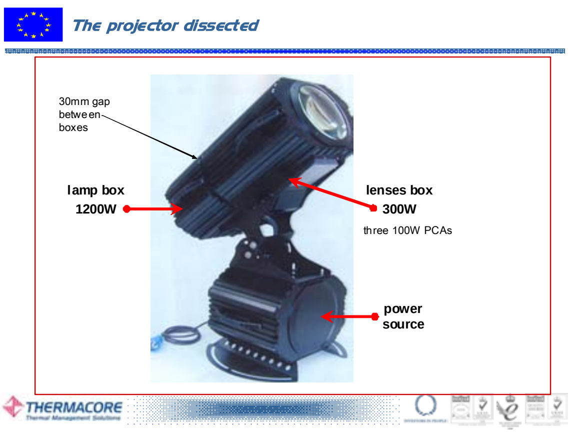
Light and heat combined:
Complexity in a confined space

As you will know if you have ever hugged a laptop, much electronic equipment is getting hotter as it gets smaller! Arguably one of the best examples of this is the ubiquitous LCD projector, where a key heat-generating component is the lamp unit. Lamp and electronics are combined in as small a space as possible, and the flow of both heat and cooling air becomes critical. The task is made more difficult by the fact that there are cosmetic challenges to make the product look attractive.

The problem is similar, but considerably more challenging, when we come to the kind of projector shown here, which is used for external lighting applications, including moving lights on high buildings.

[This case study was developed and narrated by Martin Tarr from material provided by Masoud Ameli of Thermacore. If you want further detail, the attachment is a print of sections of a report concerning this development.]



This projector is made of three components, with a power source at the base and a lamp box containing a 1200W lamp. The lenses box contains conventional electronic assemblies, which need to operate at lower temperatures than the lamp can tolerate, but themselves generate significant heat, and there is only a relatively small gap between the two boxes.

The heart of any projector is the lamp unit. Not only does it generate heat, but it is expensive, and the life of any lamp can be extended by keeping it cool. For this type of lamp, 300°C is the maximum allowable temperature, though the manufacturer recommends a lower figure of 250°C. Fortunately, in this case, half the energy dissipated by the lamp leaves through the front glass as visible light and infra-red radiation: but that still leaves 600W to remove while maintaining the internal temperature below 85°C in an external environment that may reach 40°C.

This application is also more problematic than an LCD projector because it is intended for outdoor use, so the boxes have to be completely sealed, and reasons of safety preclude the use of water cooling.

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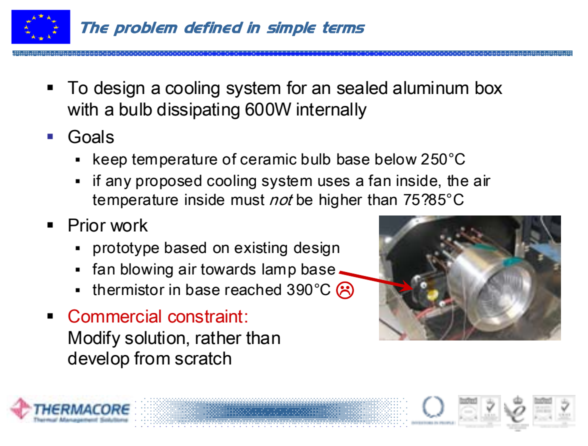
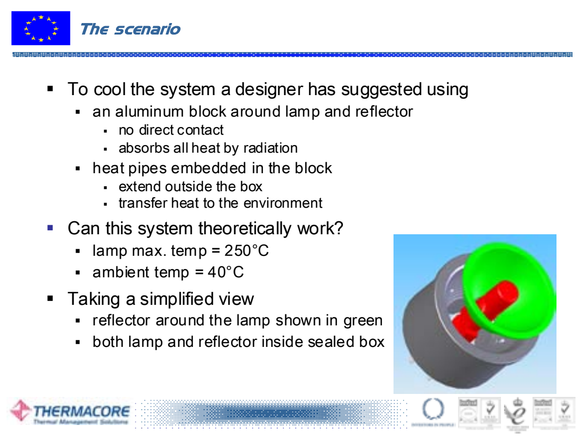


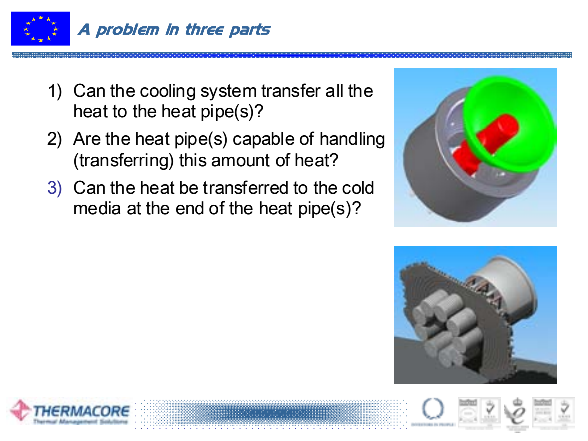
LCD projectors use just a couple of 100W of lamp power – in this application, the requirement was significantly higher, and the goals were both to keep the temperature of the bulb below the limit of 250°C recommended by the manufacturer, and to keep the internal air temperature within bounds.

As so often happens, designs aren't totally new concepts, but evolve from existing products, and a prototype projector had already been built based on an existing design. Despite arranging for the internal fan to blow towards the lamp base, the temperature-sensing thermistor in the base reached 390°C – seriously bad news. And the solution for that thermal challenge had to meet the commercial constraint that it had to be a modification to the existing concept, rather than developed from scratch.

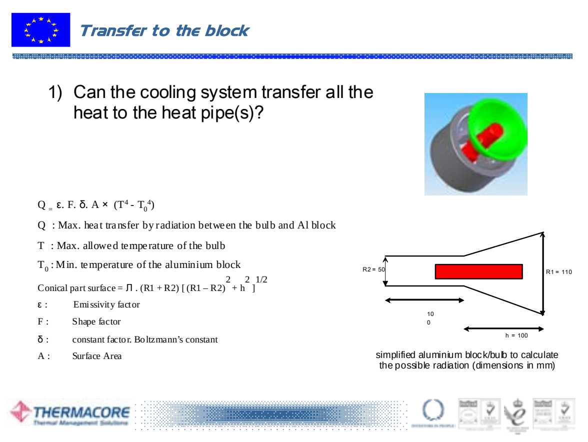


The designer has suggested placing around the lamp an aluminium block that would absorb radiated heat, with heat pipes embedded in the block to transfer heat to the external environment.

The thermal engineer has first to ask whether this cooling strategy could work, at least in theory, keeping the lamp at safe limits in the 40°C worse case ambient. For the preliminary assessment, we've shown a very much simplified lamp and reflector.



This is a problem in three parts, asking first whether the system could transfer heat to a heat pipe or heat pipes, and then whether these are capable of transferring 600W of thermal energy through to the external environment.



The first of these questions can be answered mathematically using some simplifications and standard heat transfer equations.

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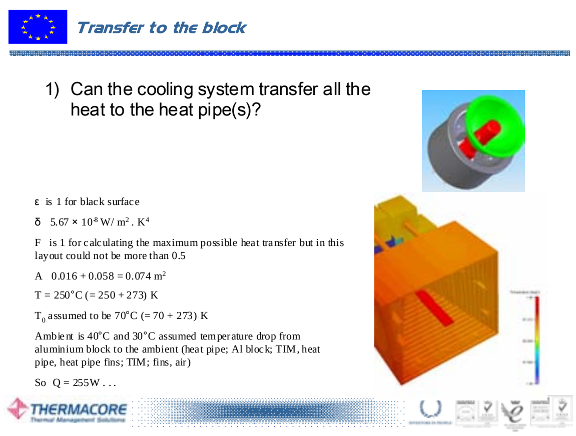
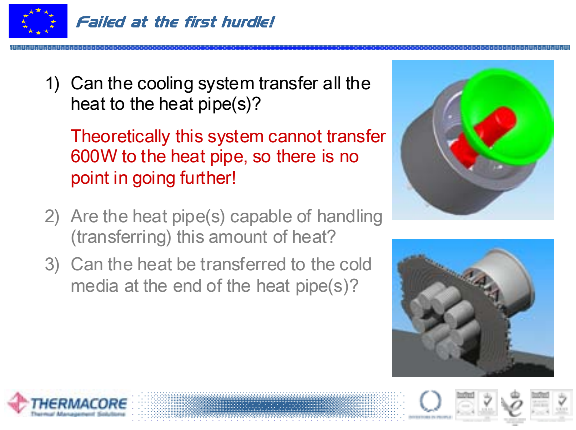
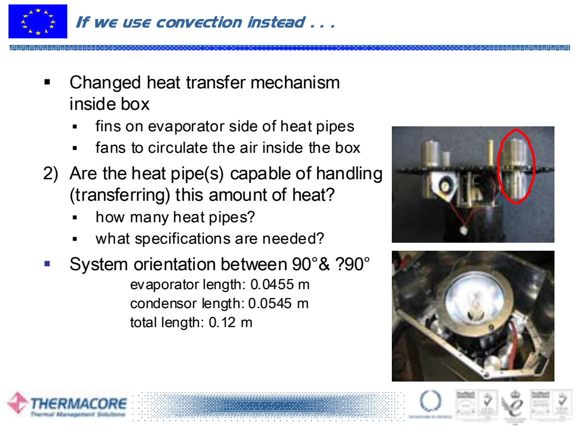


As always, we need to make realistic assumptions, but the calculation is easy enough. Unfortunately, it shows the maximum heat transfer as 255W. . .

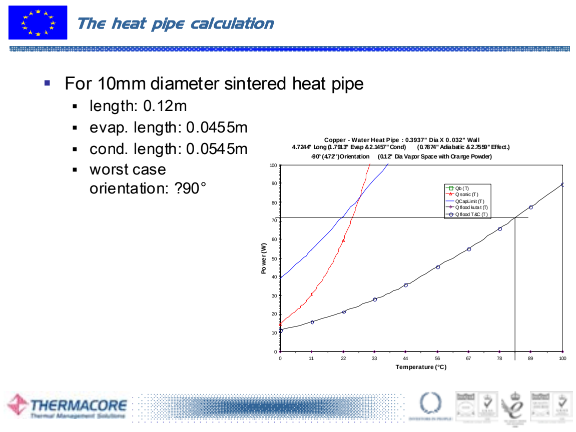


. . . , so a radiation-only system can transfer less than half the heat generated by the lamp.

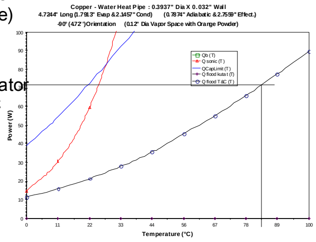
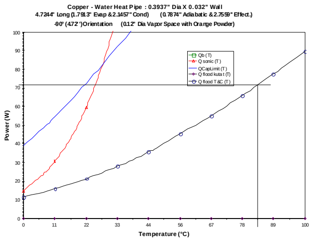
For transferring all this power, we clearly need to transfer some of this heat by convection, using air to take heat from the lamp to the heat pipes.



We are making the assumption that sufficient heat can be transferred, and at this stage we are not going to try and calculate how much air we have to move inside the box, but concentrating on whether the heat pipe or pipes can transfer the heat that the lamp generates. How many heat pipes do we want? and what specification should these have? Bear in mind that physical constraints determine the size of the heat pipe, and the application demands that the heat pipe must operate in different orientations.



The calculation for the heat pipe is based on a transfer characteristic that is easiest to interpret graphically . . .

The heat pipe calculation At this stage, the heat pipe operating temperature (typically temperature of the adiabatic section of the pipe) is not known exactly It could be as low as the minimum allowable evaporator temperature, which is 70°C (30°C ?T from ambient)  THERMACORE	. . . but we need to make assumptions about aspects such as the operating temperature before concluding . . .
The heat pipe calculation Based on the curve at 70°C ▪ power = 58W ▪ 600W/58W = 10.34 At least 11 heat pipes with this specification would be needed  THERMACORE	. . . that this style of heat pipe can transfer just 58W, worst case, so that at least 11 heat pipes of this specification would be needed.

The third question
 	
3) Can the heat be transferred to the cold media at the end of the heat pipe(s)?
▪ In order to dissipate the heat by forced convection what is needed on the condenser part of each heat pipe?
  ▪ minimum surface area
  ▪ fin numbers
  ▪ fin pitch
 	


 	
THERMACORE
	The third question is whether the heat can be transferred from the end of the heat pipes into the surrounding environment. Assuming again that we have forced convection available, what surface area is needed on the fins? so how many do we need? and on what pitch?

The third question ▪ What minimum surface area? $Q = h.A.\Delta T$ $h = 40W/m^2.K$ This is a conservative value, based on experience for this type of layout in forced convection $Q = 600W$ $\Delta T = 50\% \times 30°C = 15°C$ We assumed 30° ΔT from ambient to the evaporator block, and in forced convection we assume 50% of total ΔT to be on the air side ⇨ $A = 1\ m^2$   THERMACORE	Calculation of surface area is a simple equation, but demands an assessment of the most likely value for one of the parameters. Combining assumptions with the equations, we reach a total area required of $1m^2$ to dissipate the 600W from the lamp.

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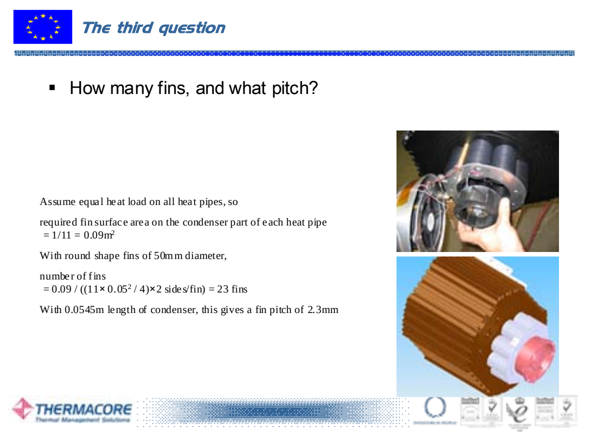
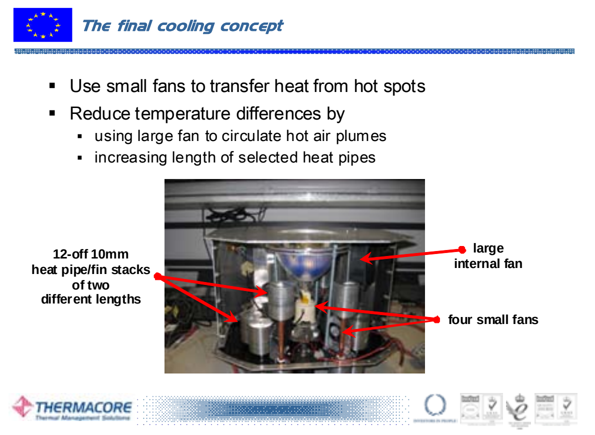
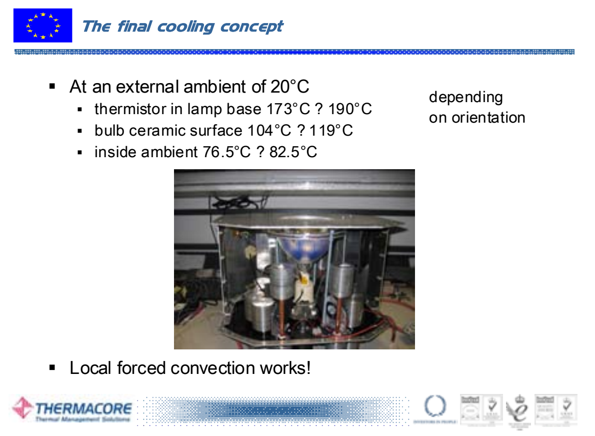


Again making assumptions about the fin size and shape, based on the practicalities of making the heat pipes, we end up with each pipe being coupled to the environment with 23 fins on 2.3mm pitch.

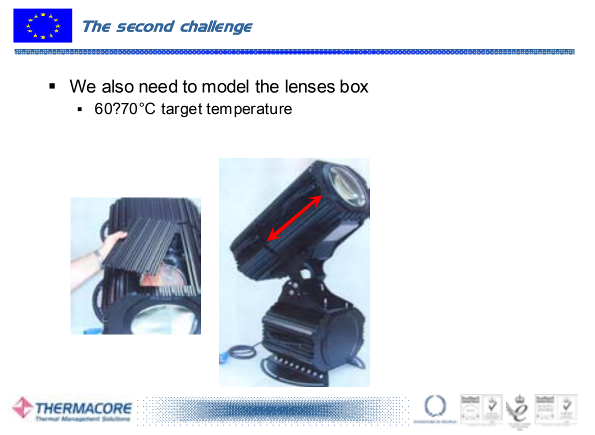


In the previous slides we have deliberately simplified the detailed work that was done. As well as calculation, a significant amount of simulation was carried out, which led to the development of the final cooling concept shown here.

Small fans have been used to transfer heat from hot spots, and temperature differences within the enclosure have been reduced by using a large fan to circulate hot air plumes, and by increasing the length of some of the heat pipes.



The result of this complex arrangement was that, at an external ambient of 20°C, the thermistor in the lamp base reached between 173°C and 190°C, depending on the orientation of the lamp box, with the temperature of the ceramic surface of the bulb kept at between 104°C and 119°C, and the inside ambient temperature between 76.5°C and 82.5°C. All these were within the design target, showing that local forced convection works!



Whilst we have made a considerable improvement by focusing on the main heat-generating element, we need a simulation of the overall product in order to give assurance that the electronics will work reliably, so we need to model the thermal parameters of the lenses box, where the target temperature is 60 to 70°C.

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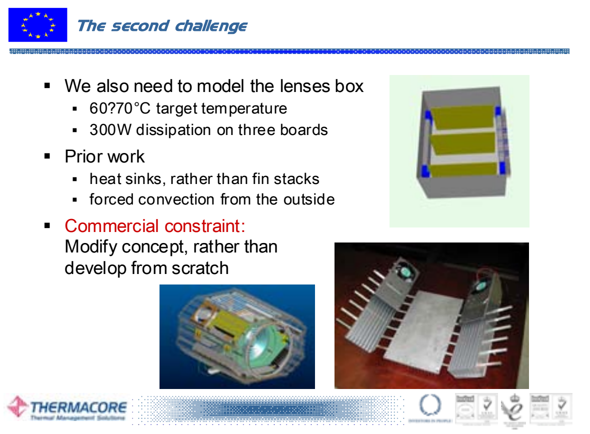
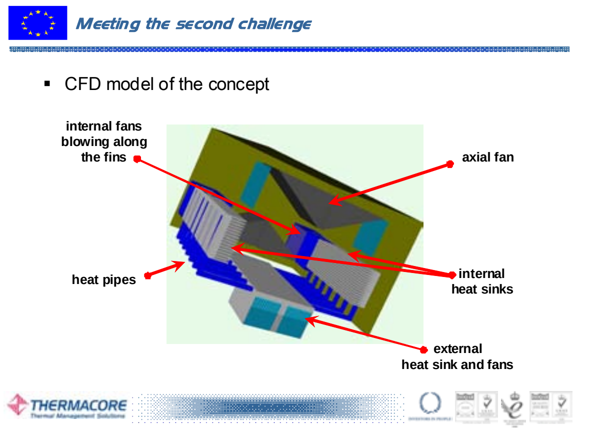
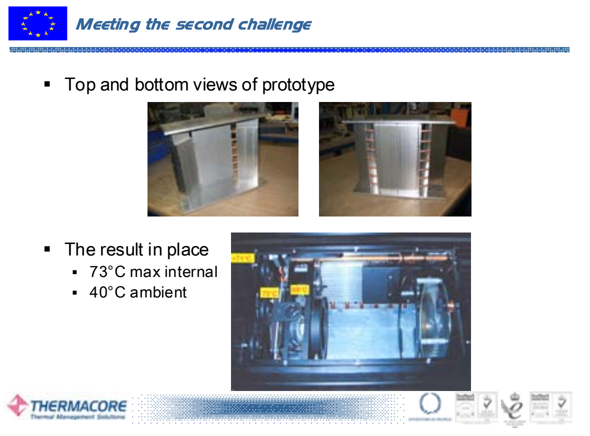


In this case, the design uses three PCB assemblies, each dissipating 100W, and the prototypes have been developed using heat sinks, rather than fin stacks, with forced convection from the outside. And again we have a commercial requirement, which is to modify the concept, rather than develop a cooling solution from scratch.



In this case, the analysis also used simulation, and here we see a CFD model of the concept. General air circulation is produced by an axial fan, but there are also smaller fans blowing along the fins of internal heat sinks, and heat is conducted from those heat sinks by heat pipes connected to an external heat sink fitted with fans.



What the resultant prototype looked like is shown here, both as self-standing heat pipe/heat sink assemblies and fitted within the lenses box. The results are well within specification, with the customer reporting internal board temperatures of between 69 and 73°C at an ambient temperature of 40°C.

So, after a systematic engineering process that has involved calculation, simulation and trials, we have working solutions for both boxes that have been verified by prototype test. These might not be the very best ways of cooling a projector that could have been devised had we been totally free to redesign every aspect of the product, but the result is fit for purpose and well within the specification.

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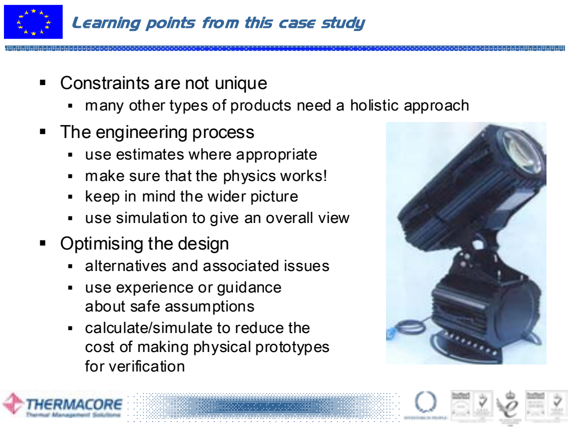

Although the inclusion of a lamp makes this an untypical product, it is not unique. Many other types of products have high heat densities, constricted airflow, and an enclosure dictated by styling considerations, so need a holistic approach, and simulation informed by an understanding of the issues.

For these, a typical design process will also be similar. In general we will use engineering estimates where appropriate, and we will certainly seek to ensure that what we are trying to do is physically possible. But we need to keep in mind the wider picture – in this case the projector lamp plus its electronics assembly – and use simulation to give an overall view that takes into account all the design parameters.

Where we don't have constraints, we also have to consider the best way of cooling the product, and this might require lateral thinking and even innovation. We have to think of alternatives, and the issues associated with each of them. We have to use experience or guidance from others to know what assumptions it is safe to make, and use a mix of calculation and simulation to reduce the cost, both in time and expense, of making physical prototypes for that all-important final step of verification.