Calculation of Power Required

Heating equipment using Elmatic Heating Elements will utilise one or more of the following methods for transferring heat to the work piece.

1. Radiation
2. Direct Immersion
3. Natural or forced convection
4. Conduction

Normally, it will be obvious from the application which method is to be used. For example, radiation is normally used for paint stoving, for solids, either convection (ovens) or conduction; for liquids direct immersion; and for gases forced convection.

In the case of radiation, power requirements are not normally amenable to calculation; usually we will advise on this by reference to our experience and data on previous applications. If necessary small scale laboratory tests can be arranged to establish the appropriate loading (usually determined as power density in kW/metre²)

In the case of the other methods of heat transfer, standard calculations can be made to determine the required total power which depends upon the following factors:-

A = Power absorbed by work-piece or material in raising its temperature the required amount in the given time. B = Power absorbed by container or enclosure for its appropriate temperature rise in the given time.

C = Power losses from the equipment (surface losses).

In practice, two calculations of power requirements need to be made.

(a) Heating up kW (A + B + $\frac{C}{2}$)

(b) Operating kW (A+C)

These two power requirements may be widely different and obviously it will be necessary to install whichever is the larger, if all the given operating conditions are to be met.

To calculate 'A' – power absorbed by material.

1) Power absorbed by material heating up

$$\text{kW} = \frac{\dfrac{kg\ of\ material}{heated\ per\ hour} \times Sp\ heat\ kj\ Kg\ K \times \dfrac{Temperature}{rise°C}}{3600}$$

2. If a phase-change occurs during the heating period i.e. solid to liquid or liquid to gas, additional power will be required. This is calculated as follows:

$$\text{kW} = \frac{\dfrac{kg\ of\ material}{Heated\ per\ hour} \times Latent\ heat\ kj\ kg\ K}{3600}$$

To calculate 'B' – power absorbed by container.

$$\text{kW} = \frac{\dfrac{kg\ of\ container}{heated\ per\ hour} \times Sp\ heat\ Kj\ kg\ K \times \dfrac{Temperature}{rise°C}}{3600}$$

To calculate 'C' – power losses.

Generally the main power loss is from the outside of the oven or container. Losses to moving material, like ventilating air or conveyor chains can be calculated in the same manner as 'A' above.

Heat Loss (kW) =

Outer surface area of container metre² x

Loss factor from graph 3 at final temp. kW/metre²

For the heating-up period the overage surface losses can be taken as approx. half the steady losses at final operating temp. hence C/2 is used in the heating up calculation.

Where the temperature of the inside of an oven is known more accurately than the outside the calculations can be made from graph 4.

Having found which of the two basic power requirements is the largest, a contingency factor should then be applied. It is advisable to allow extra installed power to cater for unforeseen losses (draughts, opening oven doors etc.) and possible future increased requirements in output. With a temperature controlled system, the running costs will be unaffected, and reserve power will always be available if required.

Installed power =

Calculated power x 110% for direct Immersion

OR

Calculated power x 130% for ovens

Any heating plant should incorporate a carefully designed thermal insulation to achieve maximum energy saving.

Properties of Solids

Table 2

Material	Specific Heat At kJ/kg K	Melting Point °C	Density at 20°C g/cm^3	Latent Heat kJ/kg K	Linear Expansion 0-100°C 10^{8}/°C
Aluminium	0.900	660	2.70		23.5
Brass	0.376	905	8.47		18.9
Copper	0.385	1083	8.96		17.0
Incoloy 800	0.502		7.95		14.2
Incoloy 825	0.502	1370-1400	8.14		14.0
Iron (cast)	0.502	1355-1385	6.95-7.35		10.2
Lead (solid)	0.159	327	11.35	23.2	35.3
Lead (molten)	0.138				
Monel	0.544	1298	8.8		14.5
Nickel	0.444	1453	8.9		13.3
Soft Solder 50Pb 50Sn	0.167	182-216	9.3	41.0	29.4
Silver	0.237	962	10.5		19.1
Steel (mild)	0.502	1500	7.77		11.0
Steel (stainless)	0.502	1400	7.94		16.0
Tin Solid	0.213	232	7.28	59.6	23.5
Tin Molten	0.267		6.80		
Titanium	0.523	1660	4.50		21.9
Zinc	0.388	420	7.14	111.0	31.0
Nichrome 80/20	0.523	1400	8.30		15.0
Nylon 6	1.632	Softens at 230	1.13		95
Polythene LD		Melts at 110	0.92		100-200
PTFE	0.962	Melts at 327	2.20		100
uPVC	1.339	Softens at 80	1.4		75-100
Polystyrene (cross linked)	1.297-1.422	Softens at 98	1.05		90
Aluminia	0.878	2040	3.78		8.1
Quartz	0.669-0.753		2.20		0.54
Asphalt	1.004		1.10		
Clay	0.879		1.46		
Coal	1.255		1.35		
Concrete	0.879		2.30		
Cotton	1.297		0.08		
Glass (soda)	0.670		2.50		
Glass (Pyrex)	0.795		2.35		
Ice	2.092	0	0.92		
Paper	0.837		0.90		
Paraffin Wax (soft)	2.888	38-52	0.90		
Paraffin Wax (hard)	2.888	52.56	0.90		
MgO compacted	0.879		3.00		
Sand (dry)	0.795		1.60		
Wood (hard)	1.255		0.70		
Wood (soft)	1.381		0.50		

Example No 3 Heating Solids

An oven is required to heat up steel components. The oven is 600mm high x 900mm wide x 900mm long and is lagged with 50mm of insulation.

On top of the oven is an extraction duct, and air is exhausted from the oven through the duct at the rate of 12m³ per hour.

Inside the oven are steel trays with the total weight if 20kg and contained in these trays are steel components weighing a total 100kg. The trays and components are to be raised from 20°C to 180°C in 45 minutes.

In this case there is only one calculation required, the heating up load.

Data required to calculate this example:

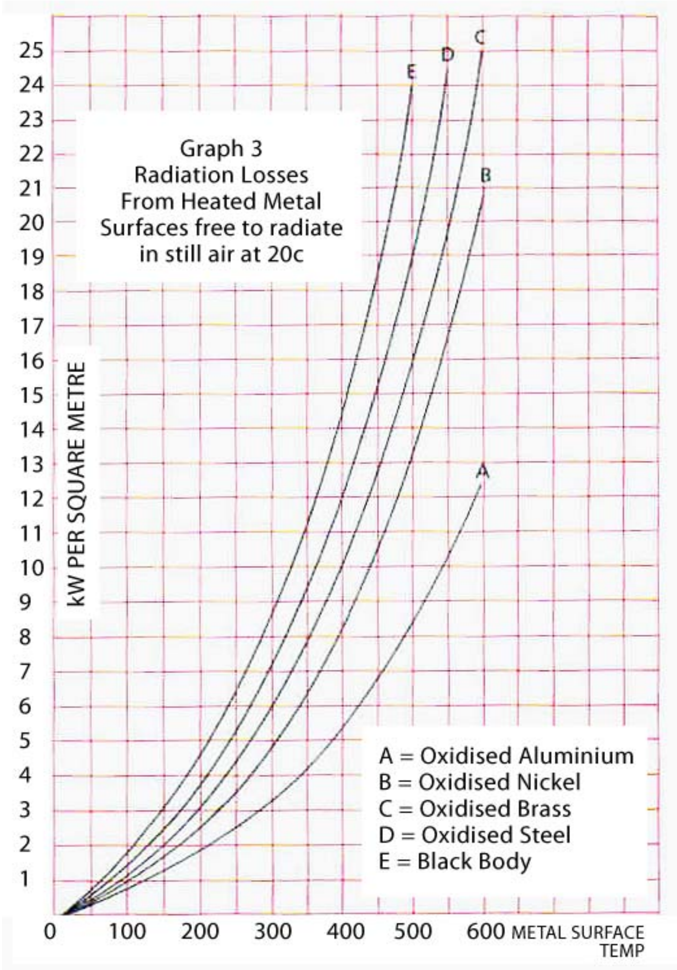
Sp. Heat of Steel = 0.502 (see table 2)
Sp. Heat of Air = 1.004 (see table 1)
Heat loss through 50mm lagging t = 160°C=0.6kW/m³ (see graph 4)
Density of Air at 20°C = 1.17kg/m³ (see table 1)
Density of Air at 180°C (approx.) = 1.17 x 0.62=0.73kg/m³
Therefore average value to use in this example = $\frac{1.17 + 0.73}{2}$
= 0.95kg/m³

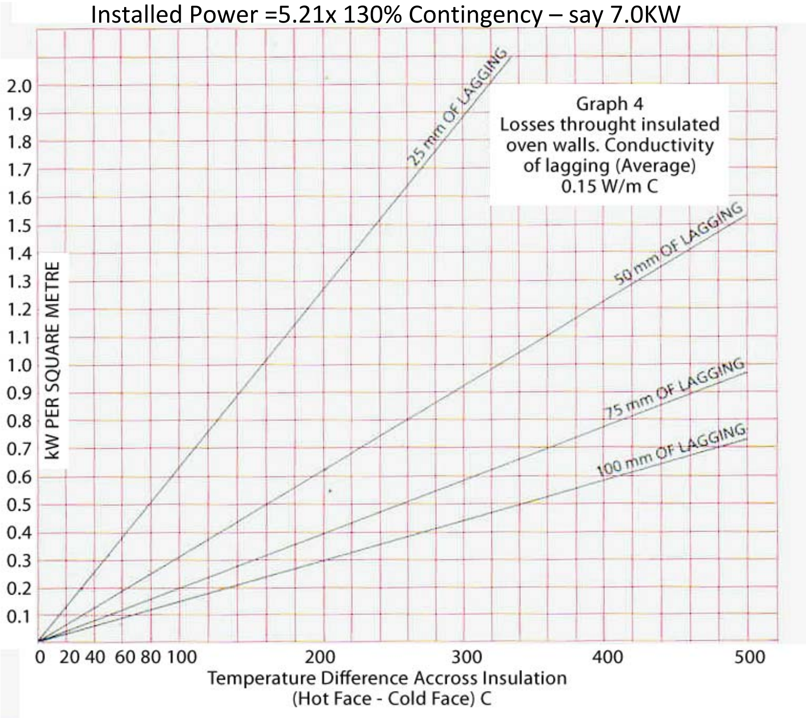
A+B	C_2	C_3
To Heat components and Trays in 45 mins.	To Heat Extracted Air	Average Oven Surface Losses

$$kW = \frac{(100+20)x\,0.503\,x\,160}{3600} \text{ X } \frac{50}{45} + \frac{12\,x\,0.96\,x\,1.004\,x\,160}{3600} + \frac{3.78\,x\,0.6}{2}$$

$=3.57 + 0.51 + 1.13 = (A+B+C_1+C_2)$
=5.21kW

Installed Power =5.21x 130% Contingency – say 7.0KW





Example No 4 Heating Liquids

A closed tank (unlagged) 1 metre Dia. X 1.2 metres long contains 600 litres of water. The tank is made of Steel and has a mass of 40kg. The water is to be heated from 20°C to 85°C in 3 hours, thereafter water is drawn off and replaced at the rate of 350 litres per hour.

To calculate the power required, the following information is required.

Specific Heat of Water = 4.1855 kJ/kg K (see table 3)
Specific Heat of Steel = 0.502 kJ/kg K (see table 2)
Weight of water = 1 kg per litre
Losses from surface of tank = 1kW/m^2 approx. (see graph 3)

Power requirement is calculated using formulae given on page 2.

A	B	C/2
To Heat Water	To Heat Tank	Average Loss from Tank Surface

$$kW = \frac{600 \; x \; 4.1855 \; x \; 65}{3600 \; x \; 3} + \frac{40 \; x \; 0.502 \; x \; 65}{3600 \; x \; 3} + \frac{(n \; x \; 1 \; x \; 1.2) + (2 \; x \; n \; x \; 0.5^2) x \; 1}{2}$$

= 15.1 + 0.12 + 2.67=(A+B+C/2)

= 17.89kW

Operating requirements (Per Hour)

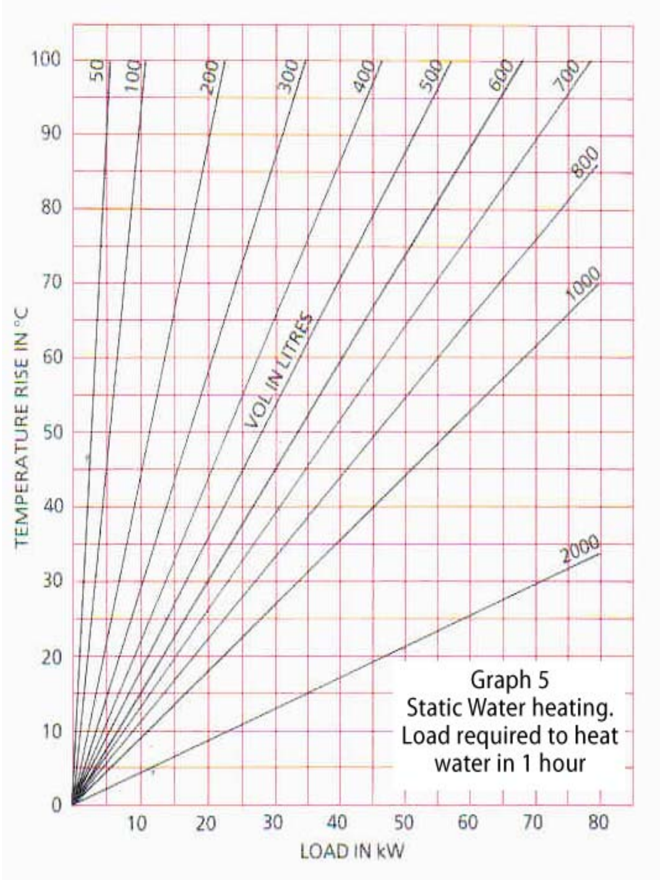
A	C
To Heat Additional Water	Loss from Tank Surface at 85°C

$$kW = \frac{350 \; x \; 4.1855 \; x \; 65}{3600} + \frac{2 \; x \; 2.67}{}$$

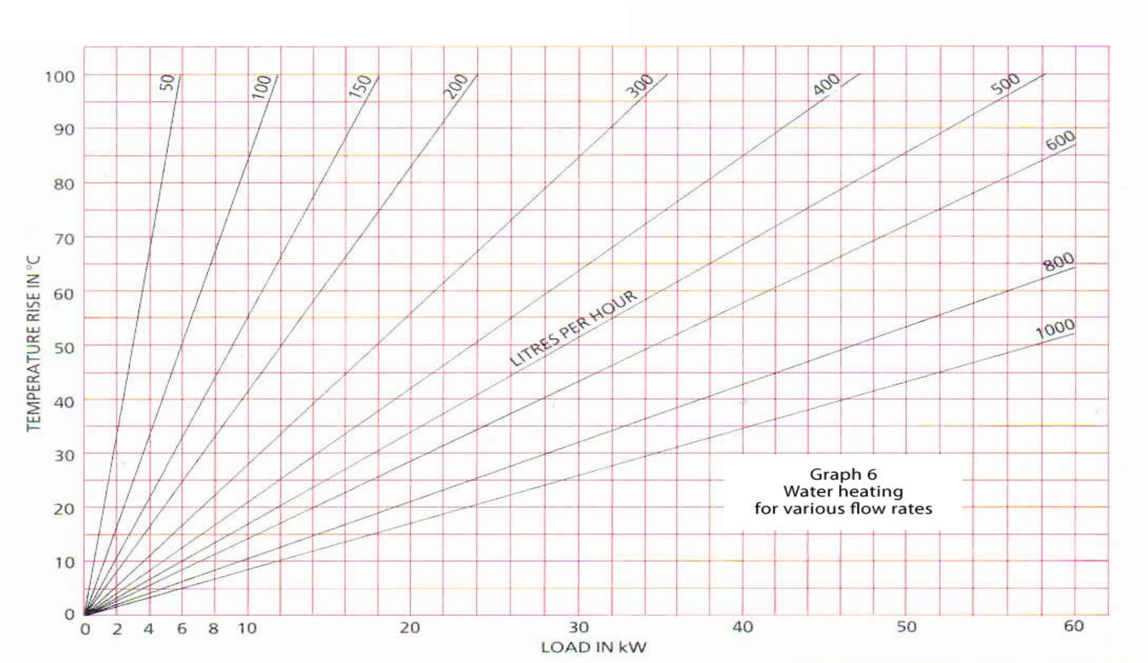
= 26.45 + 5.34=(A+C)

= 31.79kW

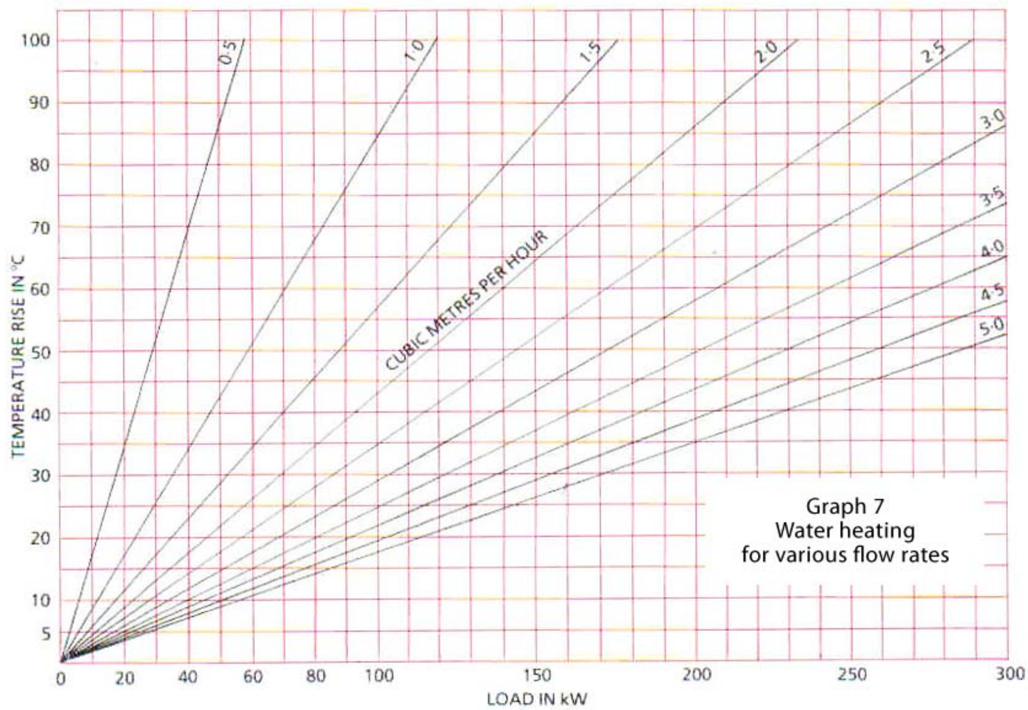
Install 31.79 x 110% contingency = 38kW with suitable thermostat for temperature control.



Graph 5
Static Water heating.
Load required to heat water in 1 hour



Graph 6
Water heating
for various flow rates



Graph 7
Water heating
for various flow rates

Properties of Liquids

Table 3

	Specific Heat	Boiling Point	Density at 20°C	Latent Heat of Evap.	Coefficient and Cubical Expansion
Liquid	**kJ/kg K**	**°C**	**g/cm^3**	**kJ/kg K**	**/°C**
Acetic Acid	2.18	118	1.05	402	0.0011
Acetone	2.15	56	0.79	518	0.0015
Alcohol (ethyl)	2.44	78	0.79	846	0.0011
Benzene	1.73	82	0.87	390	0.0013
Carbon Tetrachloride	0.866	77	1.58	194	0.0013
Castor Oil	0.956		0.96		
Ethylene Glycol	2.36	197	1.10	800	
Glycerine	2.62	290	1.26	974	0.0005
Kerosene/Paraffin	2.09	300	0.82	251	
Linseed Oil	1.84	287	0.930		
Pure Water	4.1855	100	1.00	2257	0.0003
Sea Water	3.76	104	1.03	2257	0.0003
Turpentine	1.78	160	0.87	292	0.0010
Sulphuric Acid	1.38	326	1.85	451	0.0006
Petroleum	1.17	33	0.82	577	0.0007
Hydrochloric Acid	1.381		1.26		0.0005
Machine Oil	1.67		0.92		
Olive Oil	1.46		0.90		0.0007
Nitric Acid		120	1.50		

Many of the above liquids are highly corrosive and require special consideration when designing a heater.