Technical Information

Watt Density & Heater Selection - Guidelines

Understanding Watt Density

Watt density (W/in^2) is the heat flux emanating from each square inch of the effective heating area (heated surface) of the element.

W/in^2 = Rated Watts ÷ Effective heating area

The effective heating area is the surface area per linear inch of the heater multiplied by the heated length. For strip heaters which are rectangular in shape, the surface area per linear inch is:

1-1/2" wide = 3.45 in^2 per linear inch
1" wide = 2.31 in^2 per inch.

The heated length (HL) of strip heaters is calculated as follows:

< 30-1/2" long	HL = Overall Length less 4"
≥ 30-1/2" long	HL = Overall Length less 5"

For tubular elements, watt density is determined by the following formulas.

Effective heating area = π x Dia. x Heated Length

The surface area per linear inch of standard diameter tubular elements is shown below:

Size (Dia.)	In^2/in.
0.246 inch (1/4)	0.77
0.315 inch (5/16)	0.99
0.375 inch (3/8)	1.18
0.430 inch (7/16)	1.35
0.475 inch	1.49
0.500 inch (1/2)	1.57

The following example illustrates the procedure for determining the watt density of a typical tubular heater.

Example — A 12 kW screw plug heater has three 0.475" diameter elements with a "B" dimension of 32 inches and a 2 inch cold end. The watt density is:

0.475 x π x (32 in. - 2 in.) x 3 x 2 (Hairpin) = 268 in^2

12,000 Watts ÷ 268 in^2 - 45 W/in^2

For convenience in selecting equipment, all heaters in this catalog have the watt density specified for standard ratings.

Heater Selection Guidelines

Once the total heat energy requirements have been determined, the selection of the type of electric heater is based on three criteria.

- Maximum Sheath Temperature
- Sheath Material
- Recommended Maximum Watt Density

Maximum Sheath Temperature — The sheath temperature of an electric element should be limited to prevent damage to the heater and provide reasonable life. To a large extent, the maximum sheath temperature of the heating element is determined by the final operating temperature of the process. In direct immersion applications, the sheath temperature will approximate the temperature of the heated media. In clamp-on, air and gas heating applications, the operating sheath temperature can be estimated using factors derived from empirical charts and graphs.

Sheath Material — Element sheath material is selected based on the maximum allowable sheath temperature, the material being heated and corrosion resistance required. Depending on the sheath material and construction, metal sheathed electric resistance elements will operate satisfactorily at temperatures from less than -300°F (cryogenic) to approximately 1500°F. Copper sheath elements are commonly used for low temperature and direct immersion water heating. Steel is used for oil immersion and strip heater applications. Stainless steel and INCOLOY® are used for corrosive solutions, high-temperature gas or air heating and cartridge heaters. The table below lists the maximum recommended operating temperatures for common sheath materials (UL 1030):

Copper	350°F	Chrome Steel	1200°F
Iron	750°F	Stainless 300	1200°F
Steel	750°F	INCOLOY®	1600°F[1]
MONEL®	900°F	INCONEL®	1700°F[1]

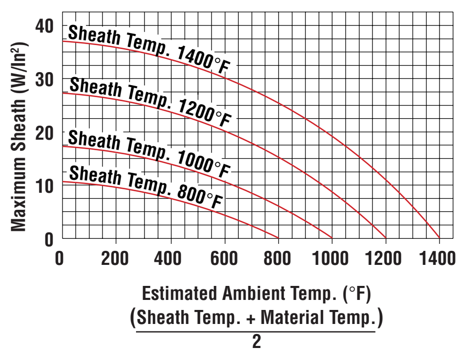
Maximum Recommended Watt Density — Some materials such as water, vegetable oils and salt baths can tolerate relatively high sheath watt densities. Other materials such as petroleum oils or sugar syrups require lower watt densities. These solutions have high viscosity and poor thermal conductivity. If the watt density is too high, the material will carbonize or overheat, resulting in damage to the heating equipment or material being heated. Other sections of this catalog provide guidelines and suggestions for sheath materials and recommended watt densities for many common heating problems.

Using the values determined in the selection criteria, choose the type of heater best suited to the application. For instance, water can be heated by direct immersion, circulation heaters or with tubular or strip heaters clamped to tank walls. The final choice of heater type will involve process considerations, appearance, available space both inside and outside, economy, maintenance, etc. The following pages cover the procedures for selecting heaters for clamp-on applications, liquid immersion heating, oil immersion heating, air or gas heating and cartridge or platen heating.

Clamp-On Heater Applications

The limiting factor in most clamp-on heater applications is the operating temperature of the heater sheath. Selecting heaters for clamp on applications requires an analysis of the maximum expected sheath temperature based on the estimated ambient temperature and the temperature of the material being heated. Graph G-175S provides a method of estimating the sheath temperature and allowable watt densities for tubular heaters for various ambient temperatures and wattage ratings.

Graph G-175S — Clamp-On Tubular Heaters



The example on the following page illustrates the procedure. 12 kW is required to heat material in a steel tank from 70°F to 800°F. Heat is to be supplied by tubular electric elements clamped to the side of the tank. Since the material is heated to 800°F, INCOLOY® sheath elements must be used.

Note 1 — For sheath temperatures above 1500°F, contact your Local Chromalox Sales office for application assistance.

Technical Information

Allowable Watt Density & Heater Selection - Guidelines

Selecting Clamp-On Tubular Heaters (cont'd.)

From the chart, a maximum sheath temperature of 1200°F results in an average ambient temperature of (800°F + 1200°F) ÷ 2 = 1000°F. From the curves, the allowable watt density is 9.5 W/in². Based on size of container, 0.475 inch diameter TRI elements 28 in. long are selected.

The 0.475 TRI element has 1.49 in² per linear inch of sheath. The heated length is the overall sheath length less 6.5 inches. The allowable wattage rating on the element is (28 - 6.5) x 1.49 x 9.5 = 305 watts. The total number of elements required is 12,000W ÷ 305W = 39 elements. Order 39 elements similar to TRI-2845 except rated 305 watts. If the application requires the use of tubular elements whose overall length is not standard, each element rating would be determined as follows:

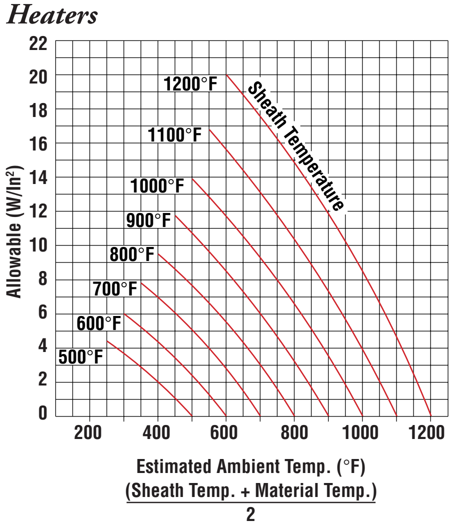
Heater Watts = (*A* - 2CE) (*Area* x 9.5W)

Where:
A = Sheath length, overall
CE = Cold pin length
Area = Effective heated area (in²/in.)
9.5 = recommended W/in² from G-175S

Selecting Clamp-On Strips Heaters

Graph G-130S provides a method of estimating the maximum allowable watt density for strip heaters for clamp on applications based on sheath operating temperature and various ambients.

Graph G-130S — Clamp-On Strip Heaters



Using the previous 12 kW example, determine the number of strip heaters required. An 800°F material temperature requires chrome steel strip heaters. From Graph G-130S, a maximum sheath temperature of 1200°F results in an ambient temperature of 1000°F inside the space between the thermal insulation and the vessel, (800°F + 1200°F) ÷ 2 = 1000°F.

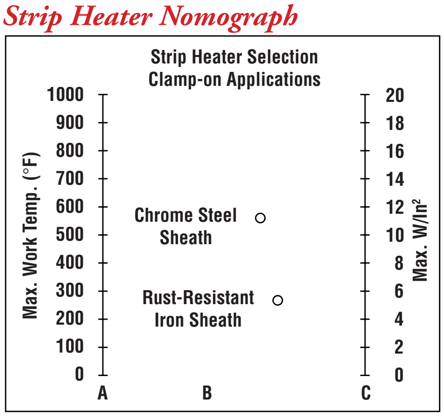
From the curve, the allowable watt density is 8 W/in². Based on the tank size, chrome steel sheathed strip heaters 24 inches long without mounting tabs were selected. To determine the number and wattage of strip heaters needed, use the formula: allowable watts per strip = (overall length minus 4" cold section) x 3.45 in² per lineal inch of sheath x 8 watts/in². Thus (25-1/2" - 4") x 3.45 x 8 = 593 (600) watts. The total number of strips required is 12,000W ÷ 600W = 20 strips. Order strips similar to OT-2507 in size but rated 600 watts. To avoid a special order, consider using 24 standard OT-2405, 500 watt strips. These heaters would have a watt density of:

500W ÷ ([23-3/4 - 4] x 3.45) = 7.35 W/in²

If the application uses 3 phase power, the total element count should be a multiple of 3 to permit a balanced electrical load.

The nomograph below may also be used for heater selection in clamp-on strip heating applications.

Strip Heater Nomograph



To Use the Graph —

1. **Select** the maximum desired work temperature on A.
2. **Choose** either chrome steel or rust-resistant iron sheath (points B) on the basis of operating temperatures.
3. **Draw** a straight line through points A and B to C. C gives the maximum allowable watts per square inch.
4. **Select** desired length heater with equivalent or less watt density.

General Recommendations for Liquid Heating Applications

Chromalox standard immersion heater ratings match the suggested watt densities for general purpose immersion heating. Extended heater life will be obtained by using the lowest watt density practical for any given application.

Standard Ratings —

Water Heaters	45 - 75 W/in²
Corrosive Solution Heaters	20 - 23 W/in²
Oil Heaters (Light Wt.)	20 - 23 W/in²
Oil Heaters (Medium Wt.)	15 W/in²
Oil Heaters (Heavy Wt.)	6 - 10 W/in²

Suggested Allowable Watt Densities for Liquids

Material	Max. Temp (°F)	Max. W/In²
Acid solutions	180	40
Alkaline solutions (Oakite)	212	40
Asphalt, tar, and other heavy or highly viscous compounds	200	10
	300	8
	400	7
	500	6
Bunker C fuel oil	160	10
Caustic soda 2%	210	45
10%	210	25
75%	180	15
Dowtherm® A	750	23
Dowtherm® A vaporizing	750	10
Dowtherm® J liquid	575	23
Electroplating tanks	180	40
Ethylene glycol	300	30
Freon	300	3
Fuel oil pre-heating	180	9
Gasoline, kerosene	300	20-23
Machine oil, SAE 30	250	18-20
Metal melting pot	500-900	20-27
Mineral oil	200	20-23
	400	16
Molasses	100	4-5
Molten salt bath	800-950	25-30
Molten tin	600	20-23
Oil draw bath	400	20-23
	600	16
Steel cast into aluminum	500-750	50
Steel cast into iron	750-1000	55
Heat transfer oils (Therminol®, Mobiltherm®, etc.)	500-650	23
Vapor degreasing solutions	275	20-23
Vegetable oil (fry kettle)	400	20-30
Water (process)	212	40-75
Water (washroom)	140	75-100

Note — The above watt densities are based on non-circulating liquids. The allowable watt density may be adjusted when heat transfer or flow rates are increased.

Technical Information

Heater Selection - Oil Heating

Watt Density & Oil Viscosity

The viscosity of oils and hydrocarbons varies widely with type and temperature. Since highly viscous liquids transfer heat poorly, sheath watt densities and operating temperatures are critical in oil heating applications. As a general rule, regular oil heaters rated 20-23 W/in² are recommended for heating light weight oils (SAE 10 to SAE 30). For medium weight oils (gear oils, etc.), 12-15 W/in² are suggested. Bunker C, tar, asphalt and other highly viscous oils may require 6-8 W/in² or less to prevent carbonization, particularly if not under flowing conditions. Some oils may have additives that will boil off or carbonize at very low watt densities. When oils of this type are encountered, a watt density test is recommended to determine a satisfactory watt density. The following charts provide guidance and suggested watt densities for various oils.

Typical Viscosities of Various Oils

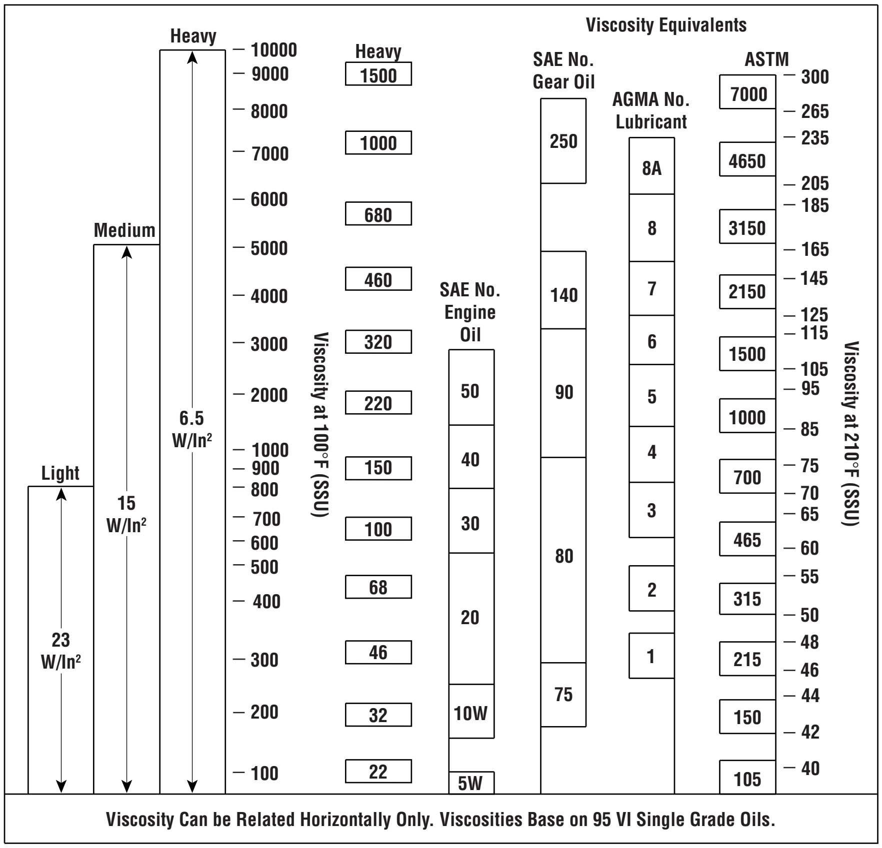
Weight	Viscosity
SAE 10	90-120 SSU at 130°F
SAE 20	120-185 SSU at 130°F
SAE 30	185-255 SSU at 130°F
SAE 40	255 SSU-up (Drops to 80 at 210°F)
SAE 50	80-105 SSU at 210°F
#2 Fuel Oil	40 SSU at 100°F (Kerosene)
#4 Fuel Oil	45-120 SSU at 100°F
#5 Fuel Oil	150-400 SSU at 100°F
Bunker C	500-2,000 SSU at 100°F
#6 Fuel Oil	3,000 SSU at 122°F (Very Viscous)

Viscosity Conversion

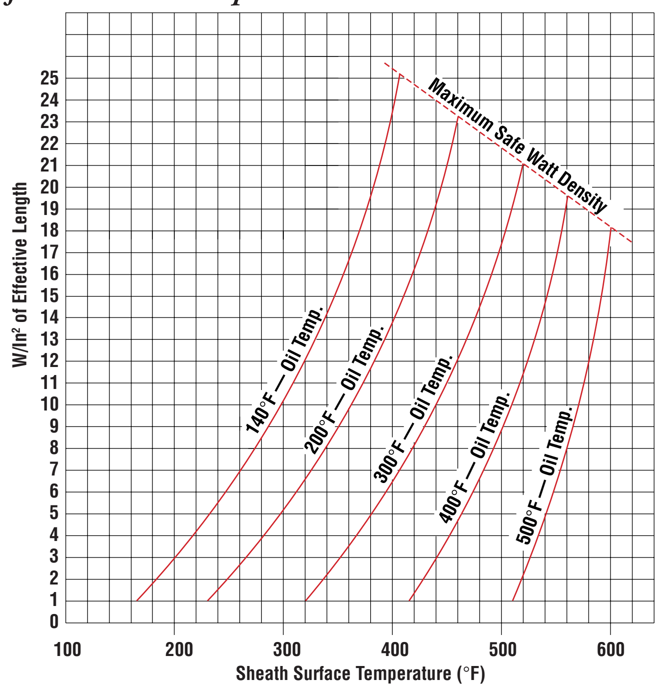
Seconds Saybolt Universal (SSU)	Kinematic Viscosity Centistokes (Cst)	Seconds Saybolt Furol (SSF)
31	1	—
35	2.56	—
40	4.30	—
50	7.4	—
60	10.3	—
70	13.1	12.95
80	15.7	13.7
90	18.2	14.44
100	20.6	15.24
150	32.1	19.3
200	43.2	23.5
250	54	28
500	110	51.6
1,000	220	100.7
5,000	1,100	500
10,000	2,200	1,000
20,000	4,400	2,000

Centistokes = Centipoise/specific gravity
Centipoise x 2.42 = Lbs/ft/hr

Oil Heating Watt Density Guide



Graph G-122S — Surface Temperatures of Oil Immersion Blade Heater for Various Oil Temperatures & Watt Densities



Notes —

1. Curves based on natural convection of machine oil or its equivalent having an SAE viscosity rating of 30 (5 centipoises at 200°F).
2. Effective Length of Immersion Heater = "B" Dimension.
3. Area Per Linear Inch of 1-1/2' Wide Immersion Blades = 3.75 Sq. In.
4. Area Per Linear Inch of 1' Wide Immersion Blades = 2.63 Sq. In.
5. In No Case, Exceed 27 Watts Per Sq. In.

Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating

Air and gas heating applications can be divided into two conditions, air or gas at normal atmospheric pressure and air or gas under low to high pressure. Applications at atmospheric pressure include process air, re-circulation and oven heating using duct or high temperature insert air heaters. Pressurized applications include pressurized duct heating and other processes using high pressures and circulation heaters. Procedures for determining heat energy requirements for either condition are similar except the density of the compressed gas and the mass velocity of the flow must be considered in pressurized applications. Selection of equipment in both conditions is critical due to potentially high sheath temperatures that may occur.

Determining Heat Requirements for Atmospheric Pressure Gas Heating

The following formulas can be used to determine kW required to heat air or gas:

Equation A —

$$kW = \frac{CFM \times lbs/ft^3 \times 60\ min \times C_p \times \Delta T}{3412\ Btu/kW} \times SF$$

Where:
CFM = Volume in cubic feet per minute
Lbs/ft^3 = Density of air or gas at initial temperature
C_p = Specific heat of air or gas at initial temperature
ΔT = Temperature rise in °F
SF = Suggested Safety Factor

For quick estimates of air heating requirements for inlet temperatures up to 120°F, the following formula can be used.

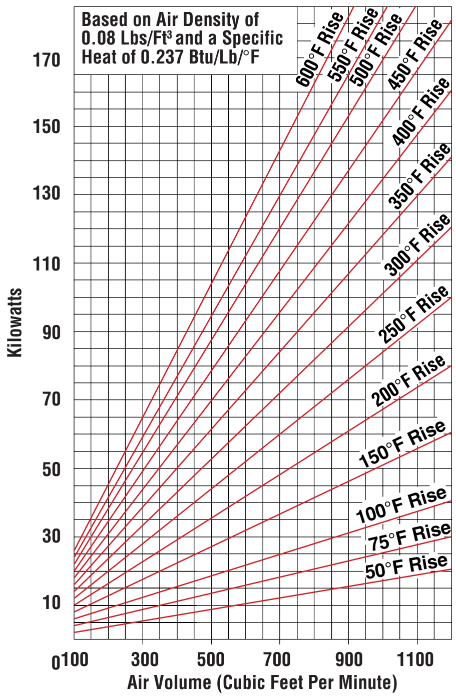
$$kW = \frac{SCFM \times \Delta T}{3{,}000} \times 1.2\ SF$$

Where:
SCFM = Volume of air in cubic feet per minute at standard conditions[1] (70° F at standard atmospheric pressure)
3,000 = Conversion factor for units, time and Btu/lb/°F
1.2 SF = Suggested safety factor of 20%

Graph G-176S — When airflow (ft^3/min) and temperature rise are known, kW requirements can be read directly from graph G-176S.
Note — Safety factors are not included.

Note 1 — Based on an average density of 0.08 lbs/ft^3 and a specific heat of 0.24 Btu/lb/°F. For greater accuracy, use Equation A and values from the Properties of Air Chart in this section.

Graph G-176S —Air Heating



Process Air Heating Calculation Example — A drying process requires heating 450 ACFM of air[1] from 70°F to 150°F. The existing ductwork measures 2 ft wide by 1 ft high and is insulated (negligible losses). To find heating capacity required, use Equation A:

$$kW = \frac{450\ ACFM \times 0.08 \times 60 \times 0.24 \times 80}{3412\ Btu/kW} \times 1.2\ SF$$

kW = 14.58

Heater Selection

Finstrip® (CAB heaters), Fintube® (DH heaters) or tubular elements (TDH, ADH and ADHT heaters) will all work satisfactorily in low temperature applications. Finstrips or finned tubular elements are usually the most cost effective. Tubular elements are recommended for high temperatures. Once the desired type of heating element is selected, the next step is to calculate the air velocity and estimate sheath temperatures to verify that maximum operating temperatures are not exceeded. Calculate the air velocity over the elements and refer to allowable watt density graphs for estimated operating temperature.

Calculating Air Velocity — Air velocity can be calculated from the following formula:

$$Velocity\ (fps) = \frac{Flow\ (ACFM)}{Area\ of\ Heater\ (ft^2) \times 60\ sec.}$$

Low Temperature Heater Selection — A typical heater selection for the previous example might be a type CAB heater with finstrip elements. Available 15 kW stock heaters include a CAB-1511 with chrome steel elements or a CAB-152 with iron sheath elements, both rated at 26 W/in^2. From the product page, the face area of a 15 kW CAB heater is 1.19 ft^2:

$$Velocity\ (fps) = \frac{450\ ACFM}{1.19\ ft^2 \times 60\ sec.} = 6.3\ fps$$

Estimating Sheath Operating Temperature — The maximum operating sheath temperatures for finstrips are 750°F for iron and 950°F for chrome steel. Using graph G-107S for iron sheath finstrips, a 150°F outlet temperature and a watt density of 26 W/in^2 requires a velocity in excess of 9 ft/sec to keep sheath temperatures below maximum permissible levels. With only 6.3 fps in the application, a CAB-152 heater with iron sheath elements is not suitable. Using graph G-108S for chrome sheath finstrips, approximately 3 ft/sec. air velocity results in a maximum of 900°F sheath temperature. Since this is lower than the actual velocity of 6.3 fps, a CAB-1511 with chrome steel finstrips is an acceptable heater selection. (Use graphs G-100S, G-105S,G-106S and G-132S for air heating with regular strip and finstrip heaters.)

High Temperature Heater Selection — Type TDH and ADHT heaters with tubular elements are recommended for high temperature applications. Steel sheath tubulars may be used where the sheath temperature will not exceed 750°F. Finned tubulars can be used in applications up to a maximum sheath temperature of 1050°F. INCOLOY® sheath tubulars may be used for applications with sheath temperatures up to 1600°F. Allowable watt densities for tubulars and finned tubulars can be determined by reference to graphs G-136S and G-151-1 through G-156-1.

Estimating Sheath Operating Temperature — Select a heater for a high temperature application with an inlet air temperature of 975°F and a velocity of 4 ft/sec. Since the temperature is above 750°F, an INCOLOY® sheath must be used. Using graph G-152-1 the allowable watt density is 11 W/in^2 for sheath temperatures of 1200°F or 22 W/in^2 for temperatures of 1400°F. In this application, a stock ADHT heater[2] with a standard watt density of 20 W/in^2 can be used.

Note 2 — Special ADHT duct heaters, derated to the required watt density, can be supplied when element ratings less than the standard 20 W/in^2 are needed.

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Allowable Watt Density & Heater Selection - Air Heating

Air & Gas Heating with Strip and Finstrip® Heaters

Custom Designs — Strip and finstrip heaters are frequently mounted in banks by the end user. Graphs G-105S and G-106S on this page can be used in conjunction with other graphs to determine maximum watt density for virtually any custom design low temperature heating application.

Graph G-105S — Strip Heaters
To use this graph:

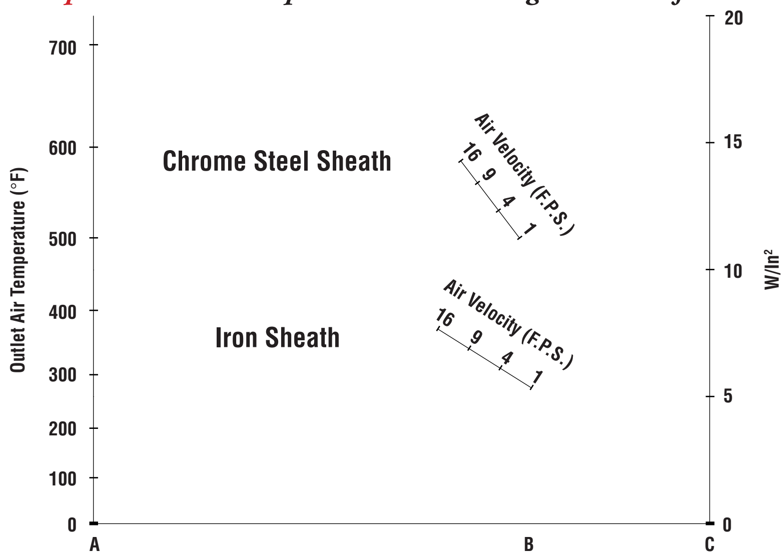
1. **Select** maximum desired outlet air temperature on line A.
2. **Choose** either chrome steel sheath or rust resisting iron sheath (points B) on the basis of operating conditions.
3. **Select** minimum anticipated air velocity on B. **Note** — natural circulation is equal to approximately one foot per second.
4. **Draw** a straight line through points A and B to a reading on C. Read maximum allowable watts per square inch from line C.
5. **Select** desired length heater with an equivalent watt density or less from the product page in this catalog.

Graph G-106S — Finstrip® Heaters
To use this graph:

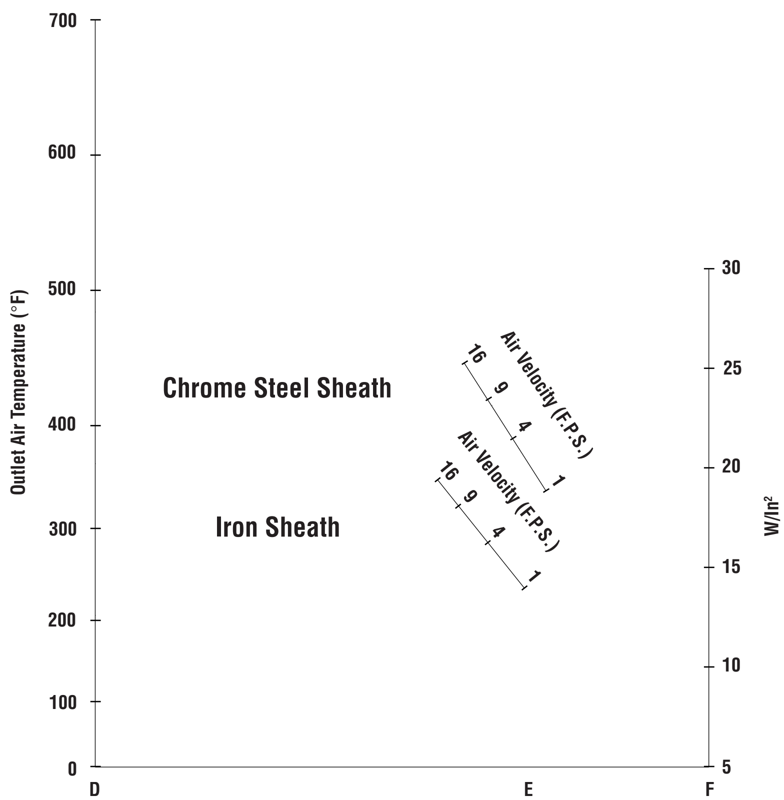
1. **Select** maximum desired outlet air temperature on line D.
2. **Choose** either chrome steel sheath or rust resisting iron sheath (points E) on the basis of operating conditions.
3. **Select** minimum anticipated air velocity on B. **Note** — natural circulation is equal to approximately one foot per second.
4. **Draw** a straight line through points D and E to a reading on F. Read maximum allowable watts per square inch from line F.
5. **Select** desired length heater with an equivalent watt density or less from the product page in this catalog.

Recommendations for Custom Installations — Strip heaters should always be mounted sideways in the ductwork with the narrow edges facing the air stream. The total number of elements installed should be divisible by 3 so that the heater load will be balanced on a three phase circuit.

Graph G-105S — Strip Heater Air Heating-Selection of Watt Density



Graph G-106S — Finstrip® Heater Air Heating-Selection of Watt Density

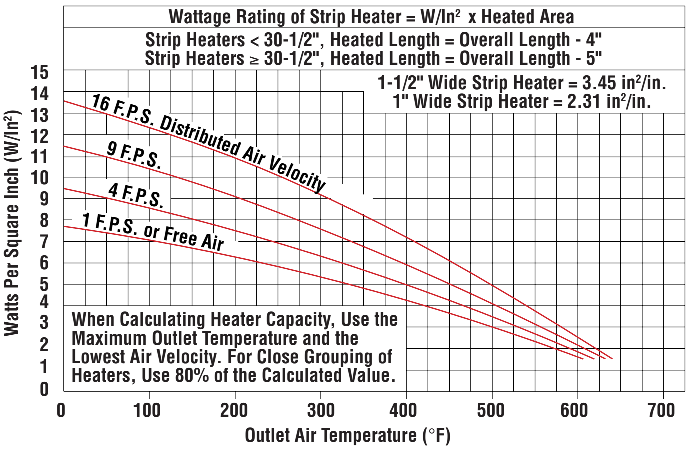


TECHNICAL INFORMATION

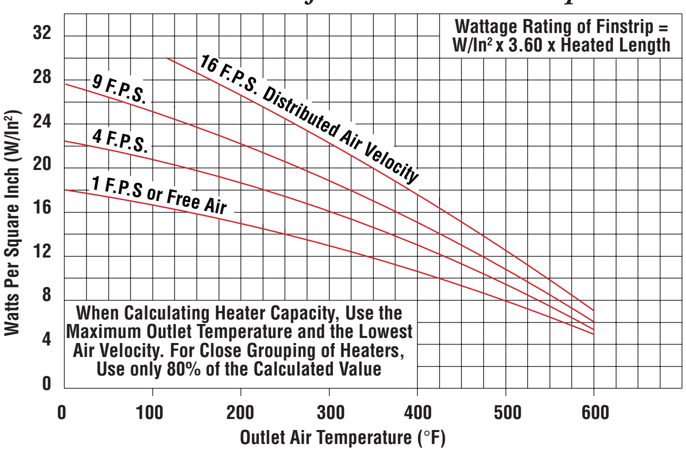
Technical Information

Allowable Watt Density & Heater Selection - Air Heating

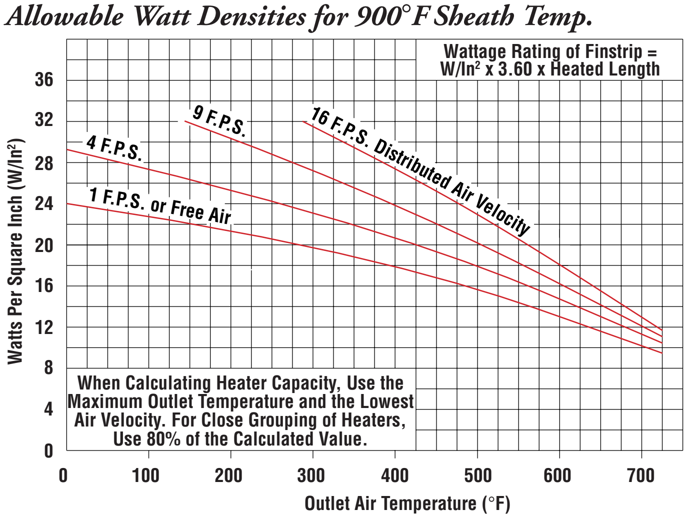
Graph G-132S — Strip Heater (Iron) Air Heating Allowable Watt Densities for 700°F Sheath Temp.



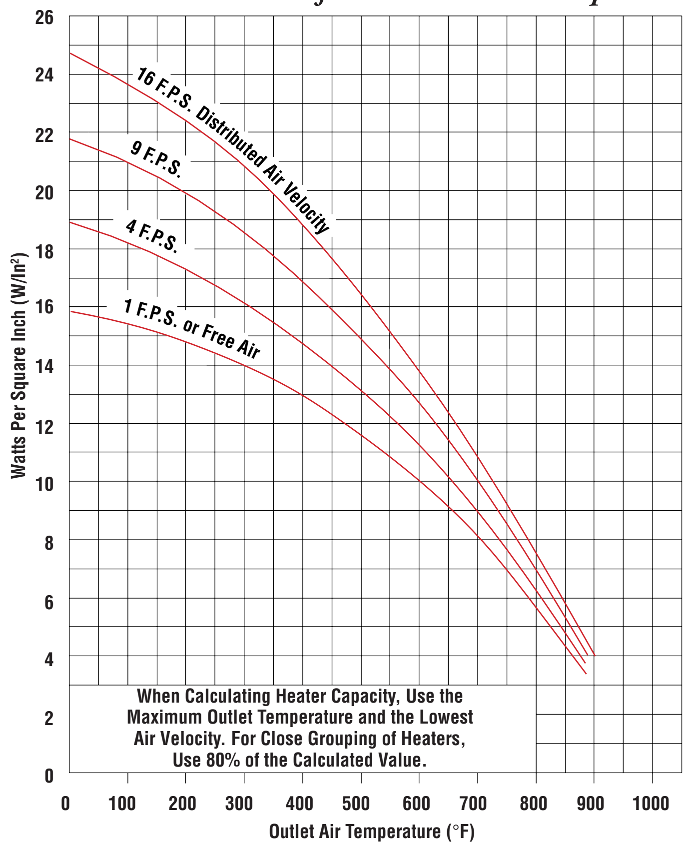
Graph G-107S — Finstrip® (Iron Sheath) Air Heating Allowable Watt Densities for 700°F Sheath Temp.



Graph G-108S — Finstrip® (Chrome Steel) Air Heating Allowable Watt Densities for 900°F Sheath Temp.



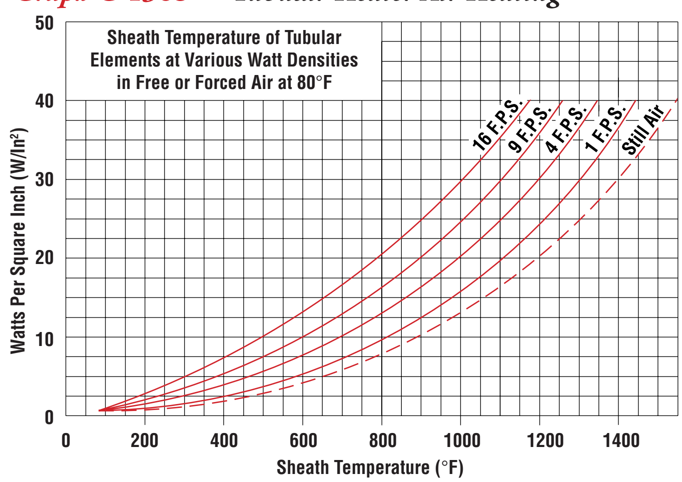
Graph G-100S — Strip Heater (Chrome) Air Heating Allowable Watt Densities for 1000°F Sheath Temp.



Notes —

Strip Heaters < 30-1/2", Heated Length = Overall Length - 4"
Strip Heaters ≥ 30-1/2", Heated Length = Overall Length - 5"
1-1/2" Wide Strip Heater = 3.45 in./in.
1" Wide Strip Heater = 2.31 in./in.

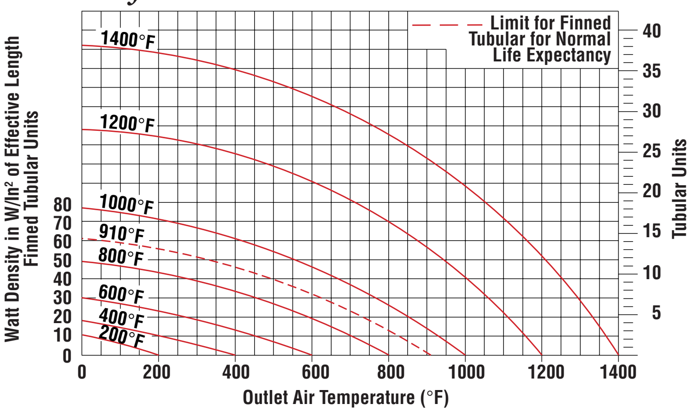
Graph G-136S — Tubular Heater Air Heating



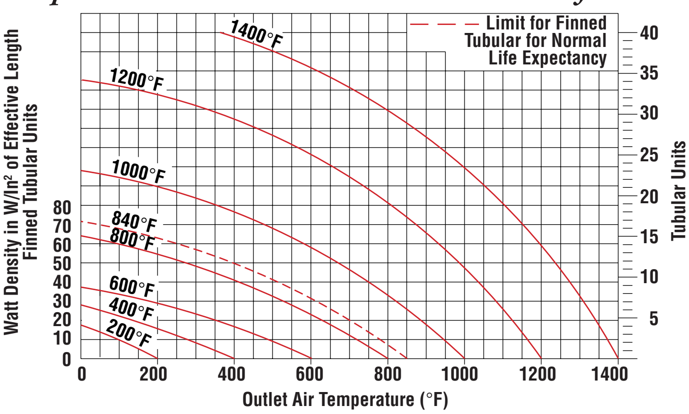
Technical Information

Allowable Watt Density & Heater Selection - Air Heating

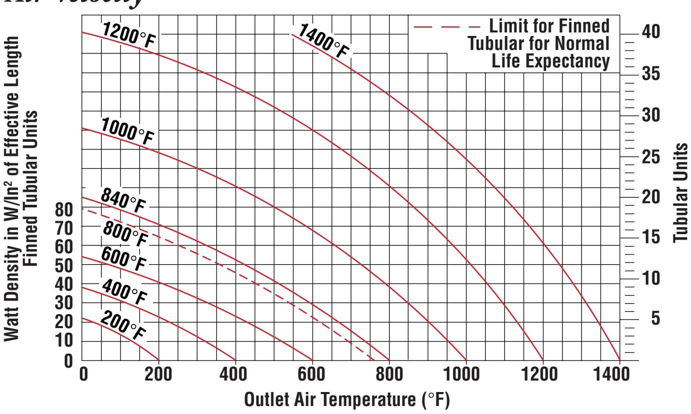
***Graph G-151-1** — Fintube® & Tubular Heaters Sheath Temperatures with 1 FPS Distributed Air Velocity*



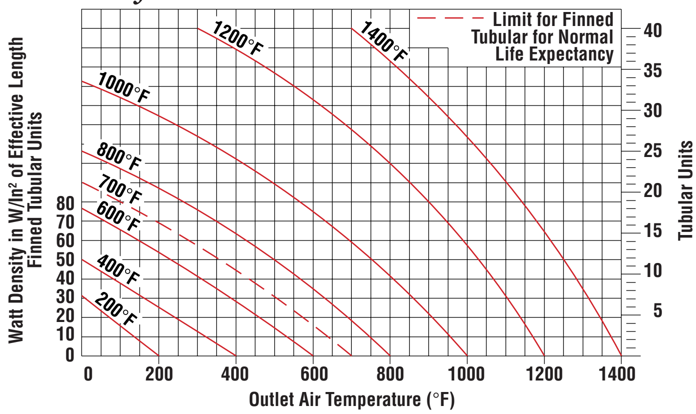
***Graph G-152-1** — Fintube® & Tubular Heaters Sheath Temperatures with 4 FPS Distributed Air Velocity*



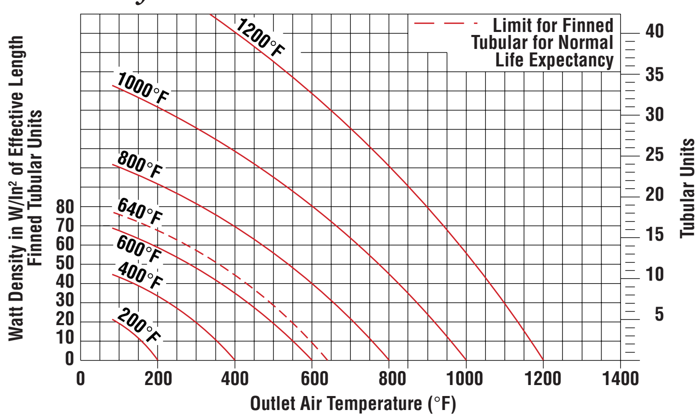
***Graph G-153-1** — Fintube® & Tubular Heaters Sheath Temperatures with 9 FPS Distributed Air Velocity*



***Graph G-154-1** — Fintube® & Tubular Heaters Sheath Temperatures with 16 FPS Distributed Air Velocity*



***Graph G-155-1** — Fintube® & Tubular Heaters Sheath Temperatures with 25 FPS Distributed Air Velocity*



***Graph G-156-1** — Fintube® & Tubular Heaters Sheath Temperatures with 36 FPS Distributed Air Velocity*