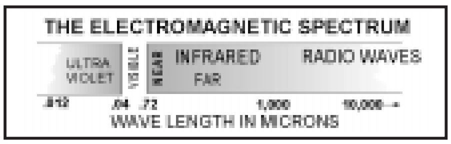
Technical Information

Radiant Infrared Heating - Theory & Principles

Infrared Theory

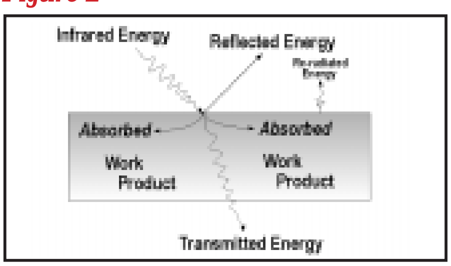
Infrared energy is radiant energy which passes through space in the form of electromagnetic waves (Figure 1). Like light, it can be reflected and focused. Infrared energy does not depend on air for transmission and is converted to heat upon absorption by the work piece. In fact, air and gases absorb very little infrared. As a result, infrared energy provides for efficient heat transfer without contact between the heat source and the work piece.

Figure 1



Infrared heating is frequently missapplied and capacity requirements underestimated due to a lack of understanding of the basic principles of radiant heat transfer. When infrared energy from a source falls upon an object or work piece, not all the energy is absorbed. Some of the infrared energy may be reflected or transmitted. Energy that is reflected or transmitted does not directly heat the work piece and may be lost completely from the process (Figure 2).

Figure 2

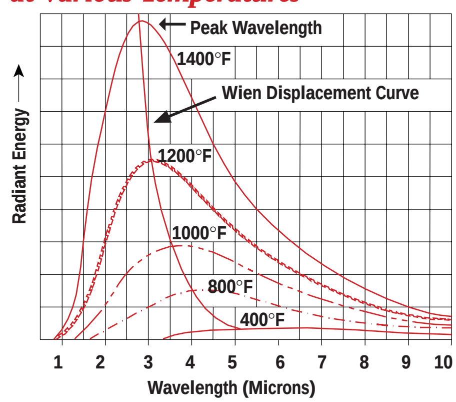


Another important factor to consider in evaluating infrared applications is that the amount of energy that is absorbed, reflected or transmitted varies with the wave length of the infrared energy and with different materials and surfaces. These and other important variables have a significant impact on heat energy requirements and performance.

Infrared Emitters & Source Temperatures — The amount of radiant energy emitted from a heat source is proportional to the surface temperature and the emissivity of the material. This is described by the Stefan-Boltzmann Law which states that radiant output of an ideal black body is proportional to the fourth power of its absolute temperature. The higher the temperature, the greater the output and more efficient the source.

Emissivity and an Ideal Infrared Source — The ability of a surface to emit radiation is defined by the term *emissivity.* The same term is used to define the ability of a surface to absorb radiation. An ideal infrared source would radiate or absorb 100% of all radiant energy. This ideal is referred to as a "perfect" black body with an *emissivity* of unity or 1.0. The spectral distribution of an ideal infrared emitter is below.

Spectral Distribution of a Blackbody at Various Temperatures



Note — As the temperature increases, the peak output of the source shifts to the left of the electromagnetic spectrum with a greater percentage of the output in the near infrared range. This is referred to as the Wien Displacement Curve and is an important factor in equipment selection.

Emissivity — In practice, most materials and surfaces are "gray bodies" having an emissivity or absorption factor of less than 1.0. For practical purposes, it can be assumed that a poor emitter is usually a poor absorber. For example, polished aluminum has an emissivity of 0.04 and is a very poor emitter. It is highly reflective and is difficult to heat with infrared energy. If the aluminum surface is painted with an enamel, emissivity increases to 0.85 - 0.91 and is easily heated with infrared energy. Table 1 lists the emissivity of some common materials and surfaces.

Absorption — Once the infrared energy is converted into heat at the surface, the heat travels into the work by conduction. Materials such as metals have high thermal conductivity and will quickly distribute the heat uniformly throughout. Conversely, plastics, wood and other materials have low thermal conductivity and may develop high surface temperatures long before internal temperatures increase appreciably. This can be an advantage when using infrared heating for drying paint, curing coatings or evaporating solvents on non-metal substrates.

Reflectivity — Materials with poor emissivity frequently make good reflectors. Polished gold with an emissivity of 0.018 is an excellent infrared reflector that does not oxidize easily. Polished aluminum with an emissivity of 0.04 is an excellent second choice. However, once the surface of any metal starts to oxidize or collect dirt, its emissivity increases and its effectiveness as an infrared reflector decreases.

Table 1 — Approximate Emissivities

Metals	Polished	Rough	Oxidized
Aluminum	0.04	0.055	0.11-0.19
Brass	0.03	0.06-0.2	0.60
Copper	0.018-0.02	—	0.57
Gold	0.018-0.035	—	—
Steel	0.12-0.40	0.75	0.80-0.95
Stainless	0.11	0.57	0.80-0.95
Lead	0.057-0.075	0.28	0.63
Nickel	0.45-0.087	—	0.37-0.48
Silver	0.02-0.035	—	—
Tin	0.04-0.065	—	—
Zinc	0.045-0.053	—	0.11
Galv. Iron	0.228	—	0.276
Miscellaneous Materials			
Asbestos			0.93-0.96
Brick			0.75-0.93
Carbon			0.927-0.967
Glass, Smooth			0.937
Oak, Planed			0.895
Paper			0.924-0.944
Plastics			0.86-0.95
Porcelain, Glazed			0.924
Quartz, Rough, Fused			0.932
Refractory Materials			0.65-0.91
Rubber			0.86-0.95
Water			0.95-0.963
Paints, Lacquers, Varnishes			
Black/White Lacquer			0.8-0.95
Enamel (any color)			0.85-0.91
Oil Paints (any color)			0.92-.096
Aluminum Paint			0.27-0.67

Transmission — Most materials, with the exception of glass and some plastics, are opaque to infrared and the energy is either absorbed or reflected. Transmission losses can usually be ignored. A few materials, such as glass, clear plastic films and open fabrics, may transmit significant portions of the incident radiation and should be carefully evaluated.

Controlling Infrared Energy Losses — Only the energy absorbed is usable in heating the work product. In an unenclosed application, losses from reflection and re-radiation can be excessive. Enclosing the work product in an oven or a tunnel with high reflective surfaces will cause the reflected and re-radiated energy to be reflected back to the work product, eventually converting most of the original infrared energy to useful heat on the work product.

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Radiant Infrared Heating - Source Evaluations

Evaluating Infrared Sources

Commonly available infrared sources include heat lamps, quartz lamps, quartz tubes, metal sheath elements, ceramic elements and ceramic, glass or metal panels. Each of these sources has unique physical characteristics, operating temperature ranges and peak energy wavelengths. (See characteristics chart below.)

Source Temperature & Wave Length Distribution — All heat sources radiate infrared energy over a wide spectrum of wavelengths. As the temperature increases for any given source:

1. The total infrared energy output increases with more energy being radiated at all wavelengths.
2. A higher percentage of the infrared energy is concentrated in the peak wavelengths.
3. The energy output peak shifts toward the shorter (near infrared) wavelengths.

The peak energy wavelength can be determined using Wien's Displacement Law.

$$\text{Peak Energy (Microns)} = \frac{5269 \text{ microns/°R}}{\text{Source Temp. (°F)} + 460}$$

$$\text{Source } 1400°F = \frac{5269 \text{ microns/°R}}{1400°F + 460} = 2.83 \text{ microns}$$

$$\text{Source } 500°F = \frac{5269 \text{ microns/°R}}{500°F + 460} = 5.49 \text{ microns}$$

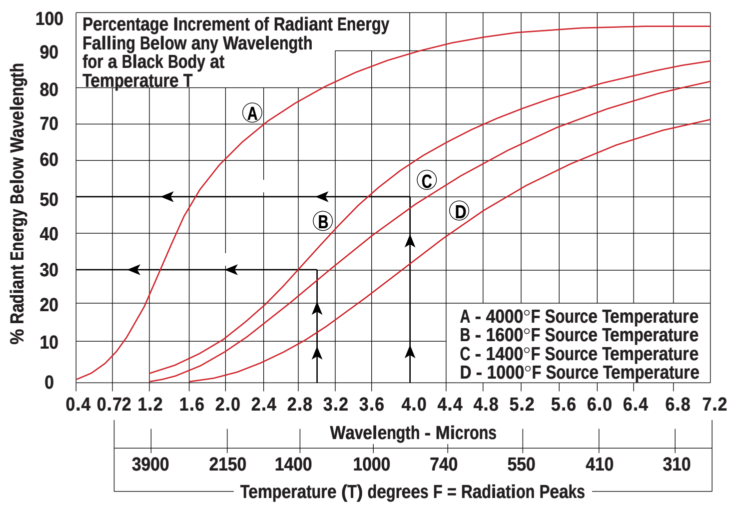
Absorption by Work Product Materials in Process Applications — While most materials absorb long (far) infrared wavelengths uniformly, many materials selectively absorb short (near) infrared energy in bands. In process heating applications this selective absorption could be very critical to uniform and effective heating.

For process heating, it is recommended that the infrared source have a peak output wavelength that best matches the selective absorption band of the material being heated. When the major absorption wavelengths of the material being heated are known, the chart below provides guidance in selecting the most efficient heat source. The relative percentage of radiant energy emitted by specific source and falling in a particular wavelength range can be determined from the chart.

Example — Plastic materials are known to have high infrared absorption rates in wavelengths between 3 and 4 microns. Select a source which provides the most effective output to heat plastics in the 3 and 4 micron range.

1. **Enter Bottom of Chart** at 3 and 4 microns, read up to corresponding points on selected element curve (use 1400°F metal sheath in this example).
2. **From These Points,** move left to read the corresponding percentages (29% and 51%).
3. **The Difference** between these two values (22%) is the percentage of radiant energy emitted by the element within selected wavelengths limits.
4. **To Obtain** the maximum percentage of the energy emitted by a given element in the desired wavelength band, multiply the percentage in 3 above by the conversion efficiency for the selected element (comparison chart 56% x 22% = 12.2%).

In this example, a high temperature source (quartz lamp 4000°F) with a peak in the 1.16 micron range, while more energy conversion efficient, would not be as effective as a lower temperature metal sheath or panel heaters with a peak in the 2.8 to 3.6 micron range. Quartz tubes (1600°F) would provide similar peak wavelengths.



Characteristics of Commercially Used Infrared Heat Source

Infrared Source	Tungsten Filament		Nickel Chrome Resistance Wire			Wide Area Panels	
	Glass Bulb	T3 Quartz Lamp	Quartz Tube	Metal Sheath	Ceramic	Ceramic Coated	Quartz Face
Source Temperature (°F)	3000 - 4000°F	3000 - 4000°F	Up to 1600°F	Up to 1500°F	Up to 1600°F	200 - 1600°F	Up to 1700°F
Brightness	Intense white	Intense White	Bright Red to Dull Orange	Dull to Bright Red	Dark to Dull Red	Dark to Cherry Red	Dark to Cherry Red
Typical Configuration	G-30 Lamp	3/8" Dia. Tube	3/8 or 1/2" Tube	3/8 or 1/2" Tube	Various Shapes	Flat Panels	Flat Panels
Type of Source	Point	Line	Line	Line	Small Area	Wide Area	Wide Area
Peak Wavelength (microns)	1.16	1.16	2.55	2.68	3 - 4	2.25 - 7.9	2.5 - 6
Maximum Power Density	1 kW/ft^2	3.9 kW/ft^2	1.3 - 1.75 kW/ft^2	3.66 kW/ft^2	Up to 3.6 kW/ft^2	3.6 kW/ft^2	5.76 kW/ft^2
Watts per Linear Inch	N/A	100	34 - 45	45 - 55	N/A	N/A	N/A
Conversion Efficiency Infrared Energy	86%	86%	40 - 62%	45 - 56%	45 - 50%	45 - 55%	45 - 55%
Response Time Heat/Cool	Seconds	Seconds	1 - 2 Minutes	2 - 4 Minutes	5 - 7 Minutes	5 - 8 Minutes	6 - 10 Minutes
Color Sensitivity	High	High	Medium	Medium	Medium	Low to Medium	Low to Medium
Thermal Shock Resistance	Poor	Excellent	Excellent	Excellent	Good	Good	Good
Mechanical Ruggedness	Poor	Fair	Good	Excellent	Good	Good	Fair
Chromalox Model	—	QR	QRT	RAD, URAD	RCH	CPL, CPLI, CPH	CPHI

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Radiant Infrared Heating - Process Applications

Application Parameters

Typical industrial applications of radiant heating include **curing** or **baking** (powders, paints, epoxies, adhesives, etc.), **drying** (water, solvents, inks, adhesives, etc.) and **product heating** (preheating, soldering, shrink fitting, forming, molding, gelling, softening, and incubating). The following are general guidelines that can be used in evaluating and resolving most radiant heating problems. Unfortunately, the process is so versatile and its applications so varied that it is not feasible to list solutions to every problem.

To determine heat energy requirements and select the best Chromalox infrared equipment for your application, it is suggested the problem be defined using a check list similar to below. Several of the key factors on the list are discussed on this and following pages:

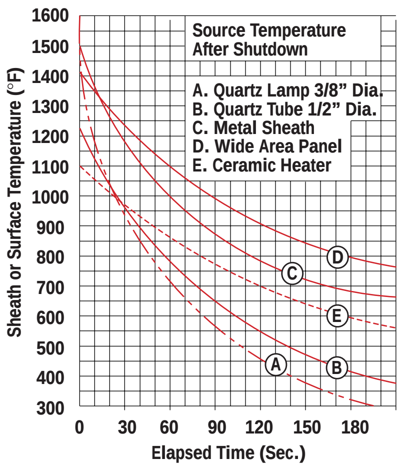
1. Product to be heated
2. Physical dimensions and weight/piece
3. Surface coating or solvents, if any
4. Infrared absorption characteristics
5. Production rate (lbs/hr, pieces/hr, etc.)
6. Work handling method during heating (continuous, batch or other)
7. Element response time (if critical)
8. Power level requirements in kW/ft² based on Time/Temperature relationship (if known)
9. Starting work temperature
10. Final work temperature
11. Ventilation (if present or required)
12. Available power supply
13. Space limitations

Infrared Absorption Characteristics — As previously discussed, many materials, particularly plastics, selectively absorb infrared radiation. The following chart provides data on some common plastic materials and the recommended source temperatures for thermoforming applications.

Plastic	Absorption Band(s) (microns)	Ideal Source Temperature (°F)
LPDE HDPE	3.3 - 3.9 3.2 - 3.7	877 - 1170 950 - 1170
PS	3.2 - 3.7 (6.4 - 7.4)	950 - 1170 245 - 355
PVC	1.65 - 1.8 (2.2 - 2.5)	2440 - 2700 1625 - 1910
PMMA PA-66	1.4 - 2.2 1.9 - 2.8 (3.4 - 5)	1910 - 3265 1405 - 2285 585 - 1075
Cellulose	2.2 - 3.6	990 - 1910
Acetate	(5.2 - 6)	440 - 545

Element Response Time — Some applications, such as continuous web heating of paper or plastic film, require quick shutdown of heaters in case of work stoppage. In these applications, residual radiation from the infrared heaters and associated equipment must be considered. Residual radiation from the element is a function of the operating temperature and mass. Quartz lamps and tubes have relatively low mass and the infrared radiation from the resistance wire drops significantly within seconds after shutdown. However, the surrounding quartz envelope acts as a secondary source of radiation and continues to radiate considerable energy. Metal sheathed elements have more mass and slightly slower response time. Wide area panels have the most mass and the slowest response time for both heat up and cool down. The following chart shows the average cool down rate of various sources after shutdown. Actual cool down of the source and work product will vary with equipment design, product temperature, ambient temperature and ventilation.

Source Temperature Vs. Time



Time-Temperature Relationship — A critical step in the evaluation of a radiant heating application is to determine the time necessary to develop work piece temperature and the elapsed time needed to hold temperature in order to obtain the desired results (curing or drying). The following chart shows time/temperature relationships for several typical infrared applications and materials.

Curing	Substrate	Surface Temp (°F)	W/In²	Time (min)
Alkyd Paint	Steel	320	3.9	3
Epoxy Paint	Steel	356	8.1	5
Acrylic Paint	Steel	392	8.1	2
Powder Coat	Steel	400	13	6

Drying & Heating	Substrate	Surface Temp (°F)	W/In²	Time (sec)
Glass Bottles	—	104	6.4	30
Adhesives	Paper	—	3.2	30
Heating				
PVC Shrinking	—	300	3.2	60
ABS Forming	—	340	9.7	—

Deriving Time-Temperature Information from Empirical Testing — If specific information is not readily available for a particular work product, a simple but effective test will usually provide enough preliminary data to proceed with a design. Place one or more radiant heaters in a position with the radiation directed at a work product sample. The distance between the face of the heater and the sample should approximate the expected spacing in the final application. Position the sample so that it is totally within the radiated area. Energize the heater(s) and record the time necessary to reach desired temperature. Calculate the W/in² falling on the work piece using the exposed area of the work product and the maximum kW/ft² at the face of the heater as listed in the product catalog page. If the data is not available and a sample test can not be performed, the following table provides a few suggested watt densities as guidance.

Application	W/In² on Work: Heat Up	Hold
Paint Baking	4-6	1 - 2
Metal Dry Off	15	8
Thermoforming	10 - 15	—
Fusing or Embossing (plastic films)	5-6	—
Silk Screen Drying	5-6	—

Contact your Local Chromalox Sales office for further information or assistance in determining time/temperature requirements for a particular application.

Power Level or Radiation Intensity — In most process applications, more than one radiant heater is needed to produce the desired results. When heaters are mounted together as close as possible, the net radiant output of the array is defined as the maximum power level or radiation intensity. The catalog pages for radiant heaters indicate the maximum kW/ft² at the face of each heater. Typical ranges for radiation intensity (power level) are as follows:

Radiant Intensity or Power Level	Heater Output (kW/Ft²)
Low	1 - 2
Medium	2 - 3
High	Over 3

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Radiant Infrared Heating - Process Applications

Determining kW Required — It is difficult to develop simple calculations for radiant heating applications because of the many variables and process unknowns. Design data gained from previous installations or from empirical tests is frequently the most reliable way of determining installed kW requirements. Total energy requirements can be estimated with conventional heat loss equations. The results of conventional equations will provide a check against data obtained from nomographs or empirical testing. As a minimum, conventional equations should include the following.

1. **Calculate the Sensible Heat** required to bring work to final temperature. Base calculations on specific heat and pounds of material per hour.
2. **Determine Latent Heat of Vaporization (when applicable).** Latent heat of vaporization is normally small for solvents in paints and is frequently ignored. However, when water is being evaporated, the kilowatt hours required may be quite significant.
3. **Ventilation Air (when applicable).** The rise in air temperature for work temperatures, 350°F or less, can usually be estimated as 50% of final work temperature rise. For higher work temperatures, assume air and work temperature are the same.
4. **Conveyor Belt or Chain Heat Requirements.** Assume temperature rise of conveyor to be the same as work temperature rise.
5. **Wall, Floor and Ceiling Losses for Enclosed Ovens.** For uninsulated metal surfaces, refer to Graph G-125S. For insulated walls, refer to Graph G-126S.
6. **Oven End Losses.** For enclosed ovens, this will depend on shape of end area and whether or not air seals are used. If silhouette shrouds are used, a safety factor of 10% is acceptable.
7. **The Sum of The Losses** calculated in 1-6 above will be the minimum total heat energy requirement based on conventional heat loss equations.

Infrared Heating Equations — Infrared energy requirements can also be estimated by using equations and nomographs developed specifically for infrared applications.

Product Heating — For product heating, the following equation can be used

$$kW = \frac{\text{Lbs/hr} \times C_P \times \Delta T\ {}^\circ F}{3412\ \text{Btu/kW} \times \text{Efficiency}(_{RE}) \times VF \times \epsilon}$$

Where:
Lbs/hr = Pounds of work product per hour
C_P = Specific heat in Btu/lb/°F
ΔT = Temperature rise in °F
Efficiency (RE) = Combined efficiency of the source and reflector
VF = View Factor is the ratio of the infrared energy intercepted by the work product to the total energy radiated by the source. For enclosed ovens, use a factor of 0.9. For other applications, refer to the view factor table.
ϵ = Absorption (emissivity) factor of the work product

Drying & Solvent Evaporation — Removing solvent or water from a product requires raising the product temperature to the vaporization temperature of the solvent and adding sufficient heat to evaporate it. To calculate heat requirements for solvent evaporation, the following information must be known.

1. Pounds of solvent to be evaporated per hour
2. Pounds of work product per hour
3. Initial temperature of product and solvent
4. Specific heat of product
5. Specific heat of solvent
6. Vaporization temperature of solvent (ie: water = 212°F)
7. Heat of vaporization of solvent
8. Source/reflector efficiency
9. View factor
10. Absorption factor (emissivity)

WARNING — Hazard of Fire. Flammable solvents in the atmosphere constitute a fire hazard. When flammable volatiles are released in continuous process ovens, the National Fire Prevention Association recommends not less than 10,000 ft^3 of air be removed from the oven per gallon of solvent evaporated. Reference NFPA Bulletin 86 "Ovens and Furnaces", available from NFPA, P.O. Box 9101, Quincy MA 02269.

For drying, use the following equation.

$$kW = \frac{Q_{WP} + Q_S + Q_{LH}}{3412\ \text{Btu/kW} \times \text{Efficiency}(_{RE}) \times VF \times \epsilon}$$

Where:
Q_{WP} = Btu required by work product to raise the temperature from initial to vaporization temperature
Q_S = Btu required by solvent to raise the temperature from initial to vaporization temperature
Q_{LH} = Btu required for the latent heat of the vaporization of the solvent
Efficiency (RE) = Combined efficiency of the source and reflector
VF = View Factor for enclosed ovens, use a factor of 0.9. For other applications, refer to the view factor table.
ϵ = Absorption (emissivity) factor of the work product

Controls — Most control systems for infrared process heating can be divided into two categories, open loop or manual systems and closed loop, fully automatic systems.

Open Loops or Manual Systems — The simplest and most cost effective control system is an input controllers (percentage timer) such as the Chromalox VCF Controller operating a magnetic contactor. The timer cycles the radiant heaters on and off for short periods of time (typically 15 - 30 seconds). This control system works best with metal sheath heaters, which have sufficient thermal mass to provide uniform radiation. It can be used with quartz tube or quartz lamp heaters by using special circuitry to switch from full to half voltage rather than full on and full off.

Closed Loop or Automatic Systems — Since infrared energy heats the work product by direct radiation, closed loop control systems that depend on sensing and maintaining air temperature are relatively ineffective (except in totally enclosed ovens). In critical applications where temperature tolerances must be closely held, non-contact temperature sensors operating SCR control panels are recommended. Non-contact temperature sensors can be positioned to measure only the work product temperature. Properly positioned, non-contact temperature sensors and SCR control panels can provide very accurate radiation and product temperature control.

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Radiant Infrared Heating - Process Applications

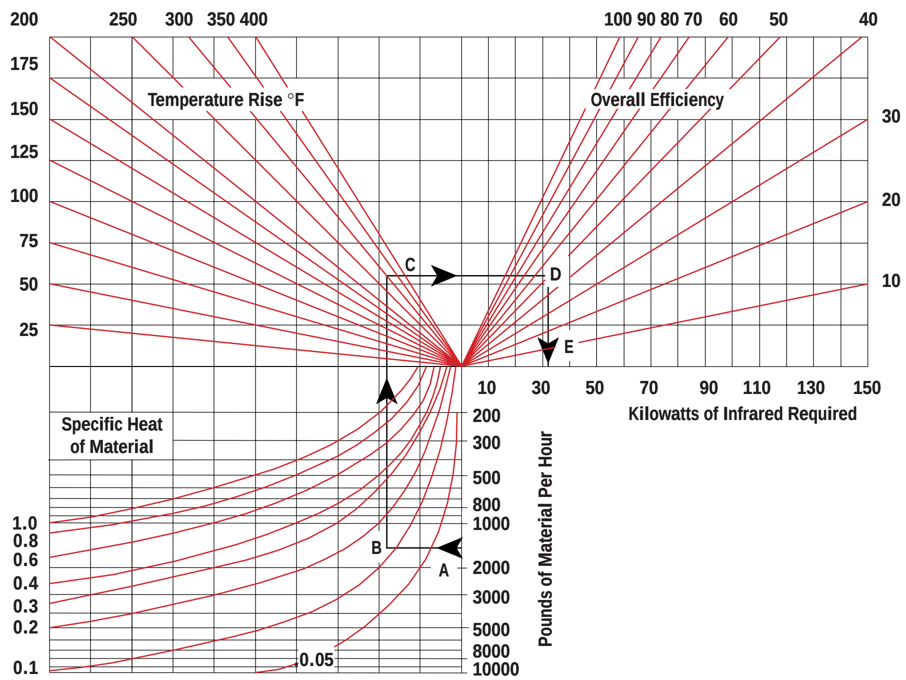
Nomograph for Product Heating — For product heating, the nomograph at the right can be used. The nomograph does not take into account heat energy requirements for air ventilation. To estimate the kW for total product heating:

1. **Determine** pounds of material per hour to be heated (A)
2. **Read across** to the specific heat of the material (B)
3. **Read up** to desired temperature rise in °F (C)
4. **Read across** to overall efficiency (D). Overall efficiency = Product Absorption Factor x View Factor x Source Efficiency. Determine Product Absorption Factor (surface emissivity) of the work product (ie: ϵ = 0.85 for enamel sheet metal). Determine View Factor (use 0.9 as a view factor for well designed or enclosed ovens). Determine Source efficiency. Typical Source/Reflector efficiencies are:

Quartz Lamps	0.70 to 0.80
Quartz Tubes	0.60 to 0.70
Metal Sheath	0.55 to 0.65

5. **Read down** to Kilowatts required (E).

Estimating Total Kilowatts for Product Heating



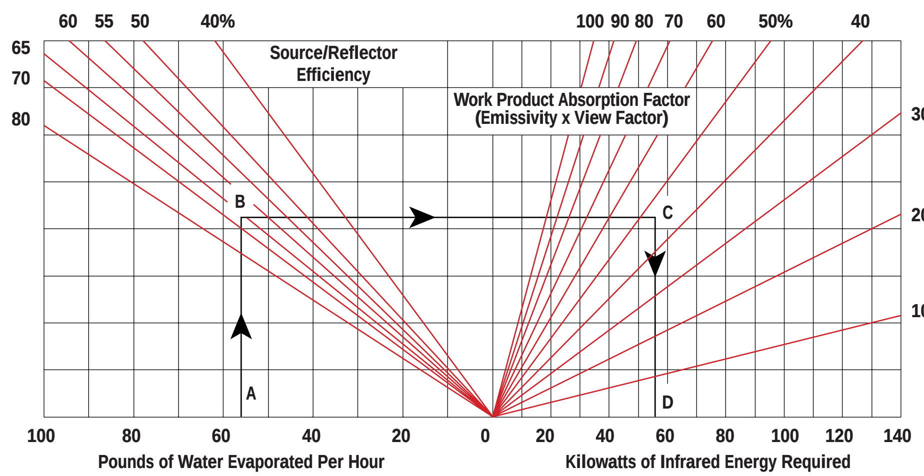
Nomograph for Drying — The nomograph to the right can be used to estimate Kilowatts required to evaporate water from the surfaces of work product. Graph is based on an initial starting product temperature of 70°F. It does not take into account heat energy requirements for air circulation or ventilation.

1. **Determine pounds** of water (solvent) per hour to be evaporated (A)
2. **Read up** to Source/Reflector efficiency (B). Depending on the configuration and cleanliness of the reflector, typical Source/Reflector efficiencies are:

Quartz Lamps	0.70 to 0.80
Quartz Tubes	0.60 to 0.70
Metal Sheath	0.55 to 0.65

3. **Read across** to Work Product Absorption Factor (C). This value is based on the emissivity of the work product surface (ie: ϵ = 0.85 for enameled sheet metal) and the view factor of the oven or space. Use 0.9 as a view factor for well designed or enclosed ovens.
4. **Read down** to Kilowatts required (D).

Estimating Infrared Kilowatts for Drying



Note — To evaporate solvents other than water, calculate the energy required to heat the solvent to vaporization temperature using the weight, specific heat and temperature rise. Calculate the latent heat of vaporization and add to the energy required to heat the solvent to vaporization temperature.

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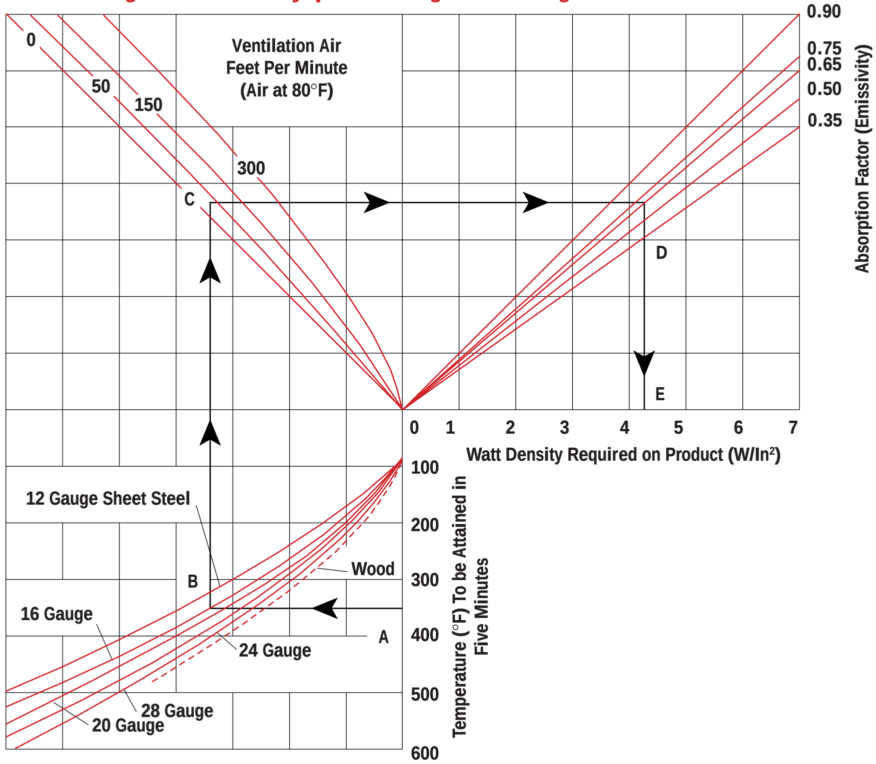
Radiant Infrared Heating - Process Applications

Baking & Curing — The nomograph to the right can be used to determine the watt density required on the work product for baking and curing of paints and coating. Lacquers are cured primarily by evaporation of the solvent and can be cured by infrared in 2 - 15 minutes. Enamels are cured primarily by polymerization and require a longer time (15 - 20 minutes). Varnishes, japans and house paints cure mainly by oxidation but can usually can be accelerated by infrared heating. To find approximate watt density needed for baking:

1. **Locate** temperature product is to reach in five minutes (A)
2. **Read across** to line representing gauge of the material being heated (B)
3. **Read up** to ventilation air in feet per minute over surface of the product (C). If not known, estimate feet per minute based on cubic feet per minute of ventilation or circulating air divided by the the approximate cross sectional area of the oven. In applications with no forced ventilation, use 2 - 5 fpm.
4. **Read right** to the absorption factor for the work product surface or coating (ie: ϵ = 0.85 for enameled sheet metal) (D)
5. **Read down** to watt density required on the product surface (E).

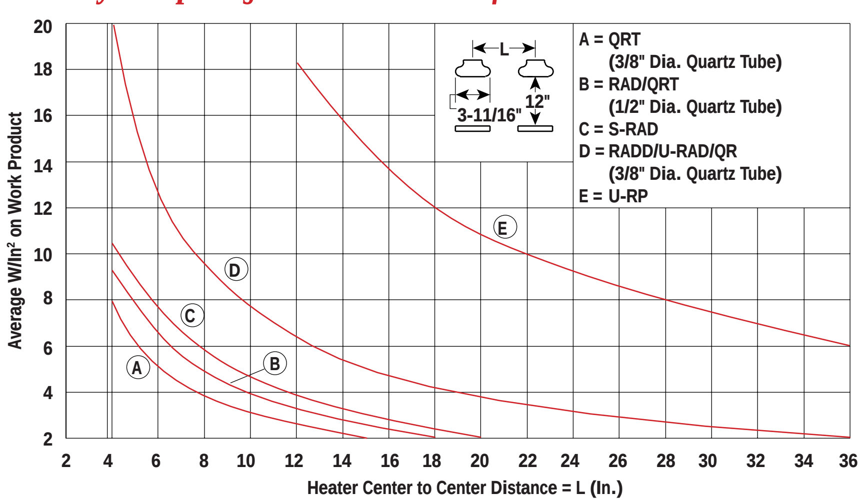
Estimating Watt Density for Curing or Baking



Determining Heater Fixture Spacing — Having determined the total required kilowatts and the desired W/in² on the work product, the next step is to deterine the spacing and the number of heaters. In most conveyor type oven applications, a 12" spacing from the face of the heater to the work product produces uniform distribution of the radiation. The graph to the right shows centerline to centerline spacing of Chromalox radiant heaters to obtain various intensities on the work based on a spacing of 12" from the face of the heater to the work product. Specific applications may require the distance to be increased or decreased.

The graph is applicable to line or point infrared sources installed in reflectors. Refer to view factor charts for ceramic heaters and flat panel infrared sources.

Intensity Vs. Spacing — Point & Line Infrared Sources



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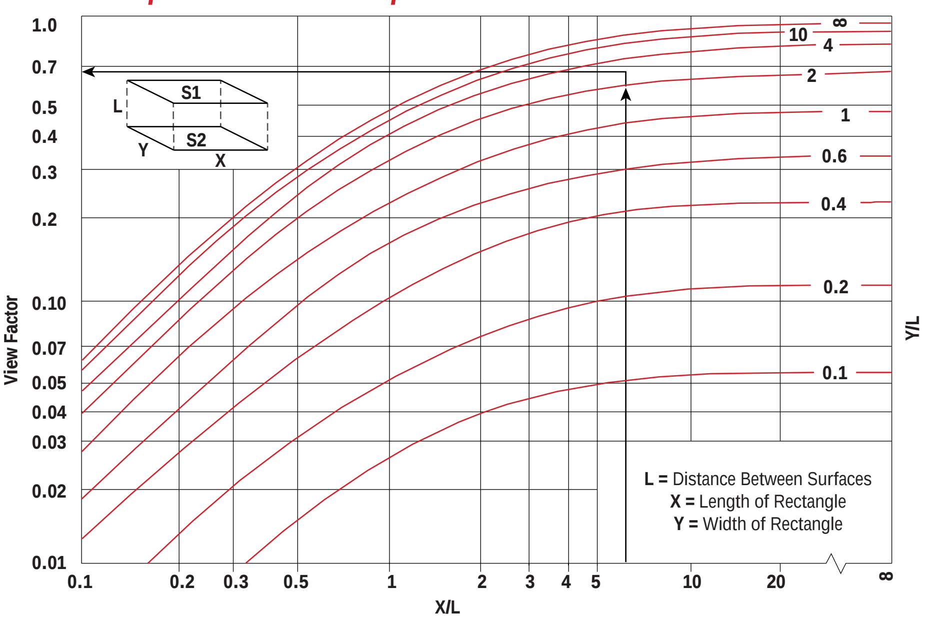
Radiant Infrared Heating - Process Applications

View Factor for Flat Panels — While the radiation pattern from line and point infrared sources can be controlled by reflectors, the radiation pattern from flat panels is diffused and the infrared energy is emitted from a large area. Consequently, the shape of the source and the target are a significant factor in determining the Watt density falling on the work product. For parallel surfaces in applications such as thermoforming or web heating, the incident energy falling on the work product is determined by a “View Factor”. View factor is defined as the percentage or fraction of infrared energy leaving the surface of a flat panel (source) which is intercepted by the surface of the work product (target). The view factor for parallel surfaces (rectangles) can be determined from the graph. **Example —** Find the view factor for a 12 by 24" panel heater mounted 4" from a continuous web infrared drying application. X/L = 24" ÷ 4" = 6, Y/L = 12" ÷ 4" = 3. Read left from the intercept of X/L = 6 and Y/L = 3 with a view factor of 0.7.

View Factor for Two Parallel Surfaces



Radiant Oven Heating Example — A manufacturer of 66 gallon electric water heaters wishes to bake the paint on sheet metal jackets (open top and bottom) at 350°F. The jackets weigh 33 lbs, are 26" in diameter by 45" high with an outside area of 25.5 ft². The process requires 20 jackets be painted per hour. The jackets will be suspended from a conveyor chain on 9 ft centers and will be rotated as they move. The chain weighs 12 lbs/ft. The heaters will be installed in a tunnel oven with 2 inches of insulation and reflective walls. The oven is 8 ft long, 4 ft wide and 7 ft high and has end openings 3 ft by 6 ft. Preliminary test results show the jackets must be baked for six minutes for a satisfactory finish. The paint weighs 7.25 lbs/gal, contains 50% volatiles and covers 212 ft² per gallon.
Assume a room temperature of 70°F
Specific heat of steel = 0.12 Btu/lb/°F
Boiling point of solvent = 170°F
Specific heat of solvent = 0.34 Btu/lb/°F
Latent heat of vaporization = 156 Btu/lb

Heat Required for Operation —

1. **Heat Absorbed by Jackets —** (20 jackets/hr x 33 lbs = 660 lbs/hr)

$$\frac{660 \text{ lbs/hr} \times 0.12 \text{ Btu/lb/°F} \times (350 - 70°\text{F})}{3412 \text{ Btu/kW}} = 6.5 \text{ kW}$$

2. **Heat Absorbed by Solvent —** Solvent volume

$$\frac{25.5 \text{ ft}^2 \times 20 \text{ jackets/hr} \times 50\%}{212 \text{ ft}^2/\text{gal}} = 1.20 \text{ gal/hr}$$

Heat required to heat solvent to 70°F

$$\frac{1.2 \text{ gph} \times 7.25 \text{ lb/gal} \times 0.34 \text{ Btu/lb} \times (170\text{-}70°\text{F})}{3412 \text{ Btu/kW}} = 0.1 \text{ kW}$$

Heat required to vaporize solvent

$$\frac{1.20 \text{ gph} \times 7.25 \text{ lb/gal} \times 156 \text{ Btu/lb}}{3412 \text{ Btu/kW}} = 0.4 \text{ kW}$$

Heat absorbed by solvent = 0.1 + 0.4 = 0.5 kW

3. **Heat Required by Ventilation Air —** (NFPA recommendation is a minimum of 10,000 cubic feet per gallon of solvent evaporated.)
Densiity of air = 0.080 lbs/ft³
Specific heat of air = 0.240 Btu/lb/°F

Note — Ventilation air is heated by re-radiation and convection from the work, oven walls, etc. Air temperature is always less than the work temperature. Assume a 200°F air temperature.

Volume = 1.20 gph x 10,000 ft³ = 12,000 ft³/hr

$$\frac{12{,}000 \text{ ft}^3/\text{h} \times 0.08 \text{ lb/ft}^3 \times 0.24 \text{ Btu/lb/°F} \times (200\text{-}70°\text{F})}{3412 \text{ Btu/kW}}$$

Heat absorbed by ventilation air = 8.78 kW

4. **Conveyor Chain & Hangers —** Normally the conveyor chain is outside the radiation pattern of the heaters and is heated by convection from air in the tunnel. Since the heat absorbed by the air has already been accounted for, the heat absorbed by the conveyor may be ignored. (Conveyor speed should provide 6 minutes in the 8 foot heated area.)

Total Heat Absorbed —

6.5 kW + 0.5 kW + 8.8 kW = 15.8 kW

Heat Losses — Heat losses from oven surface with 2 inches of insulation (Graph G-126S) = 12 W/ft². Assume inside surface temperature of wall and ceiling = 250°F, ΔT = 180°F)
Wall area 7 ft x 8 ft x 2 ft = 112 ft²
Ceiling and floor area 8 ft x 4 ft x 2 ft = 64 ft²
Open tunnel ends = 3 ft x 6 ft x 2 ft = 36 ft²

Heat loss from outside surfaces of oven

$$\frac{176 \text{ ft}^2 \times 12 \text{ W/ft}^2}{1000 \text{ W/kW}} = 2.1 \text{ kW/hr}$$

Heat loss from open oven ends (assume the open ends are equal to an uninsulated metal surface under the same conditions as the oven surfaces) (See Graph G-125S.)

$$\frac{36 \text{ ft}^2 \times 0.6 \text{ W/ft}^2 \times 180°\text{F}}{1000 \text{ W/kW}} = 3.89 \text{ kW/hr}$$

Total Heat Losses — 2.1 kW + 3.98 kW = 5.99 kW

Total Heat Capacity Required for Operation — 15.8 kW + 5.99 kW = 21.8 kW/hr

As with any process heat calculation, it is not possible to account for all the variables and unknowns in the application. A safety factor is recommended. For radiant heating applications, a safety factor of 1.4 is suggested.

Total Heat Required = 21.8 x 1.4 = 30.5 kWh

Technical Information

Radiant Infrared Heating - Comfort Heating

Indoor Spot Heating

Infrared spot heating of work stations and personnel in large unheated structures or areas has proven to be economical and satisfactory. The following guidelines may be used for spot heating applications (areas with length or width less than 50 feet).

1. **Determine** the coldest anticipated inside ambient temperature the system must overcome. If freeze protection is provided by another heating system, this temperature will be 40°F.
2. **Determine** the equivalent ambient temperature desired (normally 70°F is the nominal average).
3. **Subtract** 1 from 2 to determine the theoretical increase in ambient temperature (ΔT) expected from the infrared system. If drafts are present in the occupied area (air movement over 44 feet per minute (0.5 mph) velocity), wind shielding or protection from drafts should be considered.
4. **Determine** the area to be heated in ft^2. This is termed the "design or work area" (A_D) (Fig. 1).
5. **Multiply** the design area by one watt per square foot times the theoretical temperature increase (ΔT) desired as determined in Step 3 (minimum of 12 watts per square foot). The design factor of one watt per square foot density assumes a fixture mounting height of 10 feet. Add 5% for each foot greater than 10 feet in mounting height. Avoid mounting fixtures below 8 feet.
6. **Determine** fixture mounting locations
   a) In areas where the width dimension is 25 feet or less, use at least two fixtures mounted opposite each other at the perimeter of the area and tilted at an angle. This provides a greater area of exposure to the infrared energy by personnel in the work area. Tilt the fixtures so that the upper limit of the fixture pattern is at approximately six feet above the center of the work station area (Figure 2).
   b) When locating fixtures, be sure to allow adequate height clearance for large moving equipment such as cranes and lift trucks.
   c) Avoid directing infrared onto outside walls.
7. **Estimate** (tentatively) the radiated pattern area. Add length of fixture to the fixture pattern width (W) to establish pattern length (L). Pattern Area = L x W (Fig. 3).

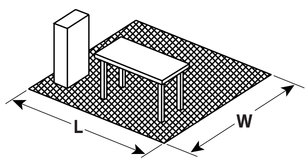


Figure 1 — Design Area

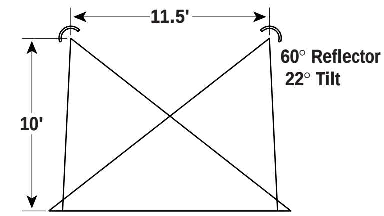


Figure 2 — Tilted Infrared Fixtures for Spot Heating

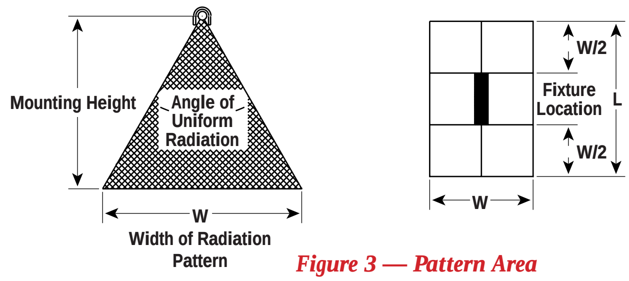


Figure 3 — Pattern Area

8. **Divide** the design area (Step 4) into the pattern area (Step 7).

$$Q = \frac{\text{Pattern Area}}{\text{Design Area}}$$

   If the pattern area is equal to or greater than the design area, quotient (Q) will be equal to or greater than 1 and coverage is adequate. If Q is less than 1, the design area exceeds the pattern area of individual fixtures. Adjust the heater locations and patterns or add additional fixtures with patterns overlapping as necessary, to ensure adequate coverage.
9. **Multiply** quotient (Q in Step 8) by the increase in theoretical temperature (ΔT of Step 3) by the design area (A_D of Step 4) to determine the amount of radiation to be installed.

   Radiation (Watts) = $Q \times \Delta T \times A_D$
10. **Many Types** of radiant heaters are available for comfort heating applications including ceiling, wall and portable floor standing models. Choose specific fixtures from the product pages. It is preferred that half the wattage requirements be installed on each side of the work station in the design area.

Controls — Manual control by percentage timers may be adequate for a small installation. To provide better control of comfort levels in varying ambient temperatures, divide the total heat required into two or three circuits so that each fixture or heating element circuit can be switched on in sequence. Staging can be accomplished by using multistage air thermo-stats set at different temperatures.

Indoor Area Heating

In many industrial environments, area heating (areas with length or width greater than 50 ft) can be accomplished economically with multiple infrared heaters. For quick estimates, determine the minimum inside temperature and use a factor of 0.5 watts per square foot of design area for each degree of theoretical temperature. If the calculated heat loss of the structure, including infiltration or ventilation air, is less than the quick estimate, select the lower value. Locate heaters uniformly throughout the area with at least a 30% overlap in radiation pattern.

Outdoor Spot Heating

The same guidelines outlined under Indoor Spot Heating should be followed except that watts per square foot for each degree of theoretical ambient temperature increase should be doubled (approximately 2 watts per square foot for each 1°F). This factor applies to outdoor heating applications with little or no wind chill effect on personnel. If wind velocities are a factor in the application, determine the equivalent air temperature from the Wind Chill Chart in NEMA publication HE3-1971 or other information source.

Note — Increasing the infrared radiation to massive levels to offset wind chill can create discomfort and thermal stress. In outdoor exposed applications, a wind break or shielding is usually more effective.