# Are More Efficient Heat Sinks

## Really More Costly?

The question arises, why pay more for a higher-efficient heat sink that is also smaller and lighter in weight, especially in cases whereby a simple, larger but heavier cast or extruded heat sink can also do the job? In most cases, the single-piece part price is the main driver as to why engineers and purchasers stay with lesser effective solutions. This is generally because they believe that they are saving money for the company in the long-run. But, is this really true?
It is very easy to compare the price of two single heat sinks, a highly efficient one versus a standard extruded type with the same thermal performance. But, such a simplistic comparison does not take into account the flow performance, effect on neighboring and downstream components, weight, volume usage, etc.

What makes a heat sink an efficient heat sink you may wonder? Such a heat sink is optimized for both flow and heat transfer and, hence, makes much better use of the volume available for cooling and the existing cooling air.
The geometry of the heat sink is optimized by using thin fins and a special design to lower the air resistance, resulting in the highest possible velocity in the fin field, while minimizing the effect of bypass flow. Because of this, it also has a lesser intrusive effect to the flow, which has a positive effect on the neighboring and downstream flows. This produces lower pressure drops over the board and through the system. The result of a comparison test, presented by Lasance C. and Eggink H., demonstrates this [1].

The shape and the amount of fins create the available surface area. The more surface area in contact with cooling air, the more energy can be dumped into the air and, therefore, the lower the heat sink temperature. Most important, the component temperature will also be lower. Of course, this is only valid if the temperature of cooling air going through the fin field is still lower than the fin temperature; otherwise, no net heat transfer from the heat sink to the air will occur. As has been shown in the literature, there exists an optimum correspondence between the number of fins and the overall cooling effect of these fins.

To arrive at a better comparison, let us look to other related effects which will result in a system price increase due to the chosen cooling solution:

1. Effect on the flow
2. Heat sink weight
3. Heat sink attachment
4. Mechanical adjustments required to handle the weight on both a board and system level, and to fulfill mechanical requirements for shock and vibration
5. Raw material usage to manufacture the cooling solution
6. Required fan performance
7. Product reliability
8. Transportation cost
9. End of life cost

Figure 1 shows a picture of a flow visualization test through a pin fin and the DUT. Compare the amount of flow entering the pin fin and the DUT, which in this case is a maxiFLOW™ heat sink. Most of the water “hitting” the pin fin is bypassing it because of the high air resistance of the fin field. Look at the flow that is left over downstream of the pin fin, which is lower than the upstream flow. Imagine what will happen if we put multiple pin fins in a row downstream of each other because we have to cool multiple devices in a row.

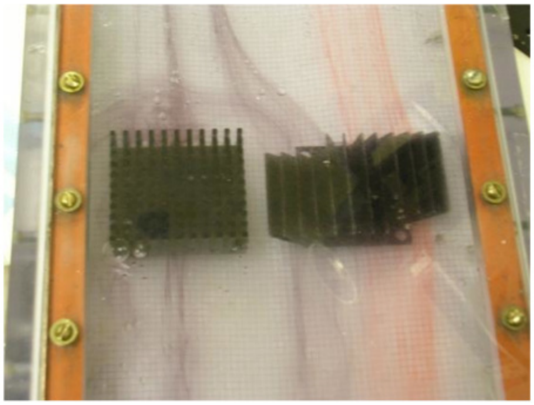

*Figure 1- Flow Test on Both a Pin-Fin (Left) and DUT (Right) in a Water Tunnel. (Flow is from top to bottom)*

The first pin fin will have sufficient cooling but, the further we go downstream, the less effective the heat sink becomes. Limited air will be available for cooling, because most of the air is bypassing the heat sinks. What is the first reaction without knowing anything about the flow structure? We need a larger heat sink downstream to get the same cooling effect; or maybe we need to consider a more powerful fan system to drive more air through the system. However, if we would have started from a system level point of view instead of concentrating on a single heat sink, we would have studied the flow field and the interaction between the heat sink and the flow more closely, and we could have arrived at a better solution.

For example, in many cases the total number of heat sinks can be reduced, because other components are better cooled and probably do not require additional cooling.

Standard extruded heat sink profiles and cast heat sinks normally have a thick base and thick fins and are made of lesser thermally conductive aluminum alloys. The lower conductivity is a result of the additives that are included, to make the manufacturing of the product easier. The base and the fins tend to be thicker, because it is more difficult to manufacture thin and tall fins. Especially for natural convection, the optimum heat sink from a thermal point of view can easily be a factor of ten thinner than what is offered. The main design driver for these types of heat sink is the ease of manufacturing and not the overall thermal performance. The end result is a more voluminous and heavier heat sink that makes bad use of the available volume and has a negative effect on the flow.

To have a stable mechanical design, a stronger mechanical attachment to the component/ board is required to handle the weight of standard heat sinks, as compared to high performance ones. An efficient light weight heat sink can still be attached by taping, glue, and other attachment methods, which use the component itself as an anchor.

Counting the weight of a standard heat sink and its attachment mechanism together, the overall product weight will be quite higher than for a design based on more efficient cooling solutions.

The same is valid for those LED designs that use the housing as a heat sink. The housing often is made by extrusion or casting processes, which limit the freedom of design. They are generally made of zinc aluminum (Zamac) with a thermal conductivity around 115 W/mK; whereas aluminum used for moulding is between 100-150 W/mK; brass annealed is around 60 W/mK; aluminum alloy AL 6063 has a thermal conductivity of 201 W/mK and aluminum alloy AL 1050A reaches 229 W/mK.

Heat spreading is an important factor in most LED applications, and drives the thermal design of LED cooling. If analysis shows heat spreading is important, the consequence is that for lower conductivity materials, the only option is to either increase the base thickness or embed heat pipes or vapour chambers, adding to cost and weight.

Forged heat sinks are made of high conductivity aluminum, but the manufacturing method itself is very limited in design freedom. So in general, to get a better performance, a larger heat sink is required. For natural convection, the use of thermally conductive plastic could be of interest because of its lower weight and greater design freedom. Plastics enhanced with carbon fibers could also be used, but require special attention because of their non-orthogonal conduction behaviour. Other options are designs that are a combination of highly efficient heat sinks and heat pipes, to either improve heat spreading when the heat sink is much larger than the source, or to transport the heat from the source to a remote heat sink.

Apart from the attachment of the heat sink to one or more component, the overall weight of the board, including the cooling solutions, affects the overall mechanical design. Additional mechanical features are needed to make the product mechanically stable and these features will add cost and weight and further limit the design freedom.

As discussed before, a more voluminous heat sink solution requires more raw material. The initial manufacturing process of aluminum, however, is energy intensive, something we would like to decrease in a world where reduction of energy consumption is key. Fortunately, it can be recycled without the loss of its properties and the recycling process uses only a fraction of the energy in the initial manufacturing process. Finally, there are manufacturing techniques such as bonding, folding and skiving, that do not suffer from these sustainability issues.

Furthermore, a lesser efficient heat sink such as a pin fin or standard extruded type of heat sink, will lead to higher air resistance and lesser optimized flow over the components/board and through the system. To overcome the higher air resistance and allow for more flow to compensate for the reduced airflow, a more powerful fan or more fans are required. A more powerful fan can mean either a larger fan type or permitting the current fan to run at a higher rotational speed. However, doubling the fan speed means increasing the input power to the fan by a factor of 8. As a result, more heat is dissipated in the system, the power supply has a higher current usage and more power is dissipated in the fan itself. This will lead to a higher fan temperature, thus reducing its lifetime. On top of this, a higher fan speed and more flow will result in higher noise levels.

Optimizing your thermal design by optimizing around the heat sink could in some cases avoid the use of a fan at all, making up for the extra costs of a more sophisticated heat sink. The use of more efficient cooling solutions will lead to a more optimized overall thermal design of the system, influencing directly the thermally and thermo mechanically-related reliability issues of the overall system.

The transportation cost of the cooling solution to the manufacturer of the system also has a price. This price is based on shipped volume and weight. Efficient cooling solutions are lower in volume and lower in weight, so will yield a reduction in transportation costs. The weight factor is also applicable for the final product, as a product equipped with lesser weight cooling solutions will be cheaper to transport. Apart from transport issues, a human effect is applicable: take, for instance, an LED-based streetlamp. Lifting a 30 kg lamp and installing it on a pole, versus lifting a 20 kg lamp, speaks for itself. Additionally, the pole needs to be designed in such a way that it can handle the weight of the lamp, potentially reducing the costs of a lesser weight lamp. Every product has a certain economic and technical lifetime and will be recycled afterwards. The cooling solution need to be recycled too. The heat sink, lamp enclosure - in most cases made of aluminium - can be recycled in a cost and energy effective way; but the lesser mass we recycle, the better.

In summary, the conclusion must be that it pays off to focus on the costs of the total system, and not only on the costs of the individual parts. In times long gone by, it was standard practice that project leaders got bonuses for buying parts as cheap as possible. Needless to say, such an attitude cannot survive in a world where end-users buy total systems, not a collection of parts. However, in the case of heat sinks, we still notice a suboptimal purchasing policy, often based on lack of knowledge and outdated protocols.

**References:**

**1- Lassance, C., Eggink, H., "A Method to Rank heat Sinks in Practice: The Heat Sink Performance tester", Proc. 21st SEMITHERM, pp. 141-145, San Jose, CA**