (Department of Mechanical Engineering, Kansas State University, Manhattan, KS, 1988), pp 72-73.

APPENDIX D:

INFORMAL SURVEY ON RADIANT HEATING DESIGN PRACTICE

Interviewees

	POC	Element
1.	Galand Radja (District Engineer)	Omaha District, USACE
2.	Charles Gibbons (District Engineer)	Fort Worth District, USACE
3.	Gene Cartee (District Engineer)	Louisville District, USACE
4.	Mike Caponegro (Mechanical Engineer)	Scott AFB MAC-St. Louis
5.	Gary Harper (*Section Chief*)	Kansas City District, USACE
6.	Scott Barmann (District Engineer)	Sacramento District, USACE
7.	Mike Aaron (District Engineer)	Sacramento District, USACE
8.	Steve Turner (Mechanical Engineer)	Fort Benning GA
9.	Newell Flood (Mechanical Engineer)	Fort Lewis, WA
10.	Peter Fludovich (Mechanical Engineer)	New Cumberland, PA Army Depot.
11.	Satish Sharma (Mechanical Engineer)	Fort Belvoir, VA
12.	Richard Luttenegger (Mechanical Engineer)	Middletown, IA Army Ammunition Plant

Questionnaire

District: Contact: Phone #:

1. What type of systems do you use and are you familiar with?

2. How do you design these systems:

   a. Use same loads as you would for a conventional system?

   b. Design for same space temperatures as for a conventional system?

   c. Use night setbacks?

3. What type of design guides do you use?

4. What type of criteria do you follow?

5. In what applications do you use these types of systems: warehouses, storage buildings, tactical shops, high bay areas, aircraft hangars?

6. What limitations have you encountered?

7. For what reasons do you use these types of systems:

   a. Energy efficiency?
   b. Simplicity of system?
   c. Lower installation and maintenance costs?
   d. User requested?

8. a. How have installed systems functioned?

   b. Have the installations been pleased with their performance?

   c. Have there been any building user/occupant complaints?

9. Have you monitored any of the facilities after they were built to attempt to verify their efficiency?

Responses

1. Omaha District - Galand Radja (10/4/90)

- Omaha primarily familiar with Low-intensity Tube-type heaters
- Designing a system that is nonproprietary is a problem. Usual practice is to design a system according to one manufacturer's information, then supply this design to other manufacturers and have them submit an equivalent design.
- Designers rely on manufacturers' information regarding system efficiency. Most claim a 20 percent energy savings over conventional systems.
- Problem: There are no set standards for measuring system efficiencies, unlike systems such as boilers
- Limitations: Hazardous area limitations and further limitations on high intensity heaters
- Used primarily in warehouses, storage areas, high bay areas
- No building occupant complaints to date
- Criteria and regulations - AFR 88-15, and ASHRAE

2. Fort Worth District - Charles Gibbons (10/4/90)

- Fort Worth familiar with tube-type heaters, all gas fired, some vented and some unvented (i.e. some are vented to the interior and others to the exterior). Used on a regular basis.
- System designs are based on manufacturers' data.
- Space loads are determined as they would be for a conventional system utilizing the same space temperatures.
- Night setbacks are used with a minimum temperature limit.
- Criteria: TM 5-810 (2 sentences)
- Primarily used in high-bay areas.
- Limitations: low ceilings, and flammable areas (or areas with flammable substances).
- Primary reason for use: 30 to 50 percent more efficient than conventional floor mounted HVAC systems, and based on life cycle cost analysis.
- Secondary benefits: Simplicity of system and lower installation and maintenance costs.

- Designers decide system type, not user requested.
- No building occupant complaints to date
- No monitoring of systems to verify manufacturer's claim of efficiency.

3. Louisville District - Gene Cartee (10/5/90)

- Familiar with tube-type radiant heaters vented to the exterior (Solartron Mfg.)
- System designs are based on manufacturers' data.
- Space loads are determined as they would be for a conventional system (but space design temperature is low in the first place).
- Night setbacks are not used, the facility where these units are used has a 24 hr. occupancy.
- Criteria: AFR 88-15
- Used in warehouses and aircraft hangars (ANG facility at Rickenbacker - retrofit)
- Limitations: Combustibility and explosive limits (per 88-15) pose the biggest problems. Determining explosive limits can be a big headache
- Primarily used because of energy efficiency
- System design is relatively simple but can be complicated by earthquake design requirements
- Lower installation and maintenance costs questionable due to uniqueness of design
- There have been building user complaints. They want warm floors (this building previously had a hydronic system).
- No monitoring of systems to verify mfg. claim of efficiency.

4. Scott AFB MAC - Mike Caponegro (10/9/90)

- To the best of Mike's knowledge, MAC does not use radiant heaters extensively.
- Air Force supposedly did a study/analysis on radiant heaters approximately 15 years ago.
- While at the Savannah District USACE (approximately 10 years ago), mechanical design section did a retrofit design for 10 or 11 hangars for either Semour Johnson AFB or Pope AFB. Design was taken to 100 percent completion, but not funded at the time, may have been funded later. This was to be an ECIP project. (L.E. Wooton at Savannah District might know more about this)

- Problems: Venting of exhaust gasses. If vented to the interior, there is a strong possibility of condensation forming on the interior side of a cold roof.

5. Kansas City COE - Gary Harper (10/9/90)

- Most familiar with gas-fired tube-type radiant heaters vented to the exterior. Have also used oil-fired tube-type heaters but had problems - oil dripping, incomplete combustion, interior soot buildup.

- Have used high intensity directional radiant heaters in rifle ranges with success.

- Use same methods and temperatures to determine loads as for conventional systems

- Use night setbacks with minimum temperature setting. Still use conventional thermostats for these systems however and have had certain problems

- Only guidance and criteria used is ASHRAE

- Primarily used for tactical repair shops

- Limitations/problems: NFPA 54 or 88b required makeup air for environments using gas fired heaters. This requirement was questioned by Gary since the units being employed used exterior air for combustion and then vented directly to the exterior. OCE stated that NFPA requirement would not be applicable in this instance.

- Units are installed due to user insistence.

- Use BLAST program to determine LCC for various heating systems. Tube-type radiant heaters determined to be the most efficient even though using this type of system may at times force design modifications - such as increasing building height to obtain adequate clearance beneath heaters and other equipment.

- Building maintenance workers like system, low and easy maintenance.

- Building users however feel otherwise, they complain that they are uncomfortable.

- Gary skeptical about tube-type heating system in cold climates. Example of cold 60 ton tank being brought into work space and introducing object with low radiant heat. Overall radiant environment of space strongly influenced by low radiant temperatures of objects proximate to workers, thus the feeling of discomfort.

- Another POC at Kansas City - Jim Turner. He has performed some of the actual design of some of the systems that Gary was talking about.

6. Sacramento District - Scott Barmann (10/9/90)

- Familiar with tube-type heaters, installed in two facilities in the recent past

- Determined space load using lower temperatures due to radiant effect rather than just consider air temperature.

- Did not use night setback. Did not consider it to be an effective strategy since low intensity heaters were intended to heat the floor slab.

- Mfg. data relied upon for design guidance and also mentioned a TR - Energy Conservation in Navy Buildings

- Mentioned two different types of tube-type heaters: 1) Vacuum type - Movement of gasses through tube induced by an exhaust motor (i.e. sucks the gasses through the tube) two Mfg. mentioned a) Corayvac b) Reflectoray 2) Pressurized type - Has fan motor at tube inlet and forces combustion gasses through the tube, mentioned one Mfg.- Powerburner.

- Used tube type system in a warehouse, positioned tubes along aisles.

- Used radiant system because they were requested by the user. User opinion was that these systems provided good building occupant comfort.

- Used BLAST to do modelling of various system types. Had to manipulate program and output to model radiant heaters.

- One of the largest deficiencies of using radiant type heaters is that there is no type of performance factor or EER rating such as with boilers and other conventional types of heating and refrigeration systems.

- Another difficulty is animosity between manufacturers. All mfg's claim to sell the greatest radiant heaters and other mfg's equipment is junk. Hard to get straight answers from anyone.

- Lack of criteria or validated design guidance is a big problem.

7. Sacramento District - Mike Aaron (10/15/90)

- Determining loads a lot of guess work. For instance, in tactical shops a certain amount of makeup air is required (1.5 cfm/sf). This air needs to be tempered before being supplied to the space, thus part of the load will be satisfied by the makeup air. How much of the load is thus taken care of by makeup air and how much will the radiant heaters need to satisfy? Furthermore, to keep the makeup air from feeling like a draft, it needs to be heated to a relatively warm temperature. Therefore, why not just heat it some more and completely eliminate the radiant heating system?

- Contrary to radiant heater manufacturers claims that radiant heating systems overcome heat stratification problems, stratification still exists.

- Installed cost can be higher than simply installing a regular HVAC system. System to temper the air needs to be installed plus the radiant system. Also, radiant system can conflict with other building systems (such as overhead cranes) and thus force other building parameters to change (e.g. building height).

- Installation costs can also be higher due to having to hang everything from the ceiling rather than with conventional systems where the real guts of the system are at floor level and easily accessible for installation and maintenance.

- If certain interior systems (such as overhead cranes) force the radiant system higher, how much system efficiency is compromised due to this increased distance between user and system? Look at radiant transfer as a function of distance.

- With radiant heaters it is hard to determine an appropriate setback strategy. Since the radiant heaters are intended to heat the slab, what do you do at night, let the slab go cold? If so, what is an appropriate warm-up time in the morning? Not much guidance in this area.

- Although radiant heaters impact the internal radiant environment, temperature controls used for these systems are still air based, not radiant based. It is questionable as to whether these types of controls are appropriate for radiant heated buildings.

- Mike knows of one instance where a CO_2 monitoring system was installed in the building so that the makeup air could be modulated. See ASHRAE 62 for alternative methods to determine ventilation rates.

- Mike mentioned that he has heard that the negative pressure systems have problems in that the fan element is under constant exposure to hot exhaust gasses.

- In Mike's opinion, case for radiant heaters has been overrated.

8. Fort Benning GA - Steve Turner (10/17/90)

- No radiant heaters at Fort Benning, but Steve is urging their use. Wants to use tube-type gas fired heaters. Desire to use them is based on conclusion that they would be more energy efficient than existing conventional HVAC systems. Preliminary study indicated that installed capacity would be one-third of a conventional system.

- Design of system based on mfg. data / design charts.

- Wants to use them in maintenance bays., motor pools, and warehouses.

- Infiltration impossible to control in some instances such as when overhead doors are left open. Not concerned with heating makeup air when it is only a small component of the total air volume infiltrating the space. Figures air temperature is going to be low to begin with, thus the desire to use radiant heat. At least occupants get benefit of warm radiant environment.

- Various reasons for radiant heaters not being used: Mechanical designers lack of familiarity with these types of systems, lack of adequate design guidance, and lack of initiative to try something that deviates from the accepted standard.

- In Steve's opinion, a good indicator that radiant heating is cost effective is that it is used extensively in the private sector where heating costs directly impact profitability of a business. Most of the businesses conducted in a high-bay type environment use this type of heating system. If this type of heating system was inefficient, it would not be used to the extent that it is.

9. Fort Lewis, WA - Newell Flood (10/19/90)

- Both Tube-type and high intensity spot radiant heaters are used at Fort Lewis. Have had very good luck with the low intensity tube-type heaters and bad luck with the high intensity spot heaters.

- Have used tube-type heaters in both new and retrofit construction. Designs are based on manufacturers' literature.

- Programmable thermostats used to control tube-type heaters. Lower temperature setting at night, thus, depending on conditions, heaters may or may not cycle at night.

- Radiant heating used in motorpools, hangers, and tactical equipment shops.

- High intensity spot heaters disliked by building occupants. They provide too much radiant heat and cause localized zones of discomfort due to the micro-environment they create. A worker will be subjected to radiant heat when in the heaters radiant zone of influence, but as soon as they move out of this zone, the conditions may be so different that the worker experiences discomfort. It is common for these heaters not to be used and fall into disrepair and ultimately be removed.

- Installed radiant heater capacity is usually about 70 percent of a conventional HVAC system for the same facility.

- Use both Corayvac and Sunray tube-type heaters.

- Radiant heating systems used because of energy efficiency. They have compared pre to post retrofit energy bills and current consumption is running approximately 40 percent of prior system.

- They have conducted some in-house studies on energy efficiency of their radiant heaters.

- In Newell's opinion, the radiant heaters work well in the Fort Lewis area due to the temperate climate. Temperatures are rather moderate and never get real cold, 40 degrees in the winter is average. The radiant heaters thus only need to knock off the chill in the air.

- Radiant heaters are used extensively at the base and personnel seem quite pleased with their performance.

10. New Cumberland PA - Peter Fludovich (10/19/90)

- Gas fired radiant heating not used at New Cumberland Army Depot. Entire depot is on a (steam) district heating system. No gas on site.

- Has used electric radiant heat in very limited instances and been pleased with the results.

- If gas distribution does materialize, they would definitely consider gas fired radiant heating as a heating option in high-bay areas.

11. Fort Campbell KY - Neal Smith (10/23/90)

- Tube-type radiant heaters used on a very limited basis at Fort Campbell. However, in the early '80's there were plans to retrofit hangers with radiant heaters under the Energy Conservation Investment Program (ECIP). The plans were taken to completion by an outside AE but the Louisville District aborted the project. Neal didn't remember the exact problem, but thought it had something to do with a conflict with some Army Regulation concerning the number of air changes per hour. This project has been placed on the back burner, but it is still something that they would like to do.

- They do a lot of helicopter repair in their shops. Often doors are left open due to the rapid turnover rate of aircraft. It is virtually impossible to maintain comfort conditions with the existing air handling equipment due to the design conditions.

- The base requested radiant heaters due to the aforementioned conditions and for energy conservation / efficiency reasons.

- Neal's opinion was that the Corps District Engineers were far too bureaucratic and inflexible in their interpretation of the regulations in light of the actual design conditions. Neal went to the district office to argue the base's case, but was not able to convince them otherwise.

12. Iowa Army Ammunition Plant - Richard Luttenegger (10/24/90)

- Entire base on a district steam heating system. No radiant heat used.

- Commented that an ammunitions plant is not a very ideal location for a radiant heating system.

- Would consider it for a vehicle maintenance facility, but no gas available. Also doesn't think that it could economically compete with their energy source - coal.

13. Fort Belvoir, VA - Satish Sharma (10/29/90)

- Not involved with radiant heater design.

- Satish has a computer program developed in Europe for the analysis of radiant heaters.

APPENDIX E:

ANNOTATED BIBLIOGRAPHY OF ASHRAE RESOURCES FOR RADIANT HEATING RESOURCES

All listed items are published by the American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE), Atlanta, GA. Items are ordered chronologically under subtype.

Handbooks

1987 HVAC Handbook. Chapter 16 "Infrared Radiant Heating."

This definitive design handbook for infrared radiant heating systems outlines the general principles of radiant heating and application considerations. This particular reference focuses on "beam" or spot heating, but does contain a section on total space heating.

1988 Equipment Handbook, Chapter 29 "Infrared Heaters."

This chapter is not a design reference per se, but rather outlines the types of radiant equipment and their uses.

Articles

Fred J. Prince, "Selection and Application of Overhead Gas-Fired Infrared Heating Devices," *ASHRAE Journal*, (October, 1962), pp 62-66

This article generally discusses infrared heating, including both full-building and spot-heating systems. Also discussed is heating unit rating, outdoor heating, and condensation or corrosion prevention.

Fred J. Prince, "Infrared Heating for Overall Comfort," *ASHRAE Journal* (December 1968), pp 57-64.

This landmark article for infrared heating lays out a design summary and procedure for space heating using radiant appliances. The appliances discussed are unvented high-intensity units. Many of the general principles discussed apply to low-intensity infrared as well.

Norman A. Buckley, P.E., "Application of Radiant Heating Saves Energy," *ASHRAE Journal* (September 1989), pp 17-26.

This article gives an up-to-date discussion of radiant heating principles, radiant heating types, and their potential for energy savings.

Papers

N.A. Buckley, P.E., and T. Seel, "Gas-Fired Low-Intensity Radiant Heating Provides a Cost-Effective, Efficient Space Conditioning Alternative," *ASHRAE Transactions*, Vol 92, pt. 1B (1986).

This paper focuses on low-intensity infrared and compares the performance of buildings retrofitted with radiant tube heaters with their performance before installation, on a degree-day basis.

N.A. Buckley, P.E., and T. Seel, "Engineering Principles Support an Adjustment Factor When Sizing Gas-Fired Low-Intensity Infrared Equipment," *ASHRAE Transactions*, Vol 93, pt. 1 (1987).

This paper attempts to show engineering grounds for radiant load adjustment factor. Experimental means are used to demonstrate that the factor has an empirically defendable effect.

N.A. Buckley, P.E., and T. Seel, "Case Studies Support Adjusting Heat Loss Calculations When Sizing Gas-Fired, Low-Intensity, Infrared Equipment," *ASHRAE Transactions*, Vol 94, pt. 1 (1988).

This study of tabular data supports work done by the same authors in 1987 (above).

D.M. Maloney, C.O. Pedersen, and M.J. Witte, "Development of a Radiant Heating System Model for BLAST," *ASHRAE Transactions*, Vol 94, pt. 1 (1988).

Maloney et al. discuss the development of a radiant heating model for the BLAST computer program, including three comfort models for use in sizing radiant systems. Simulation runs for convective and radiant buildings are compared, and application of the model for radiant heating design is discussed.

R.H. Howell, and S. Suryanarayana, "Sizing of Radiant Heating Systems: Part II–Heated Floors and Infrared Units," *ASHRAE Transactions*, Vol 96, pt. 1 (1990).

This paper discusses using the ASHRAE design heating load procedure to size radiant units. It concludes that this procedure will typically oversize units, but to what degree depends upon air infiltration into the space.

A.K. Athienitis, Ph.D., P.E., and J.G. Shou, "Control of Radiant Heating Based on the Operative Temperature," *ASHRAE Transactions*, Vol 97, pt. 2 (1991).

This study develops a numerical model for a room with radiant ceiling heat and compares control using operative temperature vs. air temperature. An experimental room with electric infrared heating is used to help verify the model. Preliminary results indicate faster response and improved comfort for operative temperature control.

Report

Ronald H. Howell, *A Study To Determine Methods for Designing Radiant Heating and Cooling Systems*, ASHRAE Report RP-394 (1987).

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