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.

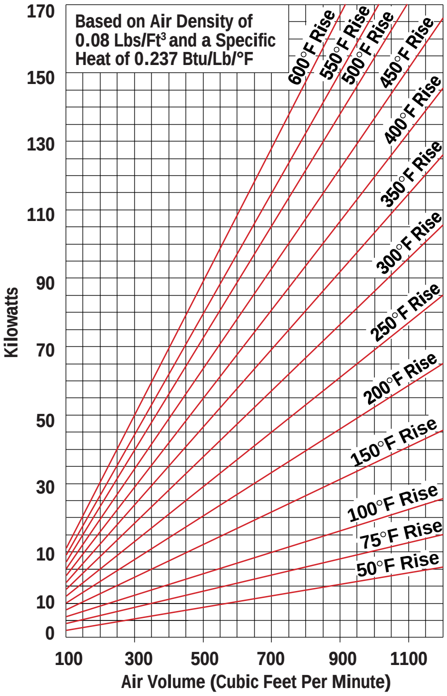
$$kW = \frac{SCFM \times \Delta T}{3{,}000} \times 1.2\ SF$$

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 duct- work 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:

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

Low Temperature Heater Selection — A ypical 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:

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

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.

Technical Information

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:

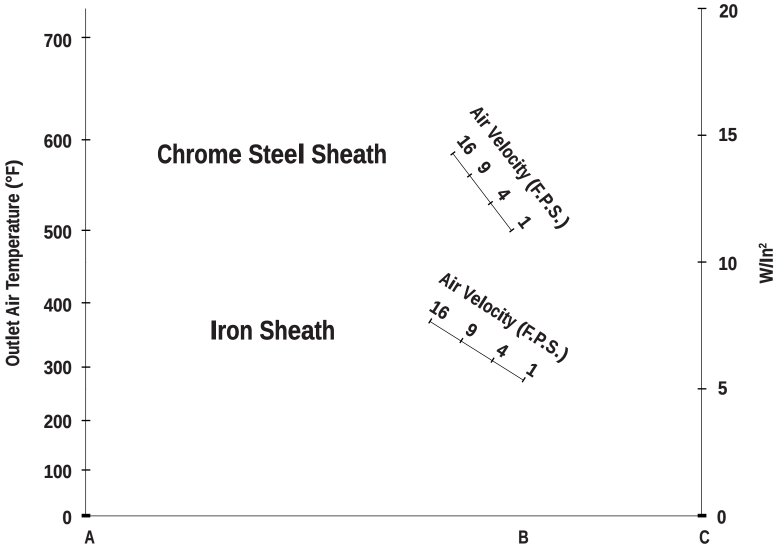
1. **Select** maximum desired outlet air temperature on line A.
2. **Choose** either chrome steel sheath or rust resisting iron sheath (points B) on the basis of operating conditions.
3. **Select** minimum anticipated air velocity on B. **Note** — natural circulation is equal to approximately one foot 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:

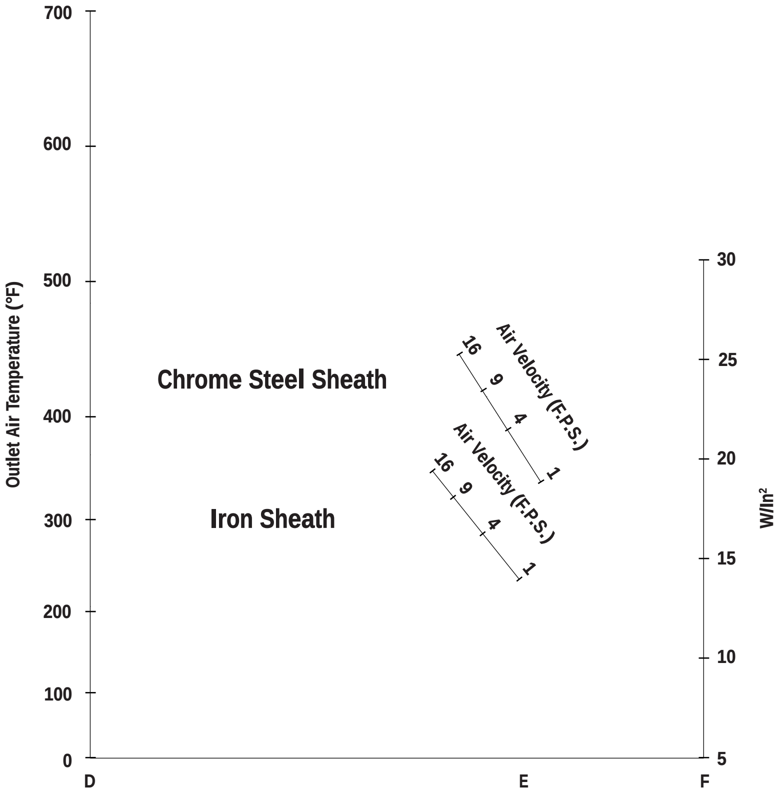
1. **Select** maximum desired outlet air temperature on line D.
2. **Choose** either chrome steel sheath or rust resisting iron sheath (points E) on the basis of operating conditions.
3. **Select** minimum anticipated air velocity on B. **Note** — natural circulation is equal to approximately one foot 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



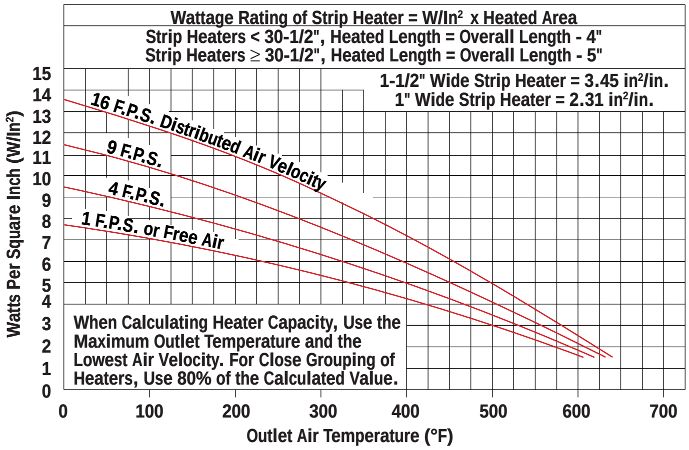
Graph G-106S — Finstrip® Heater Air Heating-Selection of Watt Density



Technical Information

Allowable Watt Density & Heater Selection - Air Heating

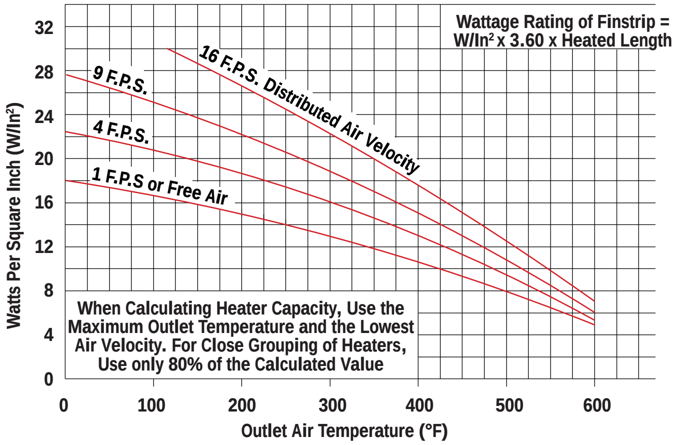
Graph G-132S — Strip Heater (Iron) Air Heating Allowable Watt Densities for 700°F Sheath Temp.


Wattage Rating of Strip Heater = W/In² x Heated Area
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 in²/in.
1" Wide Strip Heater = 2.31 in²/in.

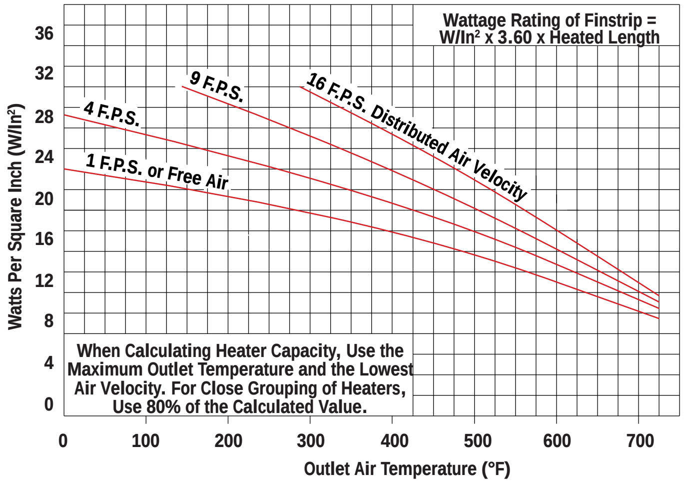
When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use 80% of the Calculated Value.

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


Wattage Rating of Finstrip = W/In² x 3.60 x Heated Length

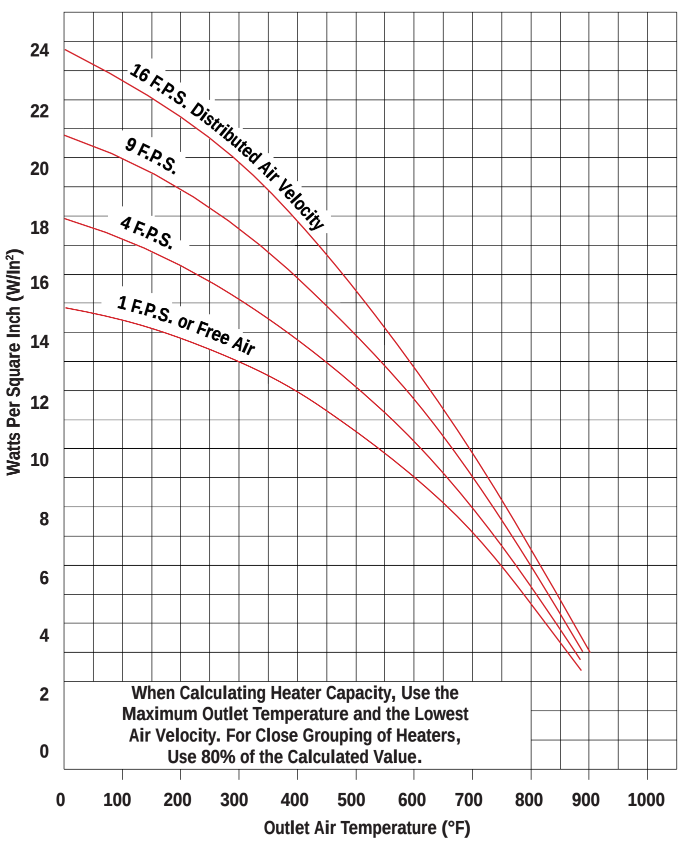
When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use only 80% of the Calculated Value

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


Wattage Rating of Finstrip = W/In² x 3.60 x Heated Length

When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use 80% of the Calculated Value.

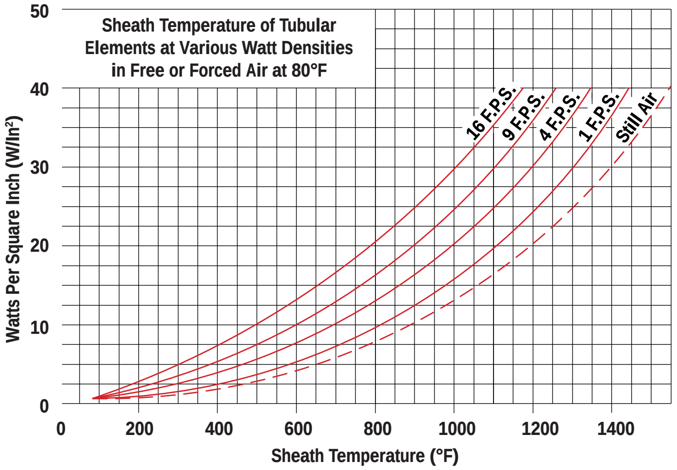
Graph G-100S — Strip Heater (Chrome) Air Heating Allowable Watt Densities for 1000°F Sheath Temp.


When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use 80% of the Calculated Value.

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.

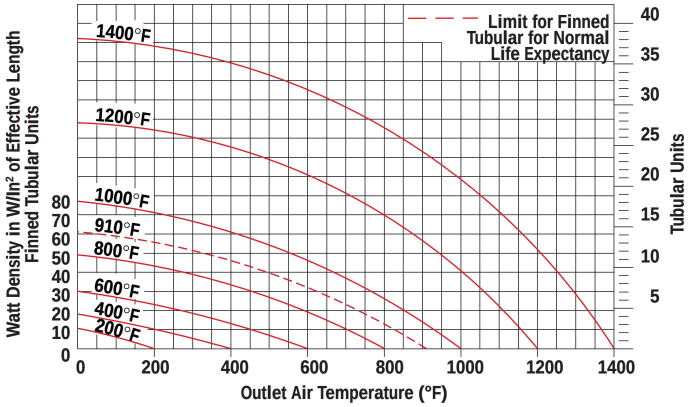
Graph G-136S — Tubular Heater Air Heating


Sheath Temperature of Tubular Elements at Various Watt Densities in Free or Forced Air at 80°F

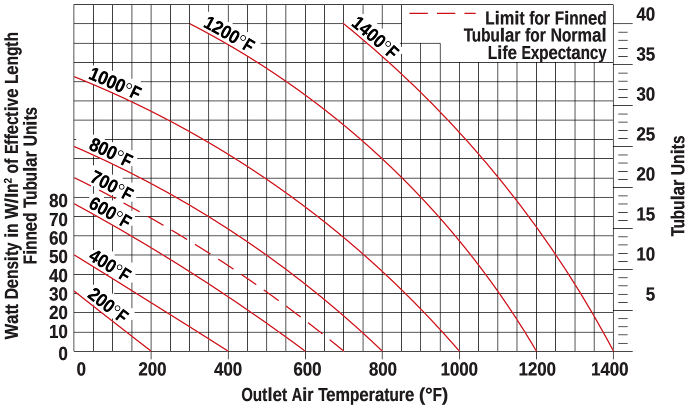
Technical Information

Allowable Watt Density & Heater Selection - Air Heating

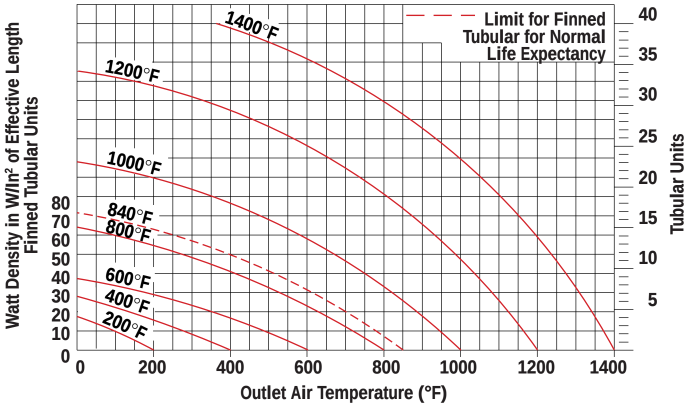
Graph G-151-1 — Fintube® & Tubular Heaters Sheath Temperatures with 1 FPS Distributed Air Velocity



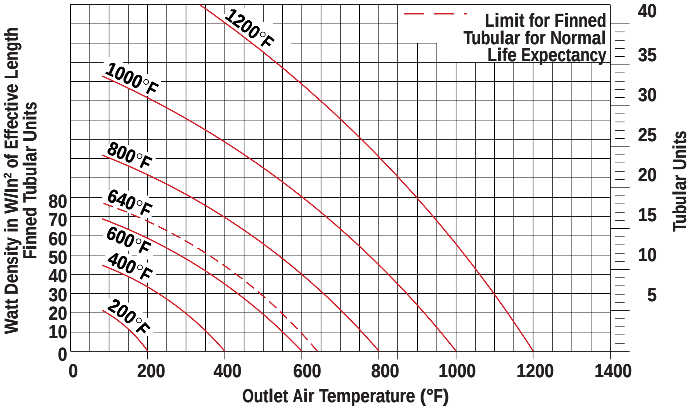
Graph G-154-1 — Fintube® & Tubular Heaters Sheath Temperatures with 16 FPS Distributed Air Velocity



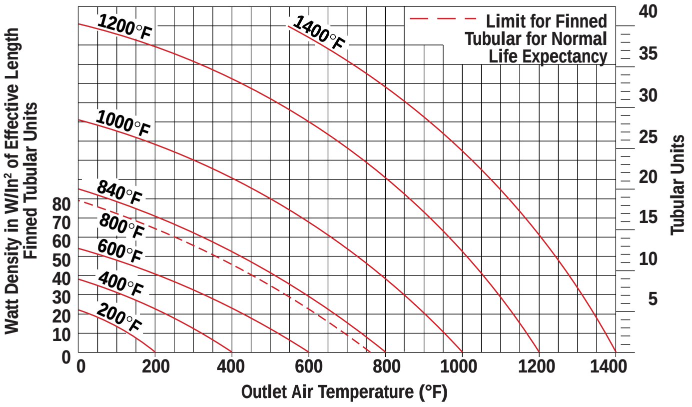
Graph G-152-1 — Fintube® & Tubular Heaters Sheath Temperatures with 4 FPS Distributed Air Velocity



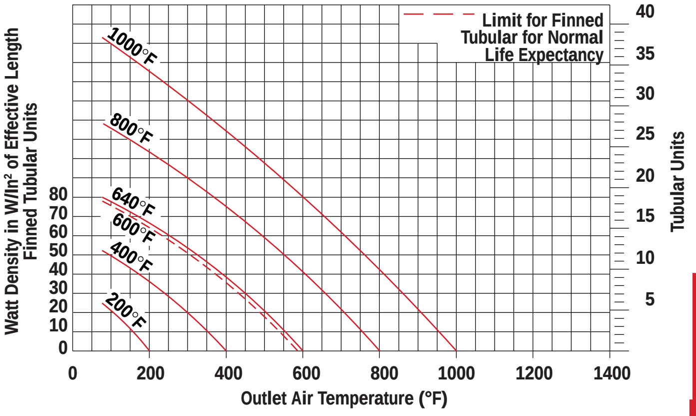
Graph G-155-1 — Fintube® & Tubular Heaters Sheath Temperatures with 25 FPS Distributed Air Velocity



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



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



Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating — Cryogenics

Industrial gases are usually stored in a liquid state with heat being added to vaporize and boil off the gas as usage requires. General heat equations apply except that pipes, tubes and vessels containing the cryogenic fluid or gas frequently represent a heat source rather than a heat loss. If the size and materials of the tanks or vessels are known, then heat calculations for the temperature rise can be performed as in standard vessel heating or boiler problems. The following example is typical of a cryogenic heating application.

Problem — Vaporize and preheat 30,000 SCFH of liquid Nitrogen (N_2) from -345°F to 70°F at atmospheric conditions. The properties of N_2 from Cryogenic Gas Tables are: Boiling point, -320°F Specific heat Btu/lb/°F = 0.474 (liq.), 0.248 (gas) Latent heat of vaporization = 85.7 Btu/lb Atm. density of N_2 at 32°F = 0.0784 lb/ft³.

Solution — Amount of liquid N_2 to be vaporized 30,000 SCFH x 0.0784 lb/ft³ = 2,352 lbs/hr

1. **Raise** liquid from -345°F to -320°F (boiling point) ΔT = 25°F.

$$\text{kW} = \frac{\text{Wt x } C_p \text{ x } \Delta T \text{ x SF}}{\text{3412 Btu/kW}}$$

Where:
Wt = Weight of material in lbs
C_p = Specific heat of the liquid N_2
ΔT = Temperature rise in °F
SF = Suggested safety factor of 20%

$$\text{kW} = \frac{\text{2,352 lbs x 0.474 x 25}}{\text{3412 Btu/kW}} \text{ x 1.2 = 9.8 kW}$$

2. **Vaporize** the liquid N_2

$$\text{kW} = \frac{\text{2,352 lbs x 85.7}}{\text{3412 Btu/kW}} \text{ x 1.2 = 70.9 kW}$$

3. **Raise** the temperature of the N_2 from boiling point -320°F to 70°F — ΔT = 390°F.

$$\text{kW} = \frac{\text{2,352 lbs x 0.248 x 390}}{\text{3412 Btu/kW}} \text{ x 1.2 = 80 kW}$$

Total kW/hr required = 9.8 + 70.9 + 80 = 169.7

Equipment Recommendations — Generally, cryogenic applications utilize both a vaporizer unit and a gas preheater. High watt density heaters immersed in the cryogenic fluid can be used for the vaporizer. Standard circulation heaters and watt densities are recommended for gas preheating. Protect the heater terminals from frost and moisture with element seals and liquid tight terminal covers.

Material Recommendations — Ordinary carbon steel is subject to brittle fracture at temperatures below -20°F and is generally not recommended. Stainless steel, high nickel bearing alloys or aluminum alloys may be used. Use Teflon® for gaskets asTeflon® remains pliable at low temperatures.

Air & Gas Heating — Batch Ovens

Most oven applications consist of heating work product inside an insulated enclosure. Heat loss calculations involve the determination of the heat requirements to heat the enclosure and work product using heated air circulated by natural or forced convection. Any make up or ventilation air must also be considered. The following example outlines the calculation of the heat required for a typical oven heating application.

Problem — An oven with inside dimensions of 2 ft H x 3 ft W x 4 ft D is maintained at 350°F. The oven has sheet steel walls with 2 inches of insulation and is ventilated with 400 cfh (ft³/hr) of 70°F air which exhausts to the outside to remove fumes. The oven is charged with 250 lbs of coated steel parts on a steel tray weighing 40 lbs. The process requires the parts to be heated from 70°F to 350°F in 3/4 hour.

Weight of steel = 290 lbs
Specific heat of steel — 0.12 Btu/lb/°F
Weight of air = 0.080 lbs/ft³ at 70°F
Specific heat of air = 0.24 Btu/lb/°F
Temperature rise = 280°F
Surface losses with 2 inch insulation = 18 W/ft²/hr at 280°F temperature difference (Graph G-126S)
Surface area of oven = 52 ft²
Time = 3/4 hr (0.75)
Airflow rate = 400 ft³/hr

Solution —

1. **Calculate** kWh required to heat metal.

$$\text{kW} = \frac{\text{290 lbs x 0.12 Btu/lb/°F x 280°F}}{\text{3412 Btu/kW}} \text{ = 2.86 kW}$$

2. **Calculate** kWh required to heat ventilated air

$$\text{kW} = \frac{\text{400 cfh x 0.080 Lbs x 0.24 } C_p \text{ x 280 } \Delta T \text{ x 0.75 } t}{\text{3412 Btu/kW}} \text{ = 0.47kW}$$

Where:
cfh = Air flow rate (400)
Lbs/ft³ = Density of air (0.080)
C_p = Specific heat of air (0.24)
ΔT = Temperature rise (280)
= Time in hours (0.75)

3. **Calculate** surface losses. Since the oven is already at temperature, losses are at full value.

$$\text{kW} = \frac{\text{18 W/ft}^2\text{/hr x 52 ft}^2\text{ area x 0.75 hr}}{\text{1,000 W/kW}} \text{ = 0.70 kW}$$

4. **Total** kW = 2.86 + 0.47 + 0.70 = 4.03 kW

5. **For Oven Applications**, add 30% to cover door losses and other contingencies. kWh required (including safety factor) is

$$\text{kWh} = \frac{\text{kW}}{t} = \frac{\text{4.03 kW}}{\text{0.75 hrs}} \text{ = 5.37 kW x 1.3 = 6.98 kW}$$

Equipment Recommendations — Several process air heaters, including strip heaters, finstrips, bare tubulars or type OV oven heaters, are suitable for oven heating applications.

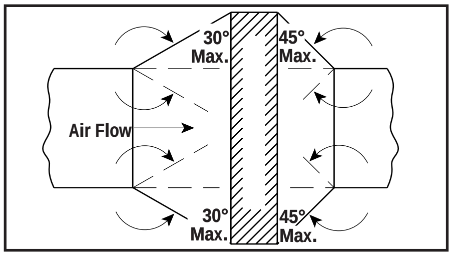
Pressure Drop for Process Air Heaters

The pressure drop through TDH and ADH process air heaters with bare tubular or finned tubular elements, CAB heaters with finstrip elements, and ADH and DH air heaters with finned tubular elements will vary considerably depending on product design and construction. Chromalox sales engineering can provide pressure drop calculations for virtually any duct heater (or circulation heater) application. Graphs G-112S3, G-189S1, G-227-2, and G-227ADH on the following page provide guidance for estimating the pressure drop for many Chromalox process air heaters[1]. Graph G-189S1 can be used for most finned tubular applications providing the elements are mounted in a three or six row configuration.

Transitions in Ducts — In some air distribution systems, the duct heater may be considerably larger or smaller than the associated ductwork. The duct heater can be adapted to different size ductwork by installing a sheet metal transition. The transition must be designed so that the slope on the upstream side of the equipment is limited to 30° (see below). On the leaving side, the slope should not be more than 45°.

Note 1 — Contact the factory for pressure drop calculations for duct heaters mounted lengthwise or in series and for GCH gas circulation heaters. These applications require special calculations for proper application and air handler sizing.

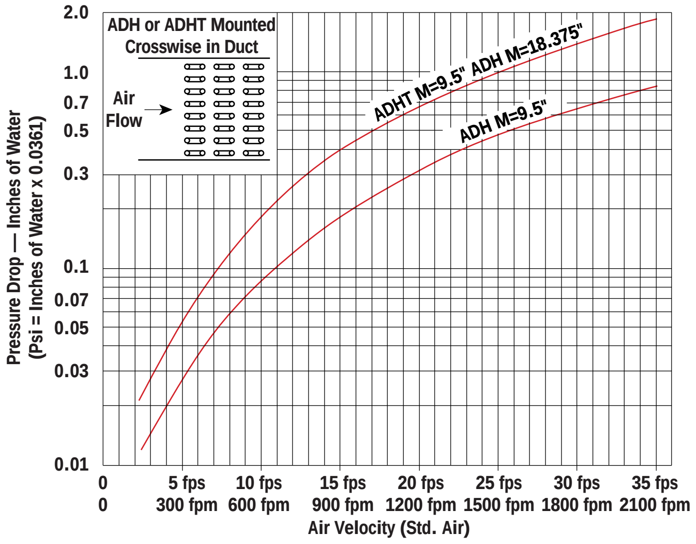
Recommended Dimensions for Duct Transitions



Technical Information

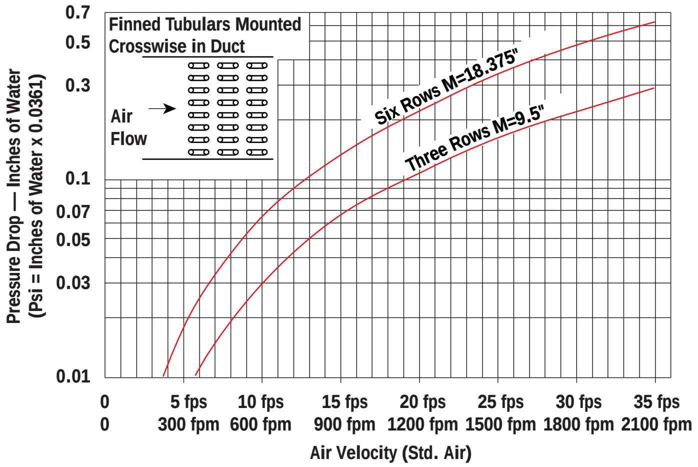
Determining Pressure Drop - Air and Gas Heating

Graph G-227ADH — Pressure Drop Vs. Velocity ADH and ADHT Tubular Element Air Heaters



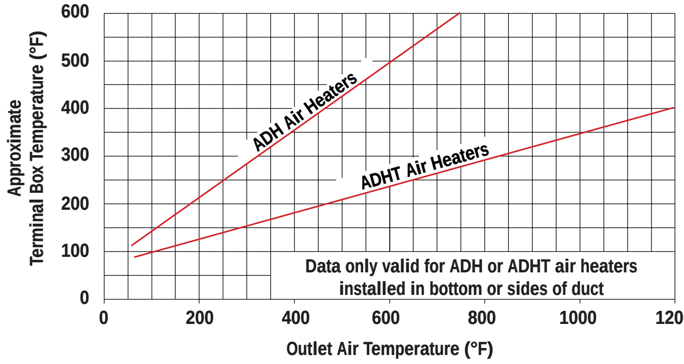
Note — Contact factory for pressure drop calculations for ADH/ADHT air heaters mounted lengthwise in duct and ADHT heaters where M is greater than 9.5"

Graph G-189S1 — Pressure Drop Vs. Velocity Fintube® Elements and Air Heaters



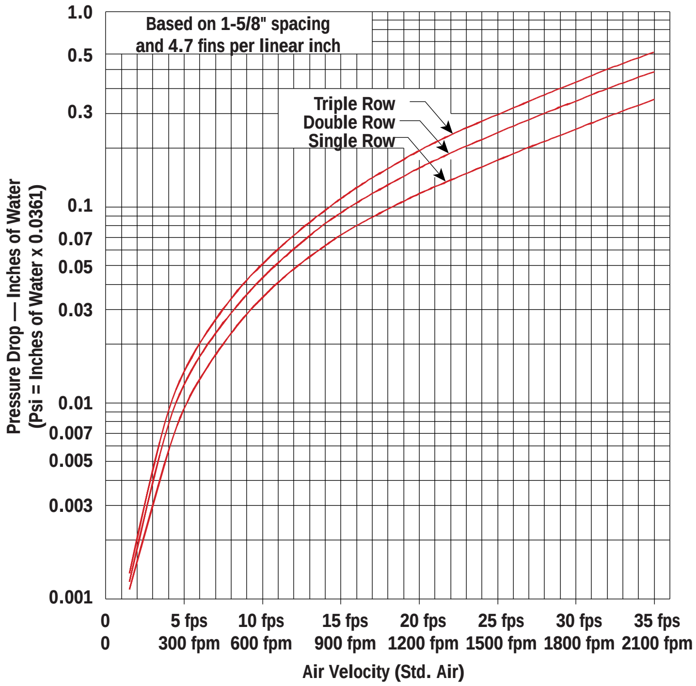
Note — Contact factory for pressure drop calculations for finned tubular element air heaters mounted lengthwise in duct.

Graph ADHTB — ADH/ADHT Terminal Box Temperatures Field Wiring Selection Guide

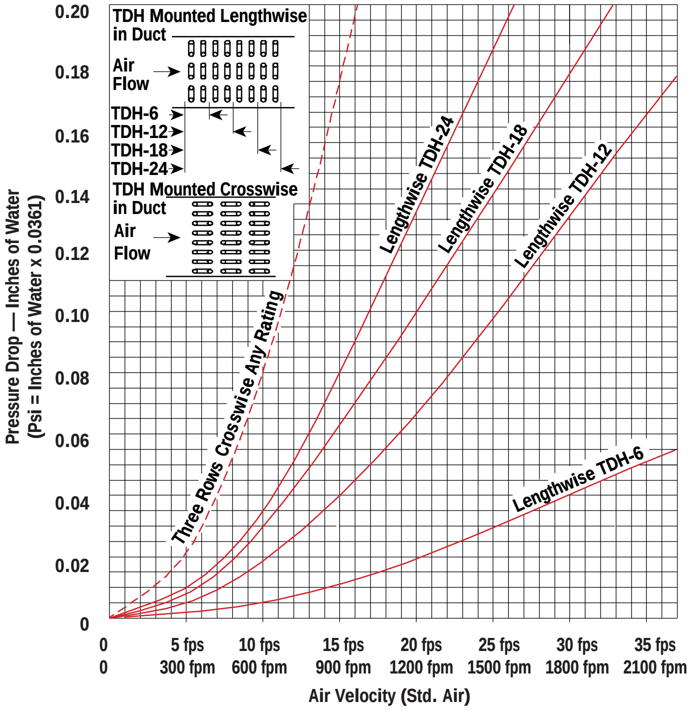


Data only valid for ADH or ADHT air heaters installed in bottom or sides of duct

Graph G-112S3 — Pressure Drop Vs. Velocity Finstrip® and CAB Air Heaters



Graph G-227-2 — Pressure Drop Vs. Velocity TDH Tubular Element Air Heaters



Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating with Circulation Heaters

To calculate the heat energy requirements for heating compressed air or gases, the first step is to determine the flow rate in pounds per hour. If the density of the air or gas under the actual pressure is known, the kW requirements can be calculated directly. The following example illustrates this procedure.

Example — Heat 20 ACFM of air at 30 psig from 60°F to 210°F. From the Properties of Air Chart, the density of air at 60°F and 30 psig is 0.232 lb/ft^3 with a specific heat of 0.24 Btu/lb/°F. The kW required can be calculated from the formula:

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

Where:

ACFM = Actual flow in ft^3/min at inlet temperature and gauge pressure (psig)

Lbs/ft^3 = Actual density at inlet temperature and gauge pressure (psig)

C_p = Specific heat of air or gas at inlet temperature and gauge pressure (psig)

ΔT = Temperature rise in °F

SF = Suggested Safety Factor

$$kW = \frac{20 \times 0.232 \times 60 \times 0.24 \times (210 - 60°F)}{3412} \times 1.2$$

$$kW = \frac{278.4\ lbs/hr \times 24 \times 150}{3412} \times 1.2 = 3.52\ kW$$

When the density and specific heat of a gas at a specific temperature and pressure are unknown, the actual flow rate can be converted to a known pressure and temperature using the physical laws of gases.

Example — Heat 45 ACFM of Nitrogen (N_2) at 35 psig from 50°F to 300°F. From the Physical and Thermodynamic Properties of Common Gases Chart, the density of Nitrogen at 70°F is 0.073 lb/ft^3 with a specific heat of 0.2438 Btu/lb/°F. Convert 45 ACFM at 35 psig and 50°F to SCFM of Nitrogen at 70°F using the following formula:

$$SCFM = ACFM \times \frac{Actual\ psia}{14.7\ psia} \times \frac{Standard\ T}{Actual\ T}$$

SCFM = Std. ft^3/min at 14.7 psia and 70°F

ACFM = Actual flow in ft^3/min at inlet temperature and gauge pressure (psig)

Actual psia = gauge pressure in lb/in^2 + 14.7 psia

14.7 psia = absolute pressure in lb/in^2

T = °Rankine (°F + 460)

$$SCFM = 45 \times \frac{(35 + 14.7)}{14.7\ psia} \times \frac{(70 + 460)}{(50 + 460)}$$

SFCM = 158.1 ft^3/min

Using the calculated SCFM in place of ACFM in equation A, the kW required is:

$$kW = \frac{158.1 \times 0.073 \times 60 \times 0.2438 \times (300 - 50)}{3412} \times 1.2$$

kW = 14.8 kW

Determining Maximum Sheath & Chamber Temperatures

When heating air or gases in insulated pipe chambers or circulation heaters, the pipe wall temperature will normally exceed the outlet gas temperature. Excessively high wall and/or sheath temperatures can create an unsafe or dangerous condition. Maximum sheath and chamber temperatures can be estimated using the mass velocity of the gas and Graph G-237. In the above air heating example, assume a 4.5 kW Series 3 heater rated 23 W/in^2 has been selected. From Chart 236, the free cross sectional area of a Series 3 (3 inch) heater is 0.044 ft^2. Calculate mass velocity from the following equation:

$$\underset{(lbs/ft^2/sec)}{Mass\ Velocity} = \frac{Flow\ lbs/hr}{Free\ area\ ft^2} \div 3{,}600\ \frac{sec}{hr}$$

$$Mass\ Velocity = \left(\frac{278\ lbs/hr}{0.044\ ft^2}\right) \div 3{,}600\ \frac{sec}{hr}$$

Chart 236 — Circulation Heaters Free Internal Cross Sectional Area

Pipe Body Nom. IPS (Std.)	Total Area (Ft^2)	Free Area (Ft^2)	No. 0.475" Elements
2	0.023	0.018	2
3	0.051	0.044	3
5	0.139	0.124	6
8	0.355	0.303	18
10	0.566	0.481	27
12	0.785	0.696	36
14	0.957	0.847	45
16	1.268	1.091	72
18	1.622	1.357	108

Mass Velocity = 1.75 $lbs/ft^2/sec$

On Graph G-237, locate the mass velocity (1.75) on the horizontal axis. From that point, locate a 23 W/in^2 curve. Read across to the vertical axis (sheath temperature rise above outlet temperature) to 880°F. Adding 880°F + 210°F (outlet temp.) = 1090°F sheath temperature. Averaging the sheath and outlet temperatures (1090°F + 210°F ÷ 2), yields a maximum chamber temperature of 650°F.

Since the maximum chamber wall temperature is less than 750°F, a stock GCH heater with a carbon steel vessel and INCOLOY® elements rated 23 W/in^2 can be used.

Graph G-237* — *Sheath Temperature Vs. Mass Velocity