HEATING & COOLING THEORIES & FORMULAE

GENERAL FORMULA FOR HEATERS

To Determine Watts (W):

$W = EI$	$W = I^2R$	$W = E^2/R$

To Determine Volts (E):

$E = \sqrt{(WR)}$	$E = W/I$	$E = IR$

To Determine Ohms (R):

$R = W / I^2$	$R = E^2/W$	$R = E/I$

To Determine Amperes (I):

$I = E/R$	$I = W/E$	$I = \sqrt{(W/R)}$

Variation of Wattage with Voltage Change

$W2 = W1 \, (E2/E1)^2$

E2 = New Voltage **W2**= New Wattage

E1 = Original Heater Voltage **W1** = Original Wattage

WATTAGE CALCULATION DATA

Basic Heat Formulas

The following formulae can be employed in determining wattage capacity required for different materials.

Formula A: Wattage required for heat-up =

$$\frac{\text{Weight of material (lbs)} \times \text{Specific Heat} \times \text{Temperature Rise°F}}{3.412 \times \text{Time (hours of fraction thereof)}}$$

Formula B: Wattage losses at operating temperature = Wattage loss/sq.ft. x Area in sq.ft.

Formula C: Wattage for melting or vaporizing =

$$\frac{\text{Weight of material (lbs)} \times \text{Heat of fusion or vaporization (BTU/lb)}}{3.412 \times \text{Heat-up time (hours of fraction thereof)}}$$

When the specific heat of a material changes at some temperature during the heat-up, due to melting (fusion) or evaporation (vaporation), perform Formula A for heat absorbed from the initial temperature up to the temperature at the point of change, add Formula B, then repeat Formula A for heat absorbed from the point of change to the final operating temperature.

Specific Applications

For specific applications, substitute the Basic Heat Formulas (A, B, or C above) into the following:

To Heat Liquids

Wattage for initial heat-up = (a) + $\frac{(b)}{2}$

Wattage for operating requirements = (a) for new material added + (b)
To insure adequate capacity, add 20% to final wattage figures. This will compensate for added heat losses not readily computed.

To Melt Soft Metals

Wattage for initial heat-up = (a) to melting point + (c) to melt (a) to heat above melting point + $\frac{(b)}{2}$

To Heat Ovens

Wattage = (a) (for air) + (a) (all material introduced into oven) + (b)
Add 25% to cover door heat losses

Forced Air Heating

Wattage = $\frac{\text{C.F.M. x temperature rise (°F)}}{3}$ CFM = Cubic Feet per Minute

FLEXIBLE HEATERS

Flexible heaters have been developed using new production techniques to position fine resistance wires or an etched foil circuit accurately and precisely over areas of almost any shape and size. The close and even spacing of the wires or the etched foil ensures a uniform distribution of heat over the entire working area. Because of its high temperature tolerance and superb electrical insulating properties, silicone rubber is well suited to the production of heated mats. They are produced by laminating the wire or foil between two sheets of silicone rubber, reinforced with a glass textile to give improved mechanical strength.

Silicone rubber mat heaters can be manufactured to any size and shape to suit customer's applications. Holes and cut-outs to accommodate existing components or obstructions, can be provided as required without disturbing the even distribution of heat. Size is generally limited to 920mm width of our standard material and a practical length of 2000mm.
The maximum continuous operating temperature for silicone rubber insulated mat heaters is 180°C, allowing a generous safety margin for short term over temperature excursions as high as 230°C. Heater mats can be supplied with inbuilt temperature sensors for controlling and/or monitoring as well as thermal limiters for over temperature protection.

Measuring conditions as follows:

A flat heating element vulcanized onto a 1.5mm aluminum plate, ambient temperature 20°C (still air), measured in steady state conditions, heating element in horizontal position.

Specific Heat Output		Surface Temp
Watts/Sq Cm	Watts/Sq Inch	Deg C
0.050	0.323	40
0.075	0.484	60
0.100	0.645	70
0.125	0.806	80
0.150	0.968	90
0.200	1.290	105
0.250	1.613	121
0.300	1.935	135
0.350	2.258	150
0.400	2.581	164
0.450	2.903	176
0.500	3.226	188
0.550	3.548	200
0.600	3.871	210
0.650	4.194	220
0.700	4.516	230
0.750	4.839	238
0.800	5.161	247
0.850	5.484	253
0.900	5.806	259
0.950	6.129	265
1.000	6.452	270
1.100	7.097	280
1.200	7.742	290
1.300	8.387	300
1.400	9.032	310
1.500	9.677	320
1.600	10.323	330
1.700	10.968	340
1.800	11.613	350
1.900	12.258	360
2.000	12.903	370

CARTRIDGE HEATERS

These are most commonly found in applications where a larger mass of metal needs to be heated. With power densities up to 250 W/sq in and maximum operating temperatures of around 750 °C, they are very much industrial products. Consisting of a wound element formed onto a ceramic core which is then encapsulated in a close tolerance, finely ground metal body, cartridge heaters are typically used in plastics processing lines, packaging machinery and in laboratory sample analysers. Tubular and sheathed heaters are variations of cartridge heaters and are constructed by sealing a nickel chrome alloy wire element, insulated by magnesium oxide granules, into a metal sleeve. These can be formed into more complex shapes and the heater

surface area can be increased with the addition of fins. Typical applications are air, oil or gas heating.
The watt densities are based on a unit installed in mild steel. Different materials affect the values, i.e. the lower the thermal conductivity of the material, the lower the maximum allowable watts per square inch.

Formula For Determination of Allowable Element Wattage

Element Wattage:3.142 x Diameter x Heated Length x Maximum watts/square inch

Formula for Determination of Watts/sq.in

$$\text{Watts/sq.in} = \frac{\text{Unit Wattage}}{3.142 \times \text{Diameter} \times \text{Heated Length}}$$

Heated Length is ½" less than sheath length

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Tolerances

Wattage tolerances is +5% -10% at rated voltage. Length tolerances are ±2% with a ± 1/16" minimum. Length tolerances apply to element sheath length.

Camber tolerances for units up to 12" long is .005" per six inch length. For units over 12" long, tolerance is .020" per foot of length. This value varies as the square of the length in feet (ie – A 36" unit has a camber tolerance of .020" x $(3)^2$ = .180"). Normally camber does not present a problem since the unit will flex enough to fit into a straight, close fit hole.

STRIP HEATERS

Strip Heaters without fins are designed for contact heating. They are used in a variety applications including mounting to the outside of tanks and container surfaces for heating of liquids and solids. They are also used for direct heating of platens, dies, and other flat metal shapes and solids.

It is extremely important that the heaters are mounted on a flat, smooth, and clean surface with good contact maintained between the heater and mounting surface. Air gaps between the mating surface will result in reduced heat transfer and possibly shorter heater life due to resulting higher heater operating temperatures.

When surface mounting strip heaters, allowance must be made for linear thermal expansion of the heater. A common method of allowing linear thermal expansion is to firmly tighten the mounting bolt on one end and allow the heater to expand within the confines of the mounting bolt on the other end of the strip heater.

In order to select an appropriate heater size, use this formula as a guide:

$$\text{Watts/cm}^2 = \frac{\text{Total Unit Wattage}}{\text{Length (cm)} \times 7.62}$$

Watts Density Guide:

Application	Max. Watt/cm²
Water heating	6.2
Low Viscosity	2.5
Liquid Heating	2.5
Light of Oil Heating	1.5 – 1.95
Heavy Oil Heating	1.0 – 1.55
Semi Solid Heating	0.75 – 1.0

FINNED STRIP HEATER

Similar in construction to the Strip Heaters these heaters include fins that make them suitable for air heating applications. Depending on the watt density these heaters can be used in still air or forced air applications.

As a general rule of thumb, Finned Strip Heaters with watt densities exceeding 20 watts/sq in. must be operated in a forced air system. Watt densities below 20 watts/sq. in. may be operated in still air in most application.

Surface temperature on the heater in combination with watt density, air flows, and system design must not exceed 1200° F.

For reasons of safety we advise that the heater sheath should be bonded to an electrical earth. The wire is insulated from the sheath with magnesium oxide powder. However, if the element fails or is overheated the element could short to earth.

In order to select an appropriate heater size, use the following formula as a guide:

$$\text{Watts/cm}^2 = \frac{\text{Total Unit Wattage}}{\text{Finned Length (cm)} \times 7.62}$$

Watt Density Guide

Type of Air	Air Speed	°C	Max Watts/cm²
Still	None	0 – 150	3.1
Still	None	150 – 315	2.5
Still	None	315 – 425	1.6
Moving	600ft/min	0 – 95	6.2
Moving	600ft/min	92 – 205	4.7
Moving	600ft/min	205 – 315	3.1
Moving	1200ft/min	0 – 95	8.2
Moving	1200ft/min	5 – 205	5.4
Moving	1200ft/min	205 – 315	3.9

HAWCO

AIR PROCESS HEATERS

Process Air Heaters are ideal for use in a variety of industrial processes including sealing, melting, bonding, drying, curing and soldering. Hot air is ideal for heating complex shapes, or when space is limited.

Process Air Heaters should be controlled with Hawco phase angle power controllers and Hawco temperature controllers.

Air Flow Conversions

SCFM = SCFH / 60 = SLPM / 28.3
SLPM = SCFH / 2.12
SCMH = SCFH / 35.3
SCFM = (Pounds of Air Per Minute) / (.080 lbs/ft3)

SCFM = Standard Cubic Feet per Minute
SCFH = Standard Cubic Feet per Hour
SLPM = Standard Liters per Minute
SCMH = Standard Cubic Meters per Hour

Technical Hint

In order to make an estimation of size of air heater required, the following guides should be considered.

Determine the volume of air or gas (Ltr/min) you will be heating

Determine temperature rise in degrees Celcisus (ΔT°C)

Calculate wattage required as follows:

$$\text{Power (Watts)} = \frac{\text{Flow Rate (litre/min)} \times \text{Temp Increase (°C)}}{47.2}$$

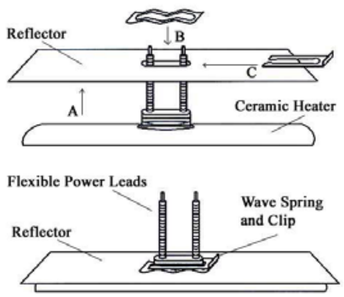
Where 28.3 Ltr/min = 1 CFM (Standard cubic foot/min)
And 1°C change = 1.8°F change

NB Take into consideration the physical size requirements of your application and determine from the specifications the air heater best suited for your application.

CERAMIC & QUARTZ INFRA RED HEATERS

Ceramic Infra Red Heaters

Ceramic Elements are the heaters of choice in most applications where radiant efficiency at competitive cost is required. The diagram below shows the installation arrangement for a Ceramic Heater. The element is pushed through the aluminised steel reflector as indicated by the arrow. The stainless steel spring is then placed down over the power leads onto the element mounting "boss". The stainless steel clip is then slid into position as shown to retain the element in place.



This system of retention allows the element to expand and contract within the reflector as it heats up and cools down. The stainless steel spring and clip are provided with each Ceramic heater. (Oval punching reflector slot dimensions 41mm x 15mm)

Recommended Radiation Distance

The recommended radiation distance of 150mm to 200mm for Industrial applications should be assumed.

Ceramic Heating Technology

Long wave radiation for curing heating and drying is an environmentally friendly, portable and cost effective method of heating. They have a cast-in iron-chrome aluminium resistance wire which operate in the temperature range of 300°C to 730°C (572°F - 1346°F).

The glazed ceramic surface protects the heating coil from the risk of corrosion or chemical attack. Ceramic elements operate in the temperature of 300°C to 730°C (572°F - 1346°F) producing an IR wavelength on the 2 – 10 micron range. Most plastics and many other materials absorb IR best in this range.

A range of aluminised steel reflectors are also available to ensure that most of the radiation generated is reflected forward on to the target area.

Watts W	Type	Mean Surface Temp °C	Wave Length Microns	KW Load Per m²	Watts/m²
150	F.T.E.	315	6.0	6	6.5
250	F.T.E.	418	4.9	10	11
300	F.T.E.	452	4.6	12	13
350	F.T.E.	480	4.5	14	15
400	F.T.E.	515	4.2	16	17
500	F.T.E.	560	4.0	20	22
600	F.T.E.	590	3.6	24	25
650	F.T.E.	630	3.55	26	28
750	F.T.E.	670	3.5	30	33
800	F.T.E.	685	3.4	32	38
1000	F.T.E.	700	3.0	40	44
125	H.T.E.	418	4.9	10	11
150	H.T.E.	452	4.6	12	13
200	H.T.E.	515	4.2	16	17
250	H.T.E.	560	4.0	20	22
325	H.T.E.	630	3.55	26	28
400	H.T.E.	685	3.4	32	38
500	H.T.E.	750	3.1	40	44

QUARTZ INFRA RED HEATERS

Quartz Heaters provide infrared radiation in the medium wavelength range of 1.5 to 5.6 microns. They are favoured in industrial applications where rapid heater response is necessary. They are most cost effective in systems with long heater off cycles as they reach maximum operating temperature in 3-5 minutes. Being similar in size to Ceramic Emitters, they can easily be used in systems where zone control of the heater area is a requirement. They have a recommended radiation distance of 100-200mm.

Manufacturing Process

Quartz Infrared Heaters consist of a wound resistance coil that is run through a series of parallel Quartz tubes, all of which is encased in a highly reflective aluminised steel body. The reflective body ensures a low loss of radiation from the back of the heater.All Elements are subjected to a high voltage(1500V) insulation test as standard

Overview

Quartz Heaters come in different ranges of wattage and voltage, with 230V being the standard. Variations on wattage and voltage are available on request.
There are three standard sizes available:

- Full Quartz Element (FQE) 247 x 62.5 x 22mm
- Half Quartz Element (HQE) 124 x 62.5 x 22mm
- Quarter Quartz Element (QQE) 62.5 x 62.5 x 22mm

Element dimensions and design can be adjusted to suit customers heating requirements.

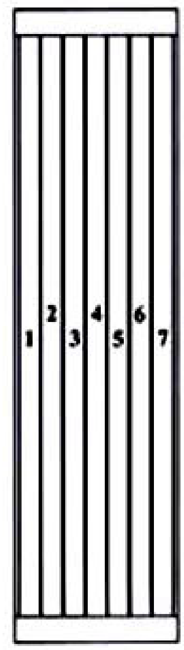
WIRING ARRANGEMENTS

Standard Wiring

Up to and including 500W FQE and 250W HQE: tubes 1,3,5 and 7 wired.
Over 500W FQE and HQE: Tubes 1, 2, 3, 5, 6, 7 wired.
(see right)

High density Wiring

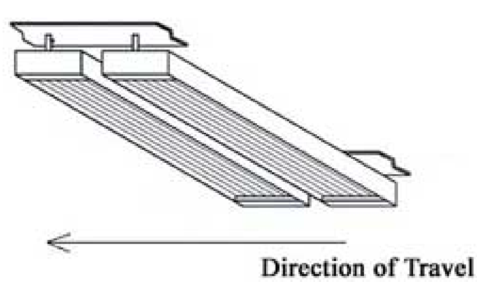
(fast response short wavelength)
up to and including 500W FQE and 250W HQE: Tubes 2, and 6 wired.
Over 500W FQE and 250W HQE: 1, 3, 5, and 7 wired.
(see right)



NB. Alternative wiring configurations and wattages greater than 1000W are available upon request.

Mounting

The Quartz Heaters are mounted using two M5 x 30mm screws that extend from the rear of the heater. Two holes also have to be punched to accommodate the power leads from the rear of the element. The heaters can be installed in reflectors, projectors or panels for improved efficiency. In moving heater arrangements the elements should be fitted with the tubes at right angles to the direction of travel.



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THERMOELECTRIC COOLERS & HEATERS (PELTIERS)

Thermoelectric coolers (TEC) are solid state heat pumps that utilise the peltier effect for reversible heating or cooling. The TEC's control temperature by pumping heat from one surface of the component to the other depending on the polarity of the electrical supply.

TEC devices need careful selection to meet design requirements and to be reliable. Both faces must be attached to a heat-sinking device, which must efficiently transfer the heat from the surfaces of the TEC without the temperature between the surfaces exceeding its Delta T rating. Further extremes of temperature can be achieved by "piggybacking" units thus keeping inside the Delta T rating. Power regulation is equally important.

Thermoelectric Wattage Calculation Guide

$$\text{Wattage} = \frac{2 \times \text{material weight (Kg)} \times \text{Specific Heat} \times \text{Temp Change (°C)}}{3.142 \times \text{Heat-up Time (hours of fraction thereof)}}$$

NOTE Item to be temperature controlled is the material weight. Heat and efficiency losses have been assumed at 100%.

Heat Sink Selection

The heatsink's purpose is to keep the non-temperature critical surface as close to ambient temperature as possible. The more efficiently this is done the greater thermal range of the controlled side.

The maximum temperature difference between the two surfaces is the Delta T (°C) rating.

To calculate the minimum size of the heatsink needed on the non-temperature controlled hot side, use the following formulae.

If possible use the most efficient heatsink possible. This will reduce stress on the TEC and extend life.

Step 1

Calculate the max temperature of the heatsink on the non-critical side.
Target Temperature on cooled controlled side + Delta T = Max temp heatsink
Example: -20°C target temp + 67°C Delta T = 47°C Max Temp

Step 2

Calculate the heatsink capacity required in °C/Watt (Heatsink temperature rise per watt)

A) Max temp heatsink – Ambient Temperature = Max temp rise of heatsink
Example: 47°C - +20°C = 27°C Max temp rise
When 20°C is the ambient temperature

B) $\frac{\text{TEC Wattage}}{\text{Max Temp Rise °C}}$ x 0.75 = °C Pet Watt heatsink

Example $\frac{\text{76.8 Watts}}{\text{27°C}}$ x 0.75 +2.13 Watt/°C Heatsink Rating

Note: Fan cooling will increase heatsink efficiency

FOR FANS

The rate of airflow required for a given temperature increase can be calculated by:-

V = (3.0 x W) dt
Where
V = Airflow in M^3/HR
W = Power loss in watts
dt = Allowed increase in ambient temperature

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