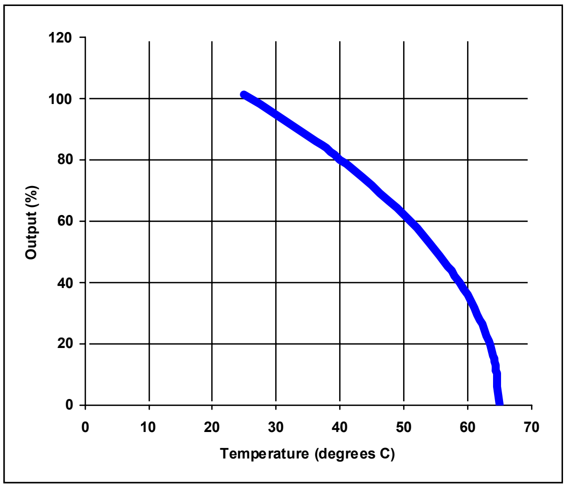
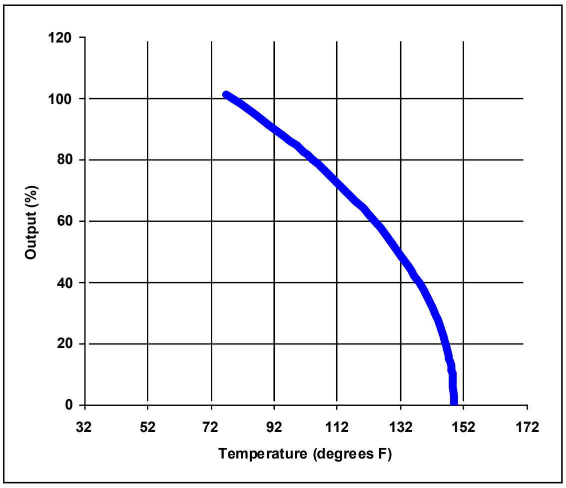
Technical notes on output rating, operating temperature and efficiency

1. Inverters: continuous output rating as function of temperature

In our datasheets inverters, and the inverter function of Multi's and Combi's, are rated at 25°C (75°F). As explained in paragraph 6, derating for higher temperatures is approximately as follows:

Temperature		cont. output
°C	°F	%
25	77	100
30	86	95
35	95	88
40	104	80
50	122	62
60	140	36
65	149	0



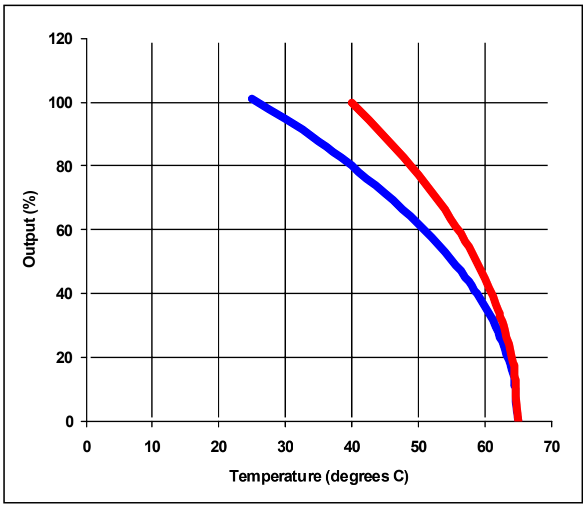


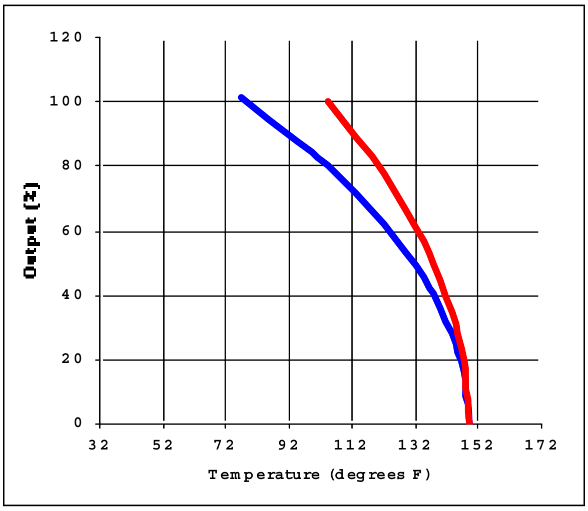
Note: The derating as given above is an approximation of the actual behaviour of our products. The formula used to calculate the derating is an approximation, and thermal behaviour of individual products will also depend on tolerances of components.

2. Battery chargers: continuous output rating as a function of temperature

In our datasheets battery chargers are rated at 40°C (104°F). The battery charger function of our Phoenix Multi and Phoenix Combi is rated at 25°C (77°F). As explained in paragraph 6, derating for higher temperatures is approximately as follows:

Blue curve: products rated at 25°C (77°F)				Red curve: products rated at 40°C (104°F)		
Temperature		Cont. output		Temperature		Cont. output
°C	°F	%		°C	°F	%
25	77	100				
30	86	95				
35	95	88				
40	104	80		40	104	100
50	122	62		50	122	77
60	140	36		60	140	45
65	149	0		65	149	0





Note: The derating as given above is an approximation of the actual behaviour of our products. The formula used to calculate the derating is an approximation, and thermal behaviour of individual products will also depend on tolerances of components.

3. Operating temperature range

The operating temperature range given in our data sheets is 0 to 50°C (32 to 122°F) Within this temperature range all components can operate within manufacturer specified temperature limits. As has been shown above, this does not mean that the full output rating is available over the whole temperature range. Derating is needed at high ambient temperatures to prevent overheating of power semiconductors and transformers.
At temperatures lower or higher than the specified operating temperature range other components (integrated circuits for example) will operate outside their temperature limits, irrespective of the load. However, practice has shown that this is not nessecarily a problem and that our products will in general function at ambient temperatures ranging from – 20 to +60°C (0 to 140°F).

4. The theory behind the graphs of paragraph 1 and 2

Electric current generates heat in the conductor through which it flows. The basic formula to calculate the rate of heat generation, or power dissipation, is:

$P = R \times I^2$ (1)

where P stands for power (measured in Watts), R (Ohm) is the resistance of the conductor and I (Ampere, or Amps) the current.

What is interesting about this formula,is that it shows that power dissipation increases with the square of the current. A resistance of for example 2 Ohm and a current of 10 Amps results in a dissipation of 2 x 10 x 10 = 200 W. Twice that current results in 4 times more heat generated: 2 x 20 x 20 = 800 W!

In power electronic circuits the situation is much more complicated: one has to do with DC losses and switching losses, losses in semiconductors and in high frequency transformers, etc. Very often, however, formula (1) appears to be a fairly good approximation of the overall losses in the circuit. The power dissipation P of the circuit can then be calculated by defining R as the overall resistance between input and output of the circuit and I as the output current.

An even better approximation is obtained if a factor is added to (1) to account for the no-load power consumption or no-load power dissipation. The no-load power consumption is the power dissipated by the circuit when it is switched on without any load connected. It is an important specification especially of inverters since in the long run it can drain a battery.

Taking into account the no-load power consumption results in the following formula:

$P_{loss} = P_o + R \times I^2_{out}$ (2)

P_{loss} is the total power dissipation in the product; P_o is the no-load power dissipation (and therefore also the no-load power consumption); R is the “resistance” between input and output; and Iout the output current.

With formula (2) efficiency, an important specification of inverters, can be calculated:

$\eta = 100 \times P_{out} / (P_{out} + P_{loss})$ (3)

where η is the efficiency in % and P_{out} the output power ($P_{out} = V_{out} \times I_{out}$).

At no-load conditions the output current $I_{out} = 0$ and the output power $P_{out} = 0$, so that:

$P_{loss} = P_o$ (4)

and:

$\eta = 0 / (0 + P_o) = 0$ %   (5)

In other words: the efficiency is 0 at no-load.

If there would be no power dissipation in the circuit ($P_{loss} = 0$), then:

$\eta = 100 \times P_{out} / (P_{out} + 0) = 100$ (6)

In words: if an ideal circuit without any losses could be made, efficiency would be 100 %.

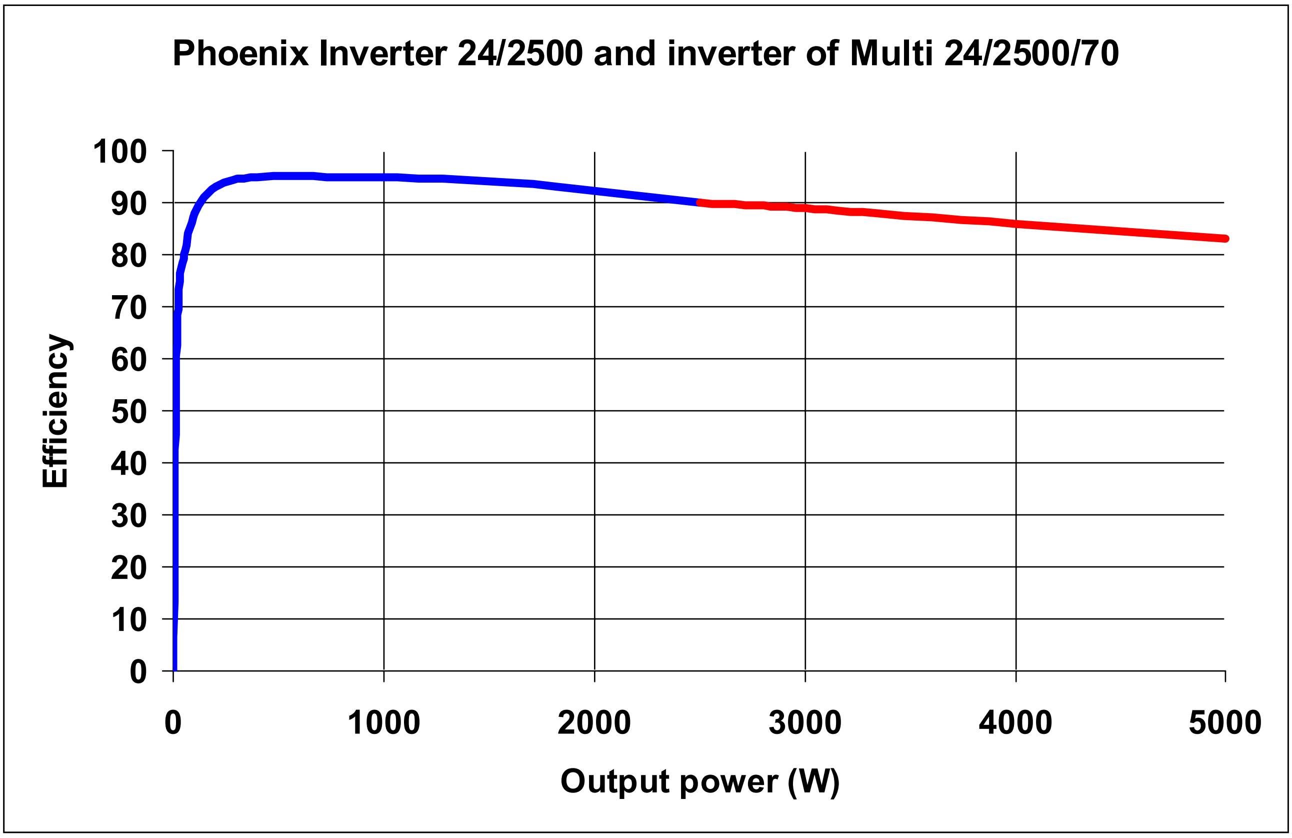
Formula (2) shows that with increasing load the losses at first do not increase very quickly because P_o will still be very much larger than $R \times I^2_{out}$ as long as Iout is small. Efficiency will start at 0 and increase when the load increases.

But with the load increasing further, $R \times I^2_{out}$ will increase even faster and become larger than P_o , so that P_{loss} will start increasing approximately with the square of the load or output current. After reaching a maximum, efficiency will therefore start decreasing as the load increases further.

5. An example of power loss and efficiency as a function of load

As an example let us look at the Phoenix Inverter 24/2500 or Phoenix Multi 24/2500/70 (both products have the same inverter). These products use high frequency switching to generate a sinewave, which is then transformed to the required output voltage by 2 toroidal transformers. Toroidal transformers have a higher efficiency, and less no load losses than the more common E-core transformers. No load losses are reduced further by powering only 1 transformer under no load or partial load conditions. The second transformer kicks in to increase efficiency at high load. This results in the following power loss and efficiency:

Output power (W)	Dissipation (W)	Efficiency (%)
0	6	0
6	6	50
12	6	67
50	10	83
100	13	88
500	25	95
1000	50	95
2000	160	92
3000	360	89
5000	1000	83



6. Output rating and temperature

The preceding explanation and example are also a good point of departure to look at output power as a function of ambient temperature.

All power conversion products of Victron Energy are protected against damage due to overheating by temperature sensors placed on transformers and on the heatsink of the hottest semiconductors.

Inverters: When the power semiconductors and / or transformers reach a preset temperature, inverters will first show a temperature prewarning, and if temperature increases further, the inverter will shut down. After cooling down, it will restart.

Battery chargers: When the power semiconductors and / or transformers reach a preset temperature, the output current will automatically be reduced to prevent a further increase in temperature.

The power semiconductors are the most critical, with a preset maximum heatsink temperature of approximately 75°C (167°F).
Knowing that, in case of forced cooling, the cooling power of a heatsink is proportional to the temperature difference between the heatsink and the cooling air flow, formula (2) can be restated as follows:

$I_{out} = K \times \sqrt{(T_{max} - \Delta T_o - T_{amb})}$ (7)

where I_{out} is the output current; K is a constant; T_{max} is the maximum heatsink temperature; ΔT_o is the temperature rise of the heatsink due to the no-load power dissipation; and Tamb is the temperature of the cooling air flow.

Formula (7) shows that when $\Delta T_o + T_{amb} = T_{max}$, $I_{out} = 0$.
In words: when the ambient temperature is so high that the no load power dissipation alone will cause the heatsink to reach the maximum temperature limit, the output current of the circuit is 0. Any output current would increase the temperature of the heatsink beyond the maximum and result in shut down of the circuit due to overheating.

Formula (7) has been used to calculate the output current- or power derating for paragraph 1, under the assumption that ΔT_o = 10°C (18°F), so that the output has to be derated to 0 at T = 75 – 10 = 65°C (149°F).

The derating formula (7) is applicable when the ambient temperature increases beyond the temperature at which the full output power is specified, in general 25°C (77°F) for inverters and 40°C (104°F) for battery chargers.

Why 25°C (77°F) for inverters? Inverters are very often used with intermittent loads. Short term power and peak power are therefore more important than the continuous rated power. Battery chargers on the contrary will regularly operate at maximum output current for several hours and are therefore rated for continuous operation at 40°C (104°F).