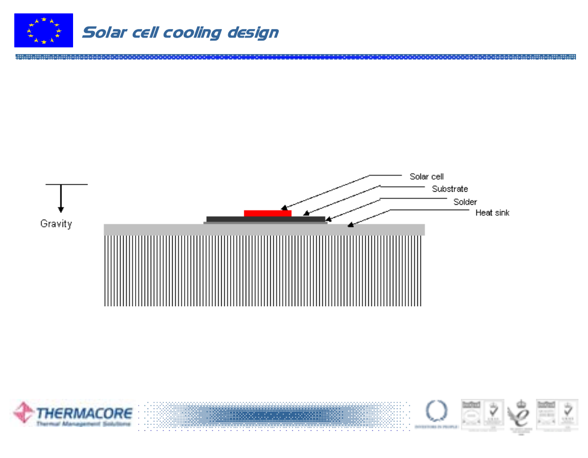
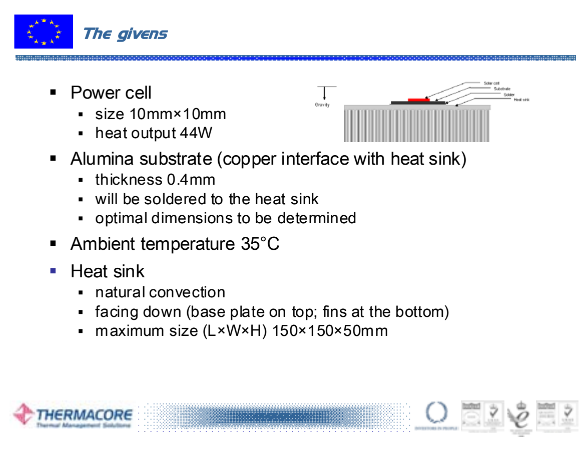
Solar cell cooling design

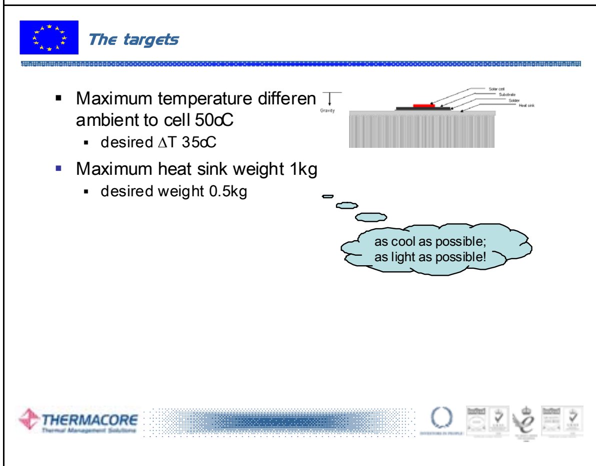


For the next few slides we will be looking at the heat sink for a solar cell, a silicon device with significant heat dissipation, that needs a large heat sink. Whilst this case study happens to use a solar cell, it could equally be a power IC. Our purpose is to show the value of simulation in helping the designer make informed decisions about design issues such as heat sinks.

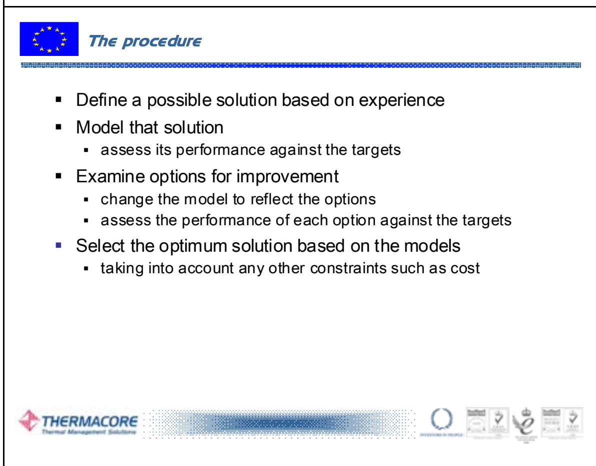
[This case study was developed and narrated by Martin Tarr from material supplied by Thermacore]



Some aspects of this product are already set, such as the characteristics of the power cell, the nature of the substrate beneath it, and the ambient temperature. The heat sink is also a 'given' – in this case only natural convection is available, and the size is constrained by external factors.



Our target is to keep the cell temperature below 85°C and the weight of the assembly below 1000gm. Of course, as is typical, we would like the assembly to be as light as possible and to run as cool as possible!



Simulation will be used to optimise our design, but we have to start somewhere. So we devise a possible solution based on our experience, model that solution and assess how well it meet the targets. Against this benchmark we will then assess various options for improvement before selecting the best of these. Of course, we will also need to take into account general constraints such as cost.

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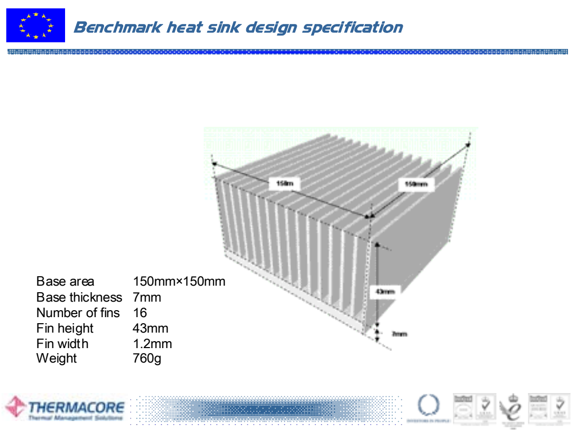
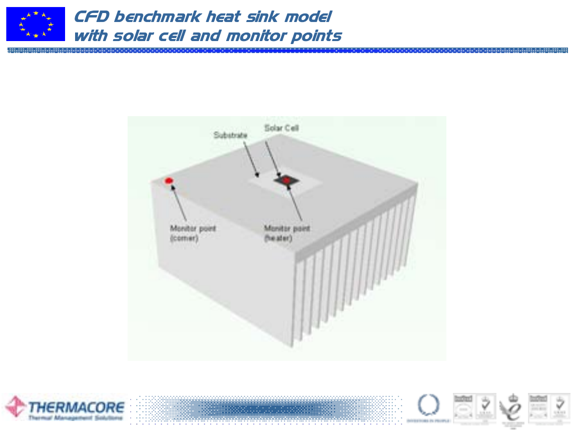
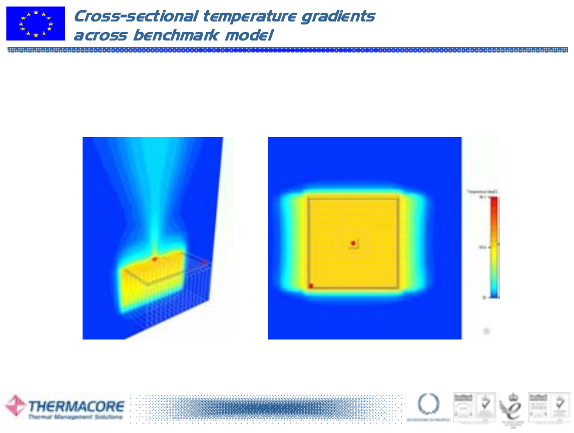


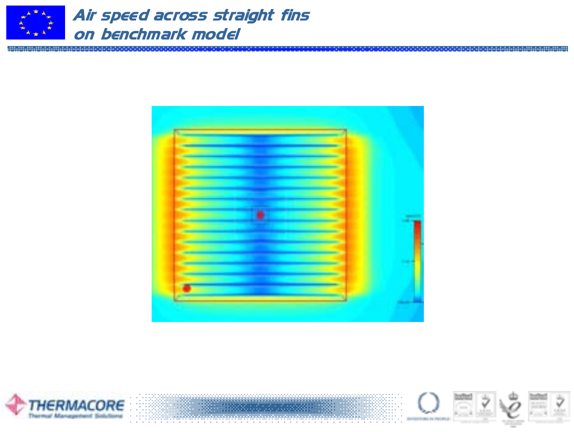
Our benchmark heat sink design is a relatively standard part that uses up all the volume available and fits in as many fins as can be produced by a relatively cheap process.



We build our model within the CFD software, building in monitoring points at key positions – the software graphics will give us a visual illustration of what is happening, whereas the monitor points give us actual values.



On the left we can see a cross-sectional view through device and heat sink, and on the right a plan view from the top. The different colours indicate the temperature rise above ambient. Notice the thermal plume on the left, and on the right that heated air only flows from the open end of the fins.



This ties in with the view that CFD also gives us of the air speed across the fins and the pressure profiles.

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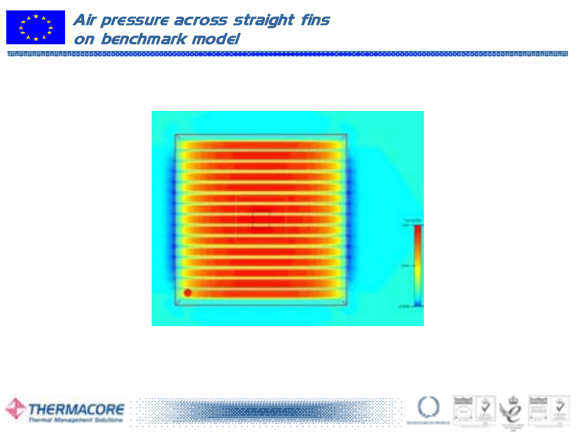
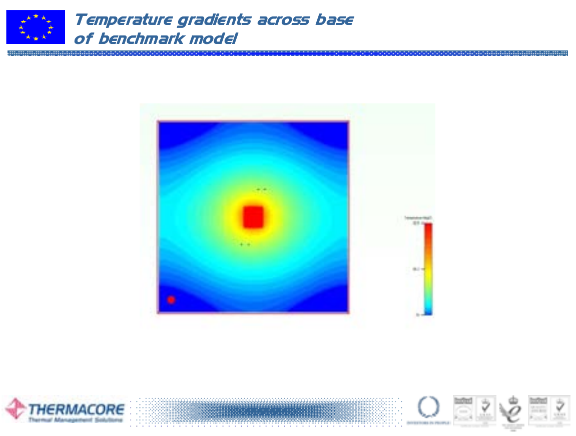
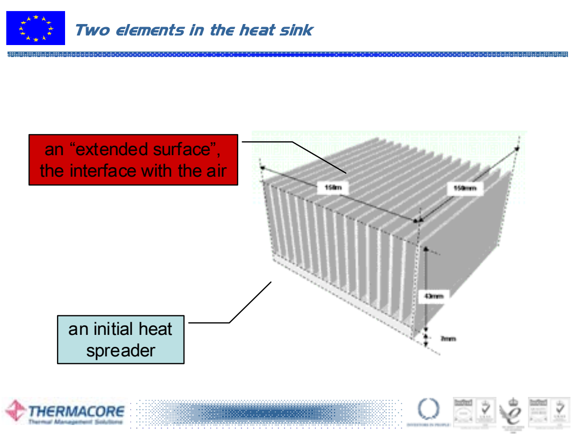


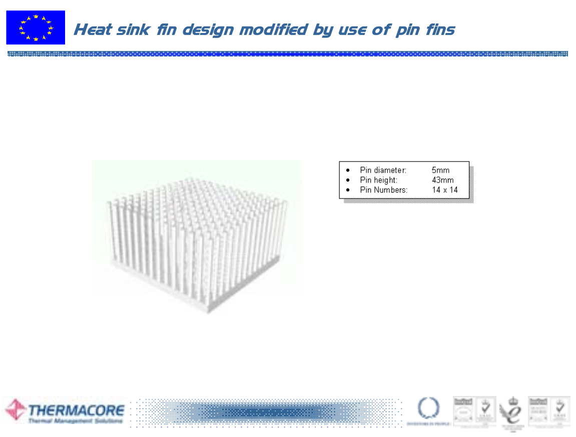
It rapidly becomes clear that the internal section of the fins sees little air movement, a situation that is frequently seen when only natural convection is available.



In this plan view we can see the temperature gradient across the base, with a large temperature difference of 14.5° between hot centre and cold corner. In consequence, the fins at the outer edges run at lower temperature, and are less effective, than those in the centre.



We have now an estimate of the performance of our benchmark product, and can look at ways of enhancing the heat sink performance. There are two elements that we can change, the heat spreader which takes heat from the chip and spreads it between the fins, and the fins themselves, which form an extended surface interfacing with the air. Both of these are going to be considered in turn.



The first two changes relate to the fins, and here we are considering both pin fins and blade fins, knowing from prior experience from unforced convection that these will allow the available air to move more freely and in multiple directions. And a bonus is that they will potentially be lighter.

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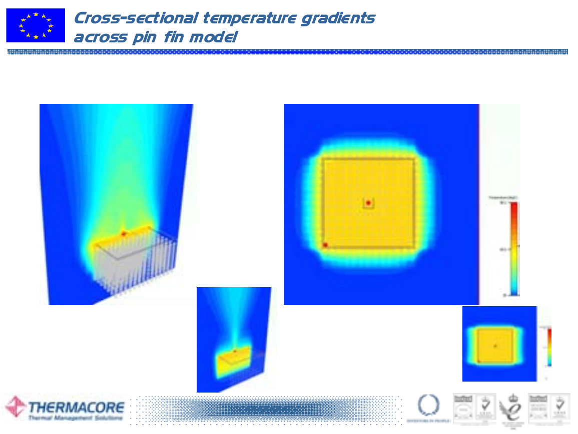
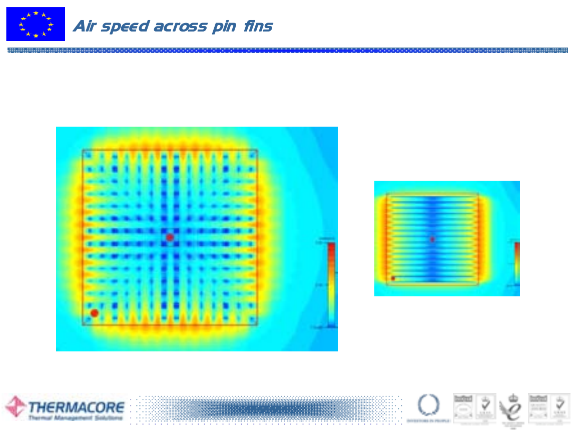
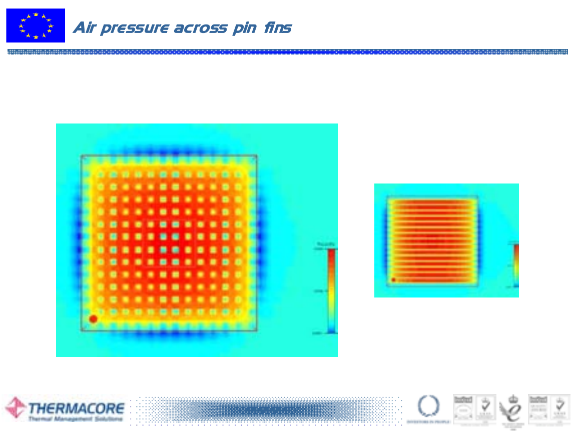
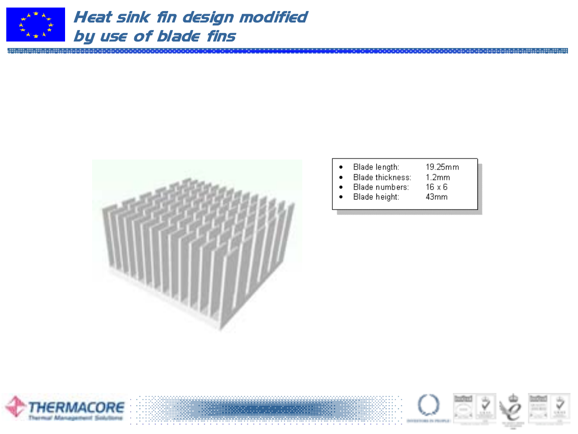
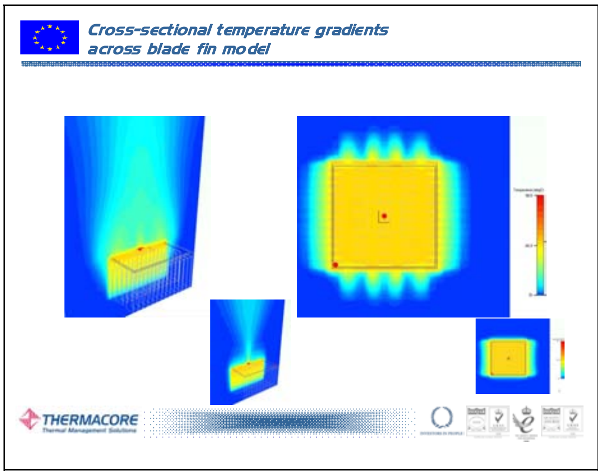
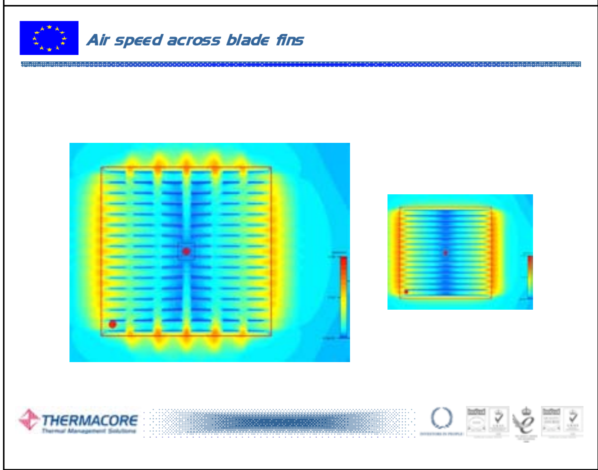
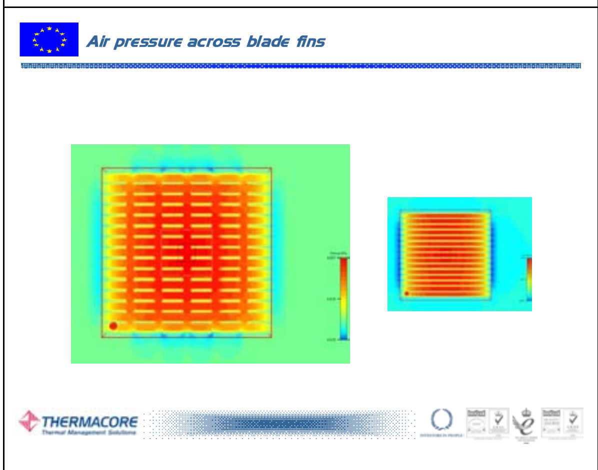
	Looking first at the pin fin, we see the same cross-sectional and plan views as before and the air speeds and pressure profiles to which they correspond. In each case, the pictures of the benchmark device are shown as insets for comparison.
	Unlike the straight fins of the benchmark model, with pin fins the heat can flow is all directions, as can be seen by both air speed . . .
	. . . and pressure profiles.
	Pin fins are sometimes criticised as having a low effective surface area, and an alternative way of breaking up the extended surface and allowing freer movement of air is the blade fin.



Again we show the same sequence of temperature gradients, . . .

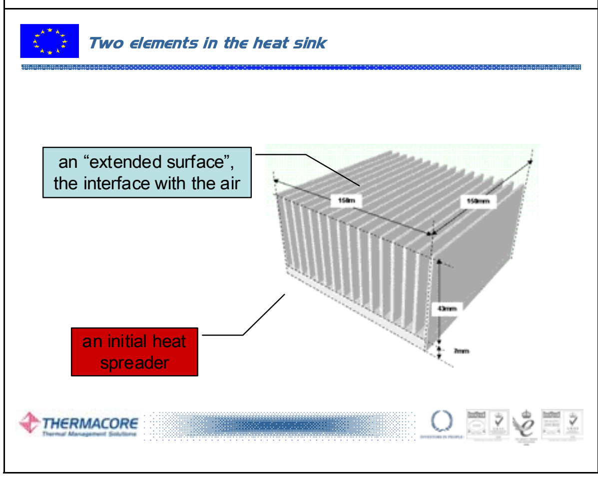


. . . air speed . . .



. . . and air pressure.

Don’t worry about trying to make notes on this – you can use the navigation to look at individual slides, and a comparison table is coming up.



The other two enhancements focus on the heat spreader, to try and make best use of the extended surface.

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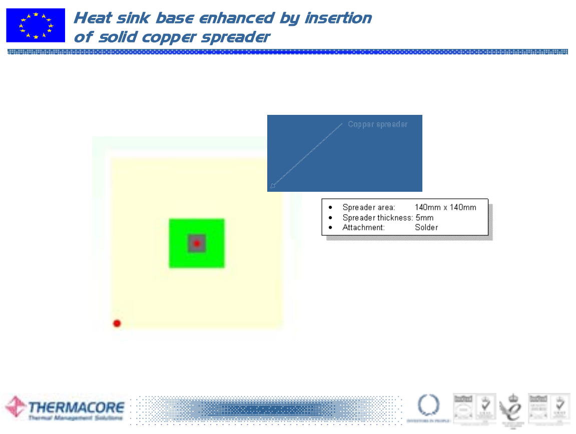
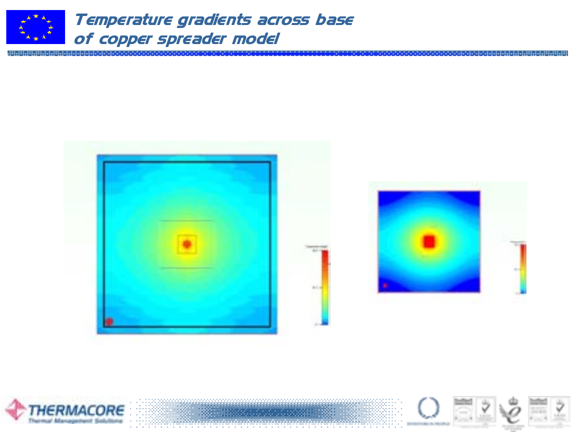
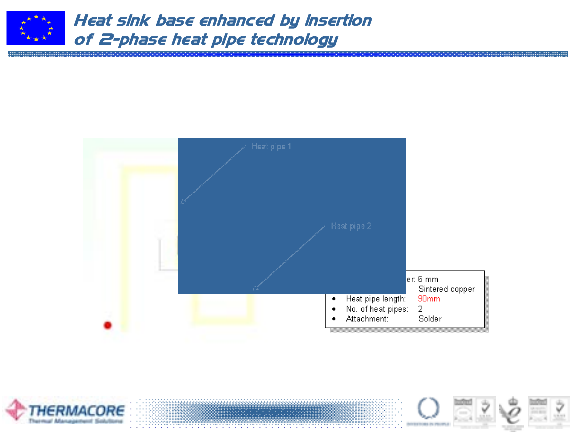
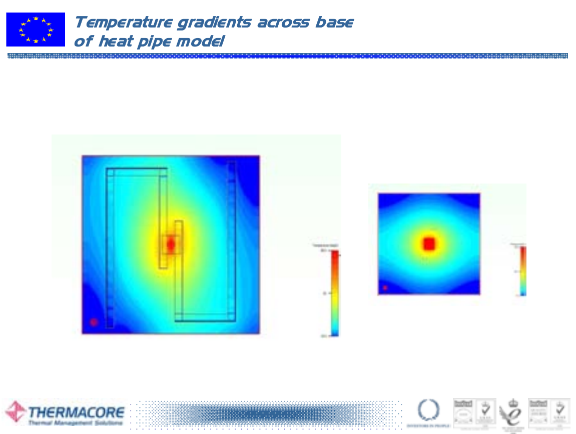
	In the first case, we embedded a solid copper spreader into the aluminium base.
	The resultant temperature gradient shows a marked improvement over the benchmark model of the inset, so we would expect the outer edges to become more effective.
	An alternative enhancement selected because it is likely to be significantly lighter, is to embed a specially-routed two-phase heat pipe in the aluminium base.
	Again, this shows significant improvement in temperature gradient, but also the distortion one might expect, given that the heat pipes lack radial symmetry.

How can we move our benchmark?

fin/base design	solid aluminium	copper spreader	embedded heat pipes
straight	92.5 / 78	85.5 / 77	85.5 / 78.5
blade	90.5 / 75	84.5 / 76	83 / 75.5
pin	91.5 / 76	85 / 76.5	84 / 76

heat sink temperature predictions below heater and in corner (°C)

fin/base design	solid aluminium	copper spreader	embedded heat pipes
straight	760	1367	800
blade	683	1290	722
pin	994	1602	1034

approximate heat sink weight (grams)

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In this table, we show the simulation results for the various design options. It's clear that using a solid aluminium heat sink will not enable us to meet our 85°C target, regardless of the fin type we choose, and we will need to use a copper spreader or heat pipes. In this case, our decision will be based on the weight constraint.

Why use simulation?

- We need its accuracy and discrimination
  - particularly with natural convection, calculation is difficult
- Modelling changes is easy
  - cheaper and quicker than cutting metal!
- Simulation encourages us to try radical change

THERMACORE

You may have noticed that the temperature differences are relatively modest, and the results are all very close to our available maximum temperature. So we need the increased accuracy of simulation as distinct from calculation.

Modelling changes is much easier, cheaper and quicker than cutting metal, and it enables us to look at some alternative solutions. For example, for this application we will probably try improving the airflow, by forced convection, or perhaps by a procedure as simple as tilting the cell.