Technical Information

Determining Heat Energy Requirements

General Applications

The objective of any heating application is to raise or maintain the temperature of a solid, liquid or gas to or at a level suitable for a particular process or application. Most heating applications can be divided into two basic situations; applications which require the maintenance of a constant temperature and applications or processes which require work product to be heated to various temperatures. The principles and calculation procedures are similar for either situation.

Constant Temperature Applications

Most constant temperature applications are special cases where the temperature of a solid, liquid or gas is maintained at a constant value regardless of ambient temperature. Design factors and calculations are based on steady state conditions at a fixed difference in temperature. Heat loss and energy requirements are estimated using "worst case" conditions. For this reason, determining heat energy requirements for a constant temperature application is relatively simple. Comfort heating (constant air temperature) and freeze protection for piping are typical examples of constant temperature applications. The equations and procedures for calculating heat requirements for several applications are discussed later in this section.

Variable Temperature Applications

Variable temperature (process) applications usually involve a start-up sequence and have numerous operating variables. The total heat energy requirements for process applications are determined as the sum of these calculated variables. As a result, the heat energy calculations are usually more complex than for constant temperature applications. The variables are:

Total Heat Energy Absorbed — The sum of all the heat energy absorbed during start-up or operation including the work product, the latent heat of fusion (or vaporization), make up materials, containers and equipment.

Total Heat Energy Lost — The sum of the heat energy lost by conduction, convection, radiation, ventilation and evaporation during start-up or operation.

Design Safety Factor — A factor to compensate for unknowns in the process or application.

Process Applications

The selection and sizing of the installed equipment in a process application is based on the **larger of two calculated heat energy requirements**. In most process applications, the start-up and operating parameters represent two distinctly different conditions in the same process. The heat energy required for start-up is usually considerably different than the energy required for operating conditions. In order to accurately assess the heat requirements for an application, each condition must be evaluated. The comparative values are defined as follows:

- **Calculated heat energy required for process start-up over a specific time period.**
- **Calculated heat energy required to maintain process temperatures and operating conditions over a specific cycle time.**

Determining Heat Energy Absorbed

The first step in determining total heat energy requirements is to determine the heat energy absorbed. If a change of state occurs as a direct or indirect part of the process, the heat energy required for the change of state must be included in the calculations. This rule applies whether the change occurs during start-up or later when the material is at operating temperature. Factors to be considered in the heat absorption calculations are shown below:

Start-Up Requirements (Initial Heat-Up)

- Heat absorbed during start-up by:
  - Work product and materials
  - Equipment (tanks, racks, etc.)
- Latent heat absorption at or during start-up:
  - Heat of fusion
  - Heat of vaporization
- Time factor

Operating Requirements (Process)

- Heat absorbed during operation by:
  - Work product in process
  - Equipment loading (belts, racks, etc.)
  - Make up materials
- Latent heat absorption during operation:
  - Heat of fusion
  - Heat of vaporization
- Time (or cycle) factor, if applicable

Determining Heat Energy Lost

Objects or materials at temperatures above the surrounding ambient lose heat energy by conduction, convection and radiation. Liquid surfaces exposed to the atmosphere lose heat energy through evaporation. The calculation of total heat energy requirements must take these losses into consideration and provide sufficient energy to offset them. Heat losses are estimated for both start-up and operating conditions and are added into the appropriate calculation.

Heat Losses at Start-Up — Initially, heat losses at start-up are zero since the materials and equipment are all at ambient temperature. Heat losses increase to a maximum at operating temperature. Consequently, start-up heat losses are usually based on an average of the loss at start-up and the loss at operating temperature.

Heat Losses at Operating Temperature — Heat losses are at a maximum at operating temperature. Heat losses at operating temperature are taken at full value and added to the total energy requirements.

Estimating Heat Loss Factors

The heat losses just discussed can be estimated by using factors from the charts and graphs provided in this section. Total losses include radiation, convection and conduction from various surfaces and are expressed in watts per hour per unit of surface area per degree of temperature **(W/hr/ft^2/°F)**.

Note — Since the values in the charts are already expressed in watts per hour, they are not influenced by the time factor *"t"* in the heat energy equations.

Design Safety Factors

In many heating applications, the actual operating conditions, heat losses and other factors affecting the process can only be estimated. A safety factor is recommended in most calculations to compensate for unknowns such as ventilation air, thermal insulation, make up materials and voltage fluctuations. As an example, a voltage fluctuation (or drop) of 5% creates a 10% change in the wattage output of a heater.

Safety factors vary from 10 to 25% depending on the level of confidence of the designer in the estimate of the unknowns. The safety factor is applied to the sum of the calculated values for heat energy absorbed and heat energy lost.

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Determining Heat Energy Requirements

Total Heat Energy Requirements

The total heat energy (Q_T) required for a particular application is the sum of a number of variables. The basic total energy equation is:

$$Q_T = Q_M + Q_L + \text{Safety Factor}$$

Where:
Q_T = The total energy required in kilowatts
Q_M = The total energy in kilowatts absorbed by the work product including latent heat, make up materials, containers and equipment
Q_L = The total energy in kilowatts lost from the surfaces by conduction, convection, radiation, ventilation and evaporation
Safety Factor = 10% to 25%

While Q_T is traditionally expressed in Btu's (British Thermal Units), it is more convenient to use watts or kilowatts when applying electric heaters. Equipment selection can then be based directly on rated heater output. Equations and examples in this section are converted to watts.

Basic Heat Energy Equations

The following equations outline the calculations necessary to determine the variables in the above total energy equation. Equations 1 and 2 are used to determine the heat energy absorbed by the work product and the equipment. The specific heat and the latent heat of various materials are listed in this section in tables of properties of non-metallic solids, metals, liquids, air and gases. Equations 3 and 4 are used to determine heat energy losses. Heat energy losses from surfaces can be estimated using values from the curves in charts G-114S, G-125S, G-126S or G-128S. Conduction losses are calculated using the thermal conductivity or *"k"* factor listed in the tables for properties of materials.

Equation 1 — Heat Energy Required to Raise the Temperature of the Materials (No Change of State). The heat energy absorbed is determined from the weight of the materials, the specific heat and the change in temperature. Some materials, such as lead, have different specific heats in the different states. When a change of state occurs, two calculations are required for these materials, one for the solid material and one for the liquid after the solid has melted.

$$Q_A = \frac{\text{Lbs} \times C_p \times \Delta T}{3412 \text{ Btu/kW}}$$

Where:
Q_A = kWh required to raise the temperature
Lbs = Weight of the material in pounds
C_p = Specific heat of the material (Btu/lb/°F)
ΔT = Change in temperature in °F $[T_2 \text{ (Final)} - T_1 \text{ (Start)}]$

Equation 2 — Heat Energy Required to Change the State of the Materials. The heat energy absorbed is determined from the weight of the materials and the latent heat of fusion or vaporization.

$$Q_F \text{ or } Q_V = \frac{\text{Lbs} \times H_{fus} \text{ or } H_{vap}}{3412 \text{ Btu/kW}}$$

Where:
Q_F = kWh required to change the material from a solid to a liquid
Q_V = kWh required to change the material from a liquid to a vapor or gas
Lbs = Weight of the material in pounds
H_{fus} = Heat of fusion (Btu/lb/°F)
H_{vap} = Heat of vaporization (Btu/lb/°F)

Equation 3 — Heat Energy Lost from Surfaces. The heat energy lost from surfaces by radiation, convection and evaporation is determined from the surface area and the loss rate in watts per square foot per hour.

$$Q_{LS} = \frac{A \times L_S}{1000 \text{ W/kW}}$$

Where:
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
A = Area of the surfaces in square feet
L_S = Loss rate in watts per square foot at final temperature ($W/ft^2/hr$ from charts)[1]

Equation 4 — Heat Energy Lost by Conduction through Materials or Insulation. The heat energy lost by conduction is determined by the surface area, the thermal conductivity of the material, the thickness and the temperature difference across the material.

$$Q_{LC} = \frac{A \times k \times \Delta T}{d \times 3412 \text{ Btu/kW}}$$

Where:
Q_{LC} = kWh lost by conduction
A = Area of the surfaces in square feet
k = Thermal conductivity of the material in Btu/inch/square foot/hour ($Btu/in/ft^2/hr$)
ΔT = Temperature difference in °F across the material $[T_2 - T_1]$
d = Thickness of the material in inches

Summarizing Energy Requirements

Equations 5a and 5b are used to summarize the results of all the other equations described on this page. These two equations determine the total energy requirements for the two process conditions, start-up and operating.

Equation 5a — Heat Energy Required for Start-Up.

$$Q_T = \left(\frac{Q_A + Q_F\,[\text{or } Q_V]}{t} + \frac{Q_{LS} + Q_{LC}}{2}\right)(1 + SF)$$

Where:
Q_T = The total energy required in kilowatts
Q_A = kWh required to raise the temperature
Q_F = kWh required to change the material from a solid to a liquid
Q_V = kWh required to change the material from a liquid to a vapor or gas
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
Q_{LC} = kWh lost by conduction
SF = Safety Factor (as a percentage)
t = Start-up time in hours[2]

Equation 5b — Heat Energy Required to Maintain Operation or Process[3].

$$Q_T = (Q_A + Q_F\,[\text{or } Q_V] + Q_{LS} + Q_{LC})(1 + SF)$$

Where:
Q_T = The total energy required in kilowatts
Q_A = kWh required to raise the temperature of added material
Q_F = kWh required to change added material from a solid to a liquid
Q_V = kWh required to change added material from a liquid to a vapor or gas
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
Q_{LC} = kWh lost by conduction
SF = Safety Factor (as a percentage)

Equipment Sizing & Selection

The size and rating of the installed heating equipment is based on the larger of calculated results of Equation 5a or 5b.

Notes —

1. **Loss Factors** from charts in this section include losses from radiation, convection and evaporation unless otherwise indicated.
2. **Time (*t*)** is factored into the start-up equation since the start up of a process may vary from a period of minutes or hours to days.
3. **Operating Requirements** are normally based on a standard time period of one hour (t = 1). If cycle times and heat energy requirements do not coincide with hourly intervals, they should be recalculated to a hourly time base.

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Determining Heat Energy Requirements - Heating Liquids

Typical Steps in Determining Total Energy Requirements

Most heating problems involve three basic steps:

1. **Determine** required kW capacity for bringing application up to operating temperature in the desired time.
2. **Calculate** the kW capacity required to maintain the operating temperature.
3. **Select** the number and type of heaters required to supply the kW required.

Note — Some applications, such as instantaneous heating of gas or air in ducts, comfort heating and pipe tracing only require calculation of the operating kW and selection of heaters.

Design Considerations

In order to calculate the initial and operating kW capacity requirements, the following factors should be considered:

- Specified heat-up time
- Start-up and operating temperatures
- Thermal properties of material(s) being heated
- Weight of material(s) being heated
- Weight of container and equipment being heated
- Weight of make up material (requirements per hour)
- Heat carried away by products being processed or equipment passing through heated area
- Heat absorbed due to a change of state
- Thermal properties and thickness of insulation
- Heat losses from the surface of material and/or container to the surrounding environment.

Liquid Heating Example

One of the most common electric heating applications is the direct immersion heating of liquids. The following example illustrates the steps in determining total energy requirements of a typical direct immersion application.

Application — A final rinse tank requires water at 180°F. The tank is 2 feet wide by 4 feet long by 2 feet high and is uninsulated with an open top. The tank is made of 3/8" steel and contains 100 gallons of water at 70°F at start up. Make up water with a temperature of 60°F is fed into the tank at the rate of 40 gallons per hour during the process. There is an exhaust hood over the tank and the relative humidity in the area is high. Work product is 300 lbs. of steel per hour.

Example — Heat the water to 180°F in 3 hours and heat 40 gallons per hour of make up water from 60°F to 180°F thereafter.

Specific heat of steel = 0.12 Btu/lb/°F
Specific heat of water = 1.00 Btu/lb/°F
Weight of steel = 490 lb/ft^3
Weight of water = 8.345 lb/gal

To Find Initial (Start-Up) Heating Capacity —

$$Q_S = \left(\frac{Q_A + Q_C}{t} + \frac{Q_{LS}}{2}\right)(1 + SF)$$

Where:
Q_S = The total energy required in kilowatts
Q_A = kWh required to raise the temperature of the water
Q_C = kWh required to raise the temperature of the steel tank
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
SF = Safety Factor
t = Start-up time in hours (3)

kW to Heat Water —

$$\frac{100\text{ gal} \times 8.345\text{ lb/gal} \times 1.0\text{ Btu/lb } (180 - 70°\text{F})}{3412\text{ Btu/kW}}$$

Q_A = 26.9 kW

kW to Heat Steel Tank —

Lbs of steel = Area x thickness x 490 lbs/ft^3

$$32\text{ ft}^2 \times \frac{0.375\text{ in.}}{12} \times 490\text{ lb/ft}^3 = 490\text{ lbs}$$

$$\frac{490\text{ lbs} \times 0.12\text{ Btu/lb } (180 - 70°\text{F})}{3412\text{ Btu/kW}}$$

Q_C = 1.89 kW

Heat Losses from Surfaces —

$Q_{LS} = L_{SW} + L_{SC}$

Where:
Q_{LS} = kWh lost from all surfaces
L_{SW} = Losses from the surface of the water
L_{SC} = Losses from the surfaces of the tank

L_{SW} = Surface losses from water (Graph G126S, Curve 2 fps @ 60% rh)

$$\frac{8\text{ ft}^2 \times 550\text{ W/ft}^2}{1000\text{ W/kW}} = 4.4\text{kW}$$

L_{SC} = Surface losses from uninsulated tank walls (Graph G125S)

$$\frac{32\text{ ft}^2 \times 0.6\text{ W/ft}^2 \times (180 - 70°\text{F})}{1000\text{ W/kW}} = 2.11\text{ kW}$$

Heat Required for Start-Up —

$$\left(\frac{26.9\text{ kW} + 1.89\text{ kW}}{3\text{ hrs}} + \frac{4.4\text{ kW} + 2.11\text{ kW}}{2}\right) \times 1.2$$

Q_S = 15.42 kW

To Find Heat Required for Operating —

$Q_O = (Q_{WO} + Q_{LS} + Q_{WS})(1 + SF)$

Where:
Q_{WO} = kW to heat additional water

$$\frac{40\text{ gal} \times 8.345\text{ lb/gal} \times 1.0\text{ Btu/lb } (180 - 60°\text{F})}{3412\text{ Btu/kW}}$$

Q_{WO} = 11.7 kW

Q_{WS} = kW to heat steel 300 Lbs. x 0.12 x (180 - 60°F)/3412 = 1.27 kW

Heat Required for Operating —

Q_O = (11.7 kW + 1.27 kW + 4.4 kW + 2.11 kW) 1.2

Q_O = 23.38 kW

Installed Capacity — Since the heat required for operating (21.85 kW) is greater than the heat required for start up (15.42 kW), the installed heating capacity should be based on the heat required for operation. With 22 kW installed, the actual initial heating time will be less than 3 hours.

Suggested Equipment — Moisture resistant terminal enclosures are recommended for industrial liquid heating applications. Install two stock 12 kW MT-2120E2 or 12 kW MT-3120E2 screw plug heaters or two 12 kW KTLC-312A over-the-side heaters with an automatic temperature control. Automatic temperature control will limit the kWh consumption to actual requirements during operation. A low water level cutoff control is also recommended.

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Determining Heat Energy Requirements

Flow Through Water Heating

Circulation heater applications frequently involve "flow through" heating with no re-circulation of the heated media. These applications have virtually no start-up requirements. The equation shown below can be used to determine the kilowatts required for most "flow through" applications. The maximum flow rate of the heated medium, the minimum temperature at the heater inlet and the maximum desired outlet temperature are always used in these calculations. A 20% safety factor is recommended to allow for heat losses from jacket and piping, voltage variations and variations in flow rate.

$$Q = \frac{F \times C_p \times \Delta T \times SF}{3412\ \text{Btu/kW}}$$

Where:

Q = Power in kilowatts

F = Flow rate in lbs/hr

C_p = Specific heat in Btu/lb/°F

ΔT = Temperature rise in °F

SF = Safety Factor

Example — Heat 5 gpm of water from 70 - 115°F in a single pass through a circulation heater.

Step 1 — Determine flow rate in lbs/hr.
(Density of water is 8.35 lbs/gal)
5 gpm x 8.35 lbs/gal x 60 min = 2505 lbs/hr

Step 2 — Calculate kW:
C_p = Specific heat of water = 1 Btu/lb/°F

$$\text{kW} = \frac{2505\ \text{lbs} \times 1\ \text{Btu/lb/°F} \times (115 - 70\text{°F})}{3412\ \text{Btu/kW}} \times 1.2\ \text{SF}$$

kW= 39.6 kW

Temperature Rise Vs. Water Flow[1]

Temp. Rise (°F)	Heater Rating (kW)						
	6	9	12	15	18	24	30
	Flow rate in GPH for given Temperature Rise						
20	122	184	245	306	368	490	613
30	81	122	163	204	245	327	409
40	61	92	122	153	184	245	306
50	49	73	98	122	147	196	245
60	40	61	81	102	122	163	204
70	35	52	70	87	105	140	175
80	30	46	61	76	92	122	153
90	27	40	54	68	81	109	136
100	24	36	49	61	73	98	122
110	22	33	44	55	66	89	111
120	20	30	40	51	61	81	102
130	18	28	37	47	56	75	94

1. Safety Factor and losses not included.

Flow Through Oil Heating

Oil Heating with Circulation Heaters — The procedure for calculating the requirements for "flow through" oil heating with circulation heaters is similar to water heating. The weight of the liquid being heated is factored by the specific gravity of oil. The specific gravity of a particular oil can be determined from the charts on properties of materials or can be calculated from the weight per cubic foot relative to water.

Example — Heat 3 gpm of #4 fuel oil with a weight of approximately 56 lbs/ft^3 from 50°F to 100°F.

Step 1 — Determine flow rate in lbs/hr.
Specific gravity = 56 lbs/ft^3 ÷ 62.4 lbs/ft^3 = 0.9
3 gpm x 8.35 lbs/gal x 0.9 x 60 min = 1353 lbs/hr

Step 2 — Calculate kW:
Specific heat of fuel oil is 0.42 Btu/lb/°F

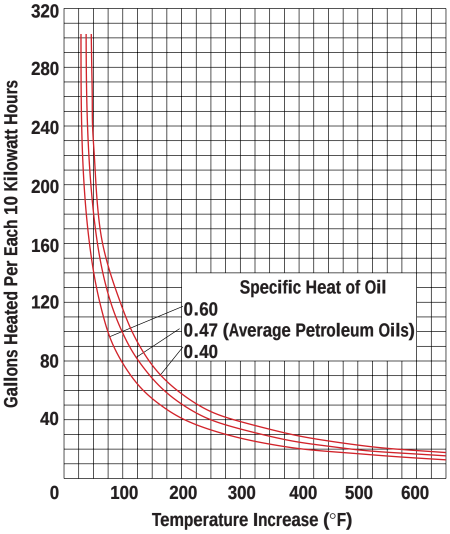
$$\text{kW} = \frac{1353\ \text{lbs} \times 0.42\ \text{Btu/lb/°F} \times (100 - 50\text{°F})}{3412\ \text{Btu/kW}} \times 1.2\ \text{SF}$$

kW = 9.99

Suggestion — Choose watt density for fuel oil and then select heater. Use a stock NWHOR-05-015P, 10 kW circulation heater with an AR-215 thermostat.

Graph G-236 — Oil Heating

Heat Required for Various Temperature Rise (Exclusive of Losses)



CAUTION — Consult recommendations elsewhere in this section for watt density and maximum sheath temperatures for oil heating.

Heating Soft Metal with Melting Pots or Crucibles

Most soft metal heating applications involve the use of externally heated melting pots or crucibles. The following example represents a typical soft metal application.

A steel melting pot weighing 150 lbs contains 400 lbs of lead. The pot is insulated with 2 inches of rock wool and has an outside steel shell with 20 ft^2 of surface area. The top surface of the lead has 3 ft^2 exposed to the air. Determine the kilowatts required to raise the material and container from 70°F to 800°F in one hour, and heat 250 lbs of lead per hour (70°F to 800°F) thereafter.

Melting point of lead = 621°F
Specific heat of solid lead = 0.0306 Btu/lb/°F
Specific heat of molten lead = 0.038 Btu/lb/°F
Heat of fusion/lead = 10.8 Btu/lb
Specific heat of steel crucible = 0.12 Btu/lb/°F
Radiation loss from molten lead surface = 1000 W/ft^2 (from curve G-128S).
Surface loss from outside shell of pot 62 W/ft^2 (from curve G-126S).
SF = Safety Factor 20%

To Find Start-Up Heating Requirements —

$$Q_T = \left(\frac{Q_A + Q_F + Q_L + Q_C}{t} + \frac{Q_{LS}}{2}\right)(1 + SF)$$

Where:

Q_A = kW to heat lead to melting point.
[400 lbs x 0.0306 Btu/lb/°F (621 - 70°F)] ÷ 3412

Q_F = kW to melt lead (400 lbs x 10.8 Btu/lb) ÷ 3412

Q_L = kW to heat lead from melting pt. to 800°F
[400 lbs x 0.038 Btu/lb/°F (800 - 621°F)] ÷ 3412

Q_C = kW to heat steel pot
[150 lbs x 0.12 Btu/lb/°F (800 - 70°F)] ÷ 3412

Q_{LS} = Surface losses from lead and outside shell
[(1000 W x 3 ft^2) + (62 W x 20 ft^2)]/2 ÷ 1000

t = 1 hour

Q_T = 9.98 kW x 1.2 = 11.99 kW

To Find Operating Requirements —

$$Q_T = (Q_A + Q_F + Q_L + Q_{LS})(1 + SF)$$

Where:

Q_A = kW to heat added lead to melting point.
(250 lbs x 0.0306 Btu/lb/°F [621 - 70°F]) ÷ 3412

Q_F = kW to melt added lead
(250 lbs x 10.8 Btu/lb) ÷ 3412

Q_L = kW to heat lead from melting pt. to 800°F
(250 lbs x 0.038 Btu/lb/°F [800 - 621°F]) ÷ 3412

Q_{LS} = Surface losses from lead and outside shell
(1000W x 3 ft^2) + (62W x 20 ft^2) ÷ 1000

Q_T = 6.69 kW x 1.2 = 8.03 kW

Since start-up requirements exceed the operating requirements, 12 kW should be installed.

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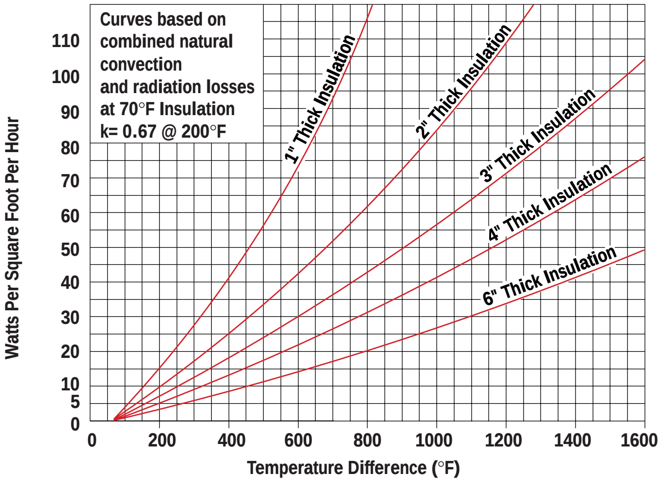
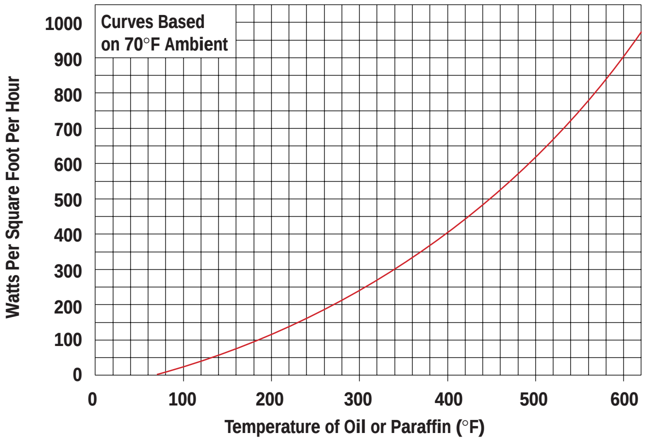
Heat Loss Factors & Graphs

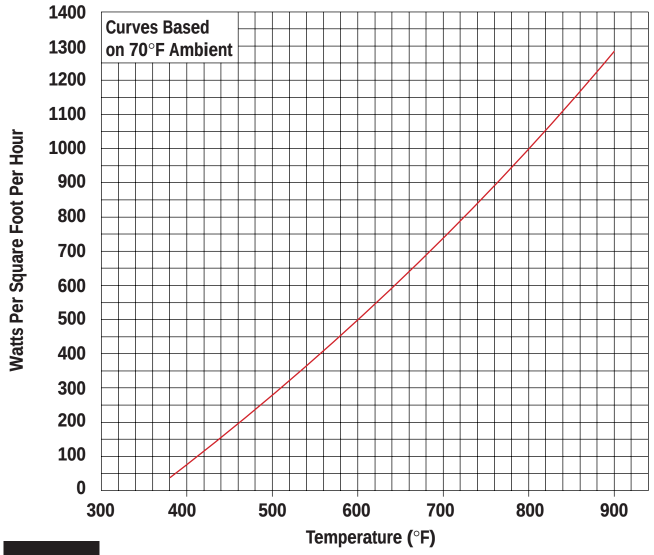
Graph G-126S — Heat Losses from Surfaces of Insulated Walls of Ovens, Pipes, Tanks, Etc.


Curves based on combined natural convection and radiation losses at 70°F Insulation k= 0.67 @ 200°F

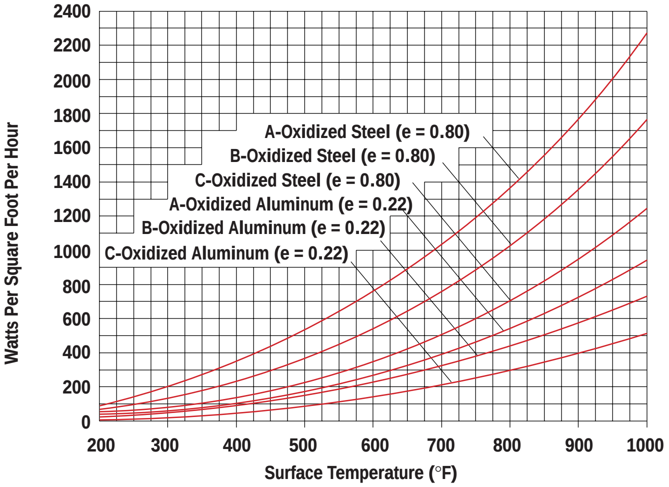
Graph G-127S — Heat Losses from Oil or Paraffin Surfaces


Curves Based on 70°F Ambient

Graph G-128S — Heat Losses from Molten Metal Surfaces (Lead, Babbit, Tin, Type Metal, Solder, Etc.)


Curves Based on 70°F Ambient

Graph G-125S — Heat Losses from Uninsulated Metal Surfaces Combined Losses from Convection & Radiation



Curve A shows heat loss from vertical surfaces of tanks, pipes, etc. and the top of a flat horizontal surface.

Curve B shows the combined heat loss from both the top and bottom surfaces of flat horizontal surfaces.

Curve C shows heat losses from only the bottom surface of flat horizontal surfaces.

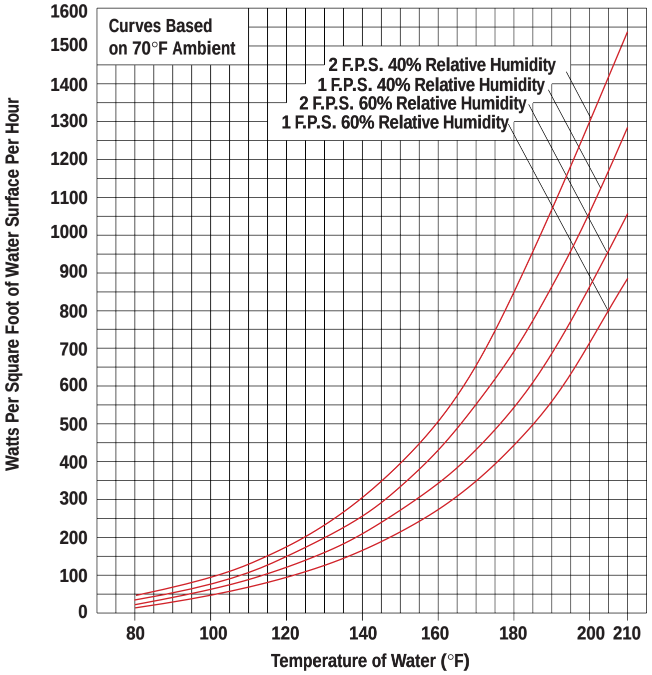
All Curves based on still air (1 fps) @ 70°F, e = emissivity.

Note — The above graph is difficult to read for surface temperatures below 250°F. To estimate heat losses for surface temperatures below 250°F, use the following formula:

$$0.6 \text{ W x ft}^2 \text{ x } \Delta T \text{ °F}$$

Where:
ΔT is the temperature difference in °F between the heated surface and the ambient.

Graph G-114S — Heat Losses from Water Surfaces


Curves Based on 70°F Ambient

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Determining Heat Energy Requirements

Pipe & Tank Tracing

The following tables can be used to determine the heat losses from insulated pipes and tanks for heat tracing applications. To use these tables, determine the following design factors:

- Temperature differential $\Delta T = T_M - T_A$
  Where:
  T_M = Desired maintenance temperature °F
  T_A = Minimum expected ambient temperature °F
- Type and thickness of insulation
- Diameter of pipe or surface area of tank
- Outdoor or indoor application
- Maximum expected wind velocity (if outdoors).

Pipe Tracing Example — Maintain a 1-1/2 inch IPS pipe at 100°F to keep a process fluid flowing. The pipe is located outdoors and is insulated with 2 inch thick Fiberglas® insulation. The minimum expected ambient temperature is 0°F and the maximum expected wind velocity is 35 mph. Determine heat losses per foot of pipe.

1. **Heat Loss Rate —** Using Table 1, determine the heat loss rate in W/ft of pipe per °F temperature differential. Enter table with insulation ID or IPS pipe size (1-1/2 in.) and insulation thickness (2 in.).
   Rate = 0.038 Watts/ft/°F.

2. **Heat Loss per Foot —** Calculated heat loss per foot of pipe equals the maximum temperature differential (ΔT) times heat loss rate in Watts/ft/°F.

   ΔT = 100°F - 0°F = 100°F
   Q = (ΔT)(heat loss rate per °F)
   Q = (100°F) (0.038 W/ft) = 3.80 W/ft

3. **Insulation Factor —** Table 1 is based on Fiberglas® insulation and a 50°F ΔT. Adjust Q for thermal conductivity (k factor) and temperature as necessary, using adjustment factors from Table 2.

   Adjusted Q = (Q)(1.08) = 3.80 W/ft x 1.08
   Q = 4.10 W/ft

4. **Wind Factor —** Table 1 is based on 20 mph wind velocity. Adjust Q for wind velocity as necessary by adding 5% for each 5 mph over 20 mph. Do not add more than 15% regardless of wind speed.

   Adjusted Q = (Q)(1.15) = 4.10 W/ft x 1.15
   Design heat loss per linear foot
   Q = 4.72 W/ft

Note — For indoor installations, multiply Q by 0.9.

Table 1 — Heat Losses from Insulated Metal Pipes (Watts per foot of pipe per °F temperature differential ¹)

Pipe Size (IPS)	Insul. I.D. (In.)	Insulation Thickness (In.) 1/2	3/4	1	1-1/2	2	2-1/2	3	4
1/2	0.840	0.054	0.041	0.035	0.028	0.024	0.022	0.020	0.018
3/4	1.050	0.063	0.048	0.040	0.031	0.027	0.024	0.022	0.020
1	1.315	0.075	0.055	0.046	0.036	0.030	0.027	0.025	0.022
1-1/4	1.660	0.090	0.066	0.053	0.041	0.034	0.030	0.028	0.024
1-1/2	1.990	0.104	0.075	0.061	0.046	0.038	0.034	0.030	0.026
2	2.375	0.120	0.086	0.069	0.052	0.043	0.037	0.033	0.029
2-1/2	2.875	0.141	0.101	0.080	0.059	0.048	0.042	0.037	0.032
3	3.500	0.168	0.118	0.093	0.068	0.055	0.048	0.042	0.035
3-1/2	4.000	0.189	0.133	0.104	0.075	0.061	0.052	0.046	0.038
4	4.500	0.210	0.147	0.115	0.083	0.066	0.056	0.050	0.041
—	5.000	0.231	0.161	0.125	0.090	0.072	0.061	0.054	0.044
5	5.563	0.255	0.177	0.137	0.098	0.078	0.066	0.058	0.047
6	6.625	0.300	0.207	0.160	0.113	0.089	0.075	0.065	0.053
—	7.625	0.342	0.235	0.181	0.127	0.100	0.084	0.073	0.059
8	8.625	0.385	0.263	0.202	0.141	0.111	0.092	0.080	0.064
—	9.625	0.427	0.291	0.224	0.156	0.121	0.101	0.087	0.070
10	10.75	0.474	0.323	0.247	0.171	0.133	0.110	0.095	0.076
12	12.75	0.559	0.379	0.290	0.200	0.155	0.128	0.109	0.087
14	14.00	0.612	0.415	0.316	0.217	0.168	0.138	0.118	0.093
16	16.00	0.696	0.471	0.358	0.246	0.189	0.155	0.133	0.104
18	18.00	0.781	0.527	0.401	0.274	0.210	0.172	0.147	0.115
20	20.00	0.865	0.584	0.443	0.302	0.231	0.189	0.161	0.125
24	24.00	1.034	0.696	0.527	0.358	0.274	0.223	0.189	0.147

[1] Values in Table 1 are based on a pipe temperature of 50°F, an ambient of 0°F, a wind velocity of 20 mph and a "k" factor of 0.25 (Fiberglas®). Values are calculated using the following formula plus a 10% safety margin:
Watts/ft of pipe = $2 \pi k (\Delta T) \div (Z) \ln (D_0/D_1)$
Where: k = Thermal conductivity (Btu/in./hr/ft²/°F)
ΔT = Temperature differential (°F)
D_0 = Outside diameter of insulation (in.)
D_1 = Inside diameter of insulation (in.)
Z = 40.944 Btu/in/W/hr/ft
In = Natural Log of D_0/D_1 Quotient

Table 2 — Thermal Conductivity (k) Factor of Typical Pipe Insulation Materials (Btu/in./hr/ft²/°F)

Insulation Type		Pipe Maintenance Temperature (°F) 0	50	100	150	200	300	400	500
Fiberglas® or Mineral Fiber Based on ASTM C-547	*k* value	0.23	0.25	0.27	0.30	0.32	0.37	0.41	0.45
	Adjustment factor	(0.92)	(1.00)	(1.08)	(1.20)	(1.28)	(1.48)	(1.64)	(1.80)
Calcium Silicate² Based on ASTMC-533	*k* value	0.35	0.37	0.40	0.43	0.45	0.50	0.55	0.60
	Adjustment factor	(1.52)	(1.48)	(1.60)	(1.72)	(1.80)	(2.00)	(2.20)	(2.40)
Foamed Glass² Based on ASTMC-552	*k* value	0.38	0.40	0.43	0.47	0.51	0.60	0.70	0.81
	Adjustment factor	(1.52)	(1.60)	(1.72)	(1.88)	(2.04)	(2.40)	(2.8)	(3.24)
Foamed Urethane Based on ASTMC-591	*k* value	0.18	0.17	0.18	0.21	0.25	Not Recommended		
	Adjustment factor	(0.72)	(0.68)	(0.72)	(0.84)	(1.00)			

[2] When using rigid insulation, select an inside diameter one size larger than the pipe on pipe sizes through 9 in. IPS. Over 9 in. IPS, use same size insulation.

Table 3 — Heat Losses from Insulated Metal Tanks (W/ft²/°F)³

Insulation Thickness (In.) 1/2	3/4	1	1-1/2	2	2-1/2	3	3-1/2	4	5	6
0.161	0.107	0.081	0.054	0.040	0.032	0.027	0.023	0.020	0.016	0.013

[3] Values in Table 3 are based on a tank temperature of 50°F, an ambient of 0°F, a wind velocity of 20 mph and a "k" factor of 0.25 (Fiberglas®). Values are calculated using the following formula plus a 10% safety margin:
Watts/ft² = $Y k(\Delta T) \div X$
Where: Y = 0.293W/hr/btu
k = Thermal conductivity
X = Thickness of insulation (in.)
Δ = Temperature differential (°F)

Note — The above information is presented as a guide for solving typical heat tracing applications. Contact your Local Chromalox Sales office for assistance in heater selection and for pipes made of materials other than metal.

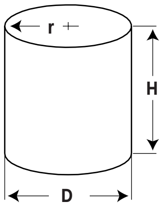
Technical Information

Determining Heat Energy Requirements

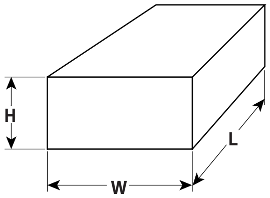
Pipe & Tank Tracing (cont'd.)

Tank tracing requires an additional calculation of the total exposed surface area. To calculate the surface area:

Cylindrical Tanks —
Area = $2 \pi r^2 + \pi DH$
$A = \pi D (r + H)$



Horizontal Tanks —
Area = $2[(W \times L) + (L \times H) + (H \times W)]$



Tank Tracing Example — Maintain a metal tank with 2 inch thick Fiberglas® insulation at 50°F. The tank is located outdoors, is 4 feet in diameter, 12 feet long and is exposed at both ends. The minimum ambient temperature is 0°F and the maximum expected wind speed is 15 mph.

1. **Surface Area —** Calculate the surface area of the tank.
   $A = \pi D (r + H)$
   $A = \pi\, 4\, (2 + 12)$
   $A = 175.9 \text{ ft}^2$
2. **Temperature Differential** (ΔT)

   $\Delta T = T_M - T_A = 50°F - 0°F = 50°F$
3. **Heat Loss Per Foot^2 —** Obtain the heat loss per square foot per degree from Table 3.

   Heat loss/ft^2/°F = 0.04 W/ft^2/°F
4. **Insulation Factor —** Table 3 is based on Fiberglas® insulation and a 50°F ΔT. Adjust Q for thermal conductivity (k factor) and temperature as necessary, using factors from Table 2.
5. **Wind Factor —** Table 3 is based on 20 mph wind velocity. Adjust Q for wind velocity as necessary, by adding 5% for each 5 mph over 20 mph. Do not add more than 15% regardless of wind speed. **Note** — For indoor installations, multiply Q by 0.9.
6. **Calculate Total Heat Loss for Tank —** Multiply the adjusted heat loss per square foot per °F figure by the temperature differential. Multiply the loss per square foot by the area.

   $Q = 0.04 \text{ W/ft}^2/°F \times 50°F\ \Delta T = 2 \text{ W/ft}^2$
   Q = Adjusted W/ft^2 x tank surface area
   $Q = 2 \text{ W/ft}^2 \times 175.9 \text{ ft}^2$

   Heat Loss from Tank = 351.8 Watts

Comfort Heating

For complete building and space heating applications, it is recommended that a detailed analysis of the building construction heat losses (walls, ceilings, floors, windows, etc.) be performed using ASHRAE guidelines. This is the most accurate and cost effective estimating procedure. However, a quick estimate of the kW requirements for room and supplemental heating or freeze protection can be obtained using the chart to the right.

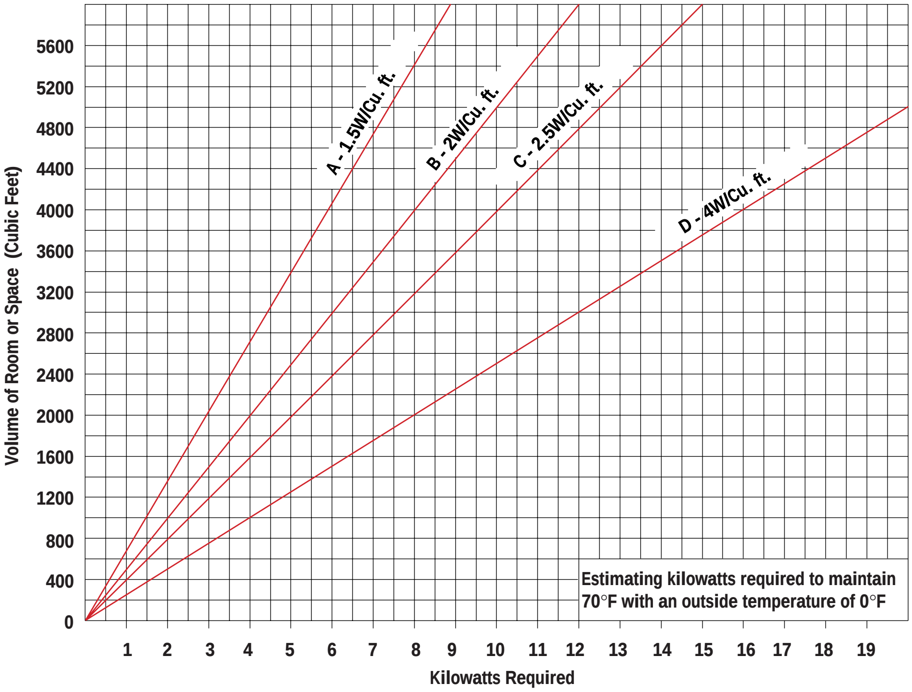
Problem — A warehouse extension measures 20 ft long x 13 ft wide x 9 ft high. The building is not insulated. Construction is bare concrete block walls and an open ceiling with a plywood deck and built-up roof. Determine the kW required to maintain the warehouse at 70°F when the outside temperature is 0°F.

Solution —

1. **Calculate** the volume of the room.

   20 ft x 13 ft x 9 ft = 2,340 ft^3
2. **Refer** to the chart, use Curve D which corresponds to the building construction.
3. **Find** the intersection of 2,340 ft^3 with curve D. The kilowatts required are 9.3 kW. Suggest using a 10 kW unit blower heater.

Comfort Heating Chart



Curve A — Rooms with little or no outside exposure. No roof or floor with outside exposure; only 1 wall exposed with not over 15% door and window area.

Curve B — Rooms with average exposure. Roof and 2 or 3 walls exposed, up to 30% door and window area. But with roof, walls and floor insulated if exposed to outside temperatures.

Curve C — Rooms with roof, walls and floor uninsulated but with inside facing on walls and ceiling.

Curve D — Exposed guard houses, pump houses, cabins and poorly constructed rooms with reasonably tight joints but no insulation. Typical construction of corrugated metal or plywood siding, single layer roofs.

Note — If the volume of the room is larger than the chart values, divide by 2, 3, 4, etc. until the trial volume fits the curve. Then select heater from this volume. Multiply heaters selected by the number used to select the trial volume.