

12 KEY CONSIDERATIONS IN
ENCLOSURE THERMAL DESIGN...
A HIGH-LEVEL 'HOW TO' GUIDE



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WHY IS ENCLOSURE THERMAL DESIGN IMPORTANT?

Before we look at the 12 key considerations in enclosure thermal design let's first consider why thermal issues need to be considered at the system, or enclosure level.

A natural focus when designing an electronics product is, well the electronics. The electronics itself however, needs to work within some kind of enclosure, be it a standardized rack system¹, or a custom-built enclosure like the housing of a SmartPhone or tablet computer, or part of another product like an automotive dashboard or aircraft flight deck.

In all cases, including a standardized rack system, the electronics has to be designed with the enclosure in mind, as the enclosure can act as either a barrier or a conduit for carrying the heat away to the ambient, or possibly both. Cooling is a system issue, which is why we advocate a top-down approach, starting at the enclosure level [Ref. 1].

Often the airflow inside the enclosure is complex, making CFD the only viable approach to developing a successful design. The flow is affected by the electronics and the enclosure design, hence the electronics and enclosure interact to provide the application thermal environment. In the vast majority of cases, the primary cooling medium is ambient air. Even in something as small as a notebook computer where there is very limited space, designers look to circulate the air in order to improve cooling performance, although heat spreading and conduction to the casing will be more important.

Whenever enclosure-level airflow prediction is needed, FloTHERM is the industry's primary tool of choice² as shown below.



Figure 1: Airflow distribution in a server system as modelled in FloTHERM

¹ Chassis design to house third party circuit card assemblies is a specialized topic.

² See references to the ThermoNator in 'Hot Air Rises and Heatsinks' [Ref. 2]

OPTIMIZING THE AIRFLOW

Enclosure thermal design is then all about optimizing the airflow when the electronics are installed. That doesn't mean that it needs to be done as an afterthought, when the design of the electronics is completed. On the contrary, to ensure the shortest design time, design cost and arrive at a product that has a low-cost high reliability cooling solution it's essential that a co-design approach is taken. The golden rule is to "start early and start simple" [Ref. 1].

This co-design can start at the concept design phase. Indeed, it can be a prerequisite for getting the architectural design for the electronics correct. Where there is flexibility over the enclosure design, FloTHERM and FloTHERM XT provide an Enclosure SmartPart offering a fast, parametrically-defined representation of the enclosure.

In other cases the enclosure design may be largely predefined, but there may still be a need to optimize the enclosure for cooling the electronics. For FloTHERM, FloMCAD Bridge provides the ability to simplify and import native CAD and standard CAD neutral file formats. For FloTHERM XT, native CAD geometry and standard CAD neutral file formats can be imported, manipulated and modified directly within the software using FloTHERM XT's inbuilt CAD kernel.

Due to their prevalence, we talk first about the key considerations when designing open systems, and then discuss closed, or sealed systems.

OPEN, FORCED CONVECTION SYSTEMS

1: SELECT THE RIGHT FAN TYPE AND SIZE

Different types of fan are available – axial, centrifugal, radial, and even mixed flow fans. These have different flow rate vs. pressure characteristics.

Radial fans generally produce the highest maximum pressure rise, but at the cost of delivering a lower maximum flowrate.

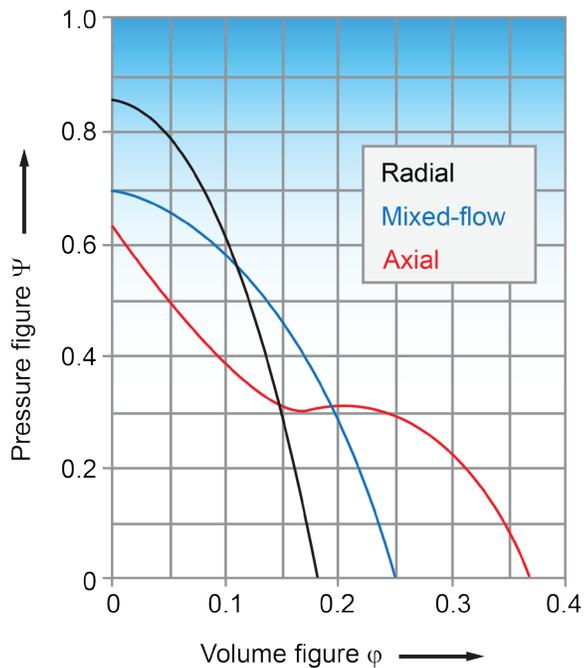


Figure 2: Normalized Pressure vs. Volume Flowrate for Different Fan Types [Ref. 3]

To achieve the same airflow, albeit with different flow rate and pressure rise characteristics, and if space permits, there may be a choice to be made between using larger fans, operated at lower speed or smaller fans operated at higher speed.

There are benefits of using a larger fan operating at lower speed as it will generate less acoustic noise and will have a longer field life. It also allows scope for intelligence to be built into the cooling solution as discussed below. There is clearly a cost implication as the larger fan is likely to be more expensive, and electromagnetic emissions (EMC) may be harder to contain, depending on how the equipment is shielded.

2: SELECT THE BEST FAN FLOW ARRANGEMENT

Another design consideration is whether to opt for a 'push' or a 'pull' type arrangement, i.e. whether fans are to be used to push air through the system or draw air out of the system. In general pull type arrangements are the most common, being found in most deskside, desktop and laptop computers. Here the air is pulled into the enclosure through vents by a fan or fans that exhaust out of the enclosure.

In pull type arrangements, the electronics (e.g. a rack of boards) acts as a flow resistance which tends to even out the flow through the card slots. For a bespoke system, in which the designs of PCB the system will house will not change, the board spacing can be optimized to get the best cooling for each board. For modular systems designed to house a range of PCBs, often from different vendors, this is not recommended.

Some systems may require a dual push and pull arrangement in order to achieve higher volume flowrates.

If a pull type arrangement is used, the static pressure inside the system will be lower than the ambient. Consequently any leaks in the system will allow air to bleed into the system and may bypass the electronics and therefore not contribute to cooling the system. This air will also bypass any filters designed to prevent dust and dirt entering the system. Conversely, if a push type system is used, air can bleed out and again not contribute to the system cooling.

During the detailed design phase, or earlier if a pre-existing enclosure is being repurposed, the mechanical design of the enclosure available as a CAD model should be used and particular attention paid to joins in the casing.

3: USE A PLENUM

In push-type arrangements the incoming air naturally forms a jet, with recirculation regions forming at the sides of the jet. However, we want the incoming air to flow uniformly over the downstream electronics, especially when forced air cooling a rack of PCBs where equally apportioned airflow through the gaps between the cards is desired. A pressure plate can be introduced downstream of the fan to make flow more uniform. The downside is that this adds to the overall system pressure drop that the fan has to overcome. The higher the flow resistance, the more uniform the flow rate through it. Hence the flow uniformity needs to be balanced with the cost, in terms of increased pressure drop, required to achieve it. Both FloTHERM and FloTHERM XT have general Flow Resistance and Perforated Plate SmartParts to assist with this task.

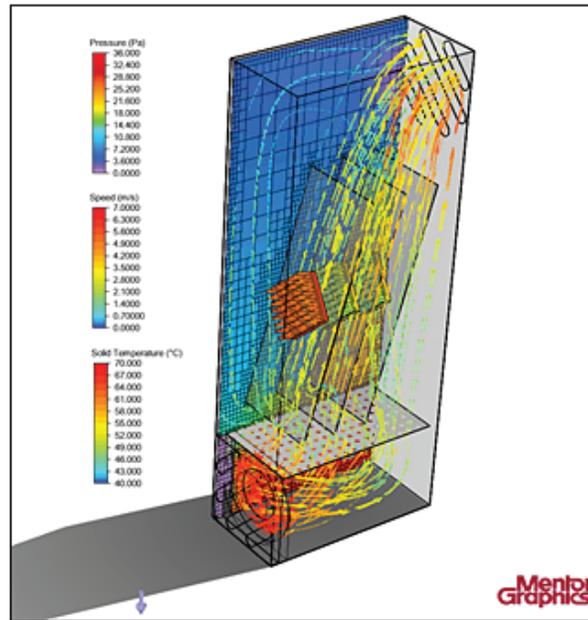


Figure 3: Flow resistance SmartPart in FloTHERM XT model of a rack system

Another factor to consider is that even axial fans generate non-axial flow. At high volume flowrate and low pressure rise, axial fans predominantly exhaust air axially. At lower flowrates the radial and tangential components of the air leaving the fan increase. Unless a plenum arrangement is used, this can change the near field flow pattern downstream of the fan and hence the local cooling.

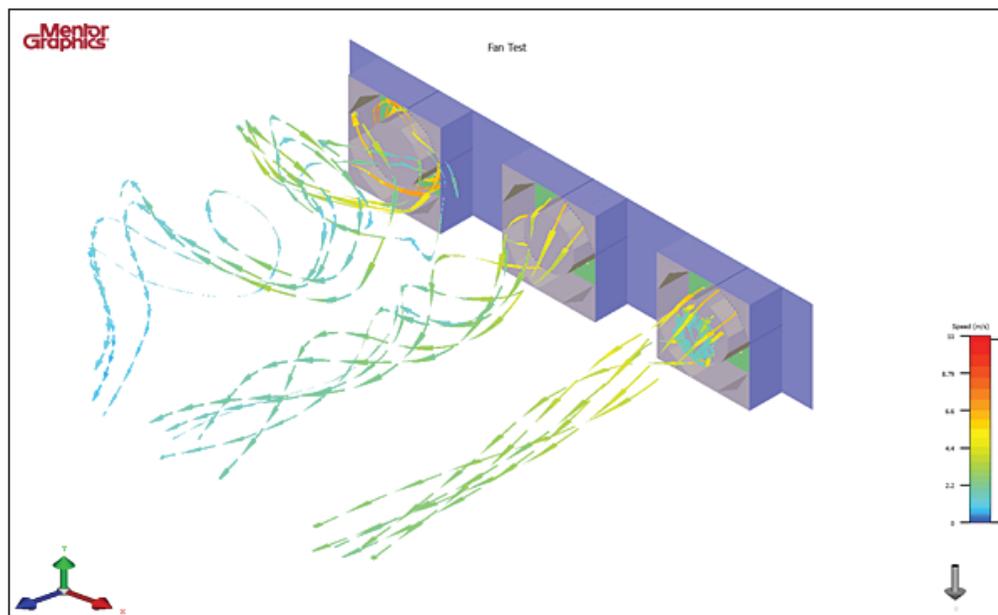


Figure 4: FloTHERM model of an identical fan operating at three different operating points and showing different spreads.

4: SIZE VENTS CORRECTLY

Regardless of whether a push or pull type fan arrangement is used, arrangements need to be made for air to enter the system. The size of the vent or vents affects the volume of air flowing through the system. What is perhaps less apparent is that it will also affect the flow pattern within the system.

Similar considerations to fan sizing also apply to vent sizing. Larger vents will reduce the overall system pressure drop which will increase the volume flow through the system. How much will depend on the flow resistance of all the other geometry. It will also affect the speed with which air enters or exits the system via the vent. In pull-type systems the jet effect caused by the air entering at high speed can set up flow recirculation regions within the system leading to hot spots.

5: OPTIMIZE FAN & VENT PLACEMENT

Where a fan is placed on one wall of the enclosure, typical of desktop computers, rack-mounted servers, etc. the position of the fan will influence the flow pattern within the system.

In the case of pull type systems, having the exhaust fan near to the top of the enclosure helps ensure that it exhausts the hottest air in the system, as buoyancy effects are always present and otherwise will give rise to a blanket of hot air at the top of the enclosure. Conversely, in push type systems, the inlet fan should be positioned near to the bottom of the enclosure to bring cold air to ensure that as it passes up over the electronics, assisted by buoyancy effects.

We advocate activating buoyancy in all simulations as this adds to the realism of the results obtained at no cost in terms of simulation time with Mentor Graphics' software. It is essential for naturally ventilated systems. Care with vent placement is also needed to prevent hot exhaust air being drawn back into the system.

6: OPTIMIZE BOARD PLACEMENT

Something that's often overlooked is the potential to adjust the location of the PCB or PCBs within the enclosure. In a rack system it is obvious that the card spacings can be altered, but in other systems this is perhaps less apparent. Altering the position of the PCB can adjust the amount of air that flows over and under the PCB. Minor changes can provide improvement in the cooling performance. This may arise from the interaction of the leading edge of a PCB with the near field flow around a fan or vent for example.

OPEN, FREE CONVECTION SYSTEMS

Free convection systems range from digital TV set top boxes to rack systems and historically telecom racks. In naturally vented systems, all the convective cooling arises from buoyancy induced by air inside the system becoming hotter, and therefore lighter, than the surrounding air.

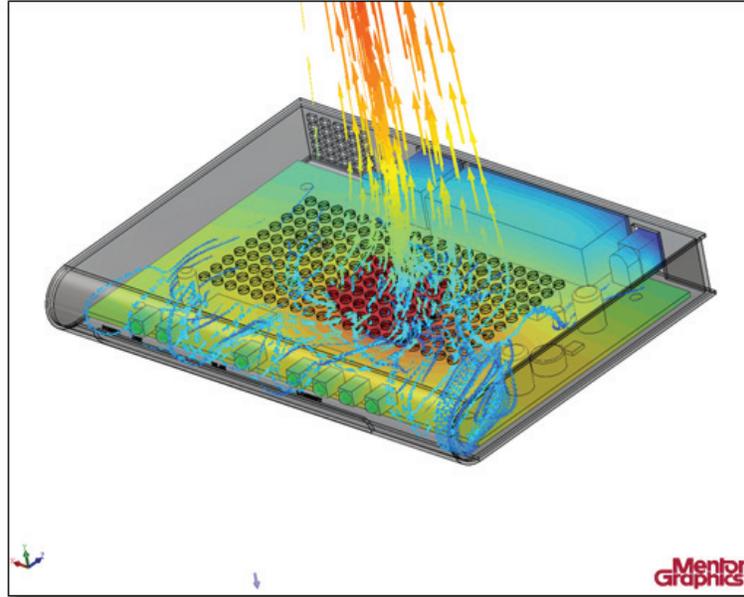


Figure 5: Buoyancy induced airflow in a FloTHERM XT model of a router

7: DESIGN VENTS CAREFULLY

Smooth uniform airflow is key to good design, and consideration needs to be given to the detailed design of the vent grilles to minimize pressure loss while maintaining electromagnetic compatibility and immunity (EMC/EMI). To design the inlet vent grille, it is often necessary to consider how the air approaches the vent, requiring the solution domain to be extended beyond the enclosure, to include the mounting surface for the unit.

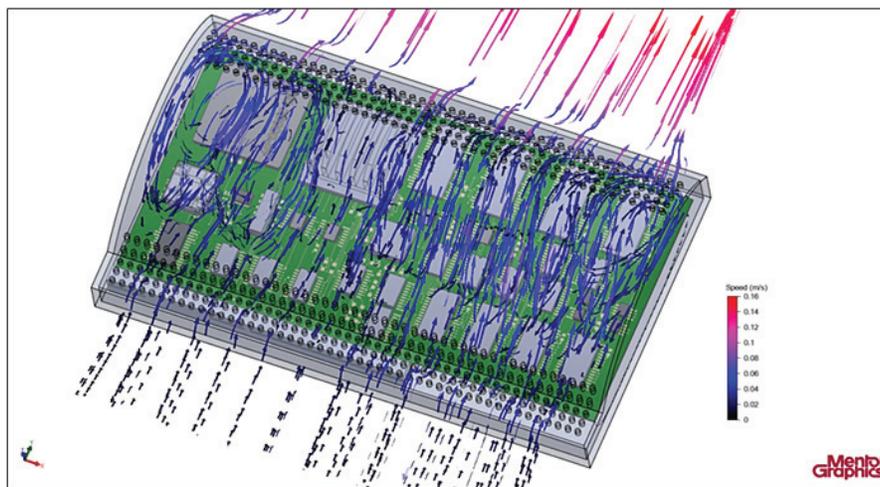


Figure 6: Flow distribution in FloTHERM XT showing the optimized vent arrangement for a naturally ventilated, wall mounted electronics system

ENCLOSED / SEALED SYSTEMS

In larger enclosed systems, fans can be used to recirculate the air, e.g. through an internal heat exchanger. When considering using a fan within an enclosed system it's important to bear in mind that the fan itself, and the additional power draw on the power supply will add heat into the system, so the improvement in cooling performance needs to outweigh the additional cooling required.

8: DON'T IGNORE CONDUCTION TO THE ENCLOSURE

Conduction to the enclosure can be the primary cooling mechanism for some fully enclosed systems, e.g. avionics boxes, and even SmartPhones.

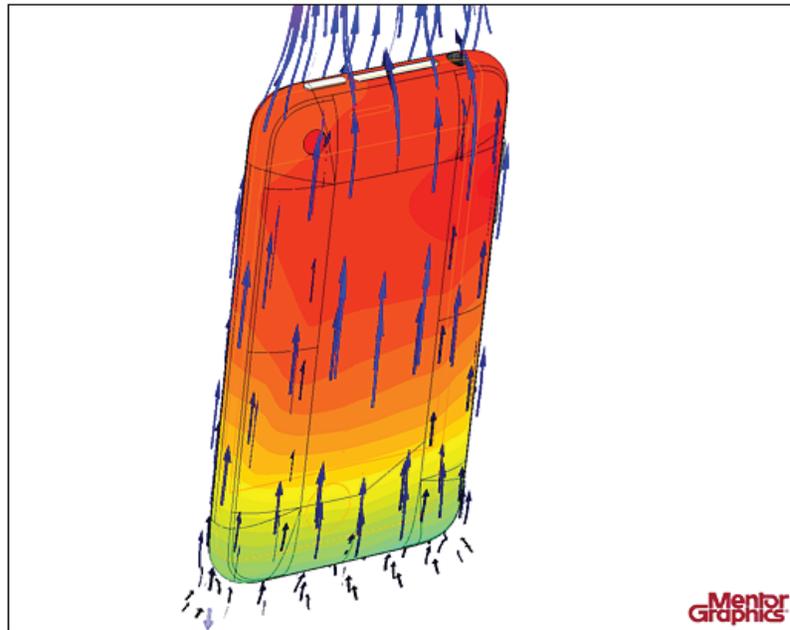


Figure 7: Case temperatures and buoyancy-driven airflow for a FloTHERM XT model of a Smartphone

Thought needs to be given to how heat is to be removed from the casing. Often only natural convection to the ambient or conduction to a human hand are the only ways in which heat can ultimately leave the system. In both cases it is highly desirable to spread the heat as much as possible to make the best possible use of the surface area of the casing. As such, the casing should be as thermally conductive as possible, so that it extends the hot area in the same way that a heatsink does. If not heat loss from the casing will be reduced, and at the same time a hot spot will arise which may lead to problems due to the safe limit for touch temperature.

As a system-level cooling solution, we should also mention that conducting rails can be used to carry heat to wedgelocks that clamp a PCB to an externally cooled cold wall e.g. as part of a ruggedized enclosure also providing mechanical stability for the board mounting. This approach only applies to a certain type of system, e.g. a sealed avionics box, but it is sometimes possible to apply the same principle in other systems where the casing itself can be used as part of the cooling solution. Gap pads can for example be inserted between the top of board-mounted components and a metal enclosure to provide additional heatsinking.

9: DESIGN IN INTERNAL HEAT SPREADERS IF NECESSARY

A final point about conduction concerns the use of heat internal spreaders. Depending on the type of system, internal heat spreaders can be used to augment the cooling. These can be either tightly mechanically integrated as part of the PCB construction, as in the case of a metal core PCB (MCPCB), or a mechanically-separate system-level cooling solution that provides heat spreading on either the top or back of the PCB or memory module. Such solutions usually need to be designed in from the outset.

Many material options are available – highly oriented pyrolytic graphite (HOPG), various ceramics, silicon carbide (SiC) and flat heat pipe constructions. Material and processing costs vary considerably, and the use of an internal heat spreader also adds to the assembly cost as heat must be efficiently conducted into the heat spreader for it to be effective. Although internal heat spreaders offer a simple means of improving thermal performance, the benefit should be weighed against other options.

10: THERMAL RADIATION EFFECTS

Thermal radiation effects are often ignored in early design as this is generally a conservative assumption, and often the model fidelity does not provide sufficiently accurate surface temperatures to warrant the additional computational overhead. If radiative heat loss is considered important its effects can be represented as an augmentation to convective heat transfer coefficients, increasing them by about 5 W/m²K on materials having a high emissivity (e.g. greater than 0.8).

Radiation effects should be considered during detailed design both to avoid general overdesign but also to avoid problems. For example a temperature-sensitive component on one board may be heated by radiation from a high power dissipating component on an adjacent PCB. Radiation is particularly important when natural convection makes a significant contribution to the cooling. In rack systems cooled by natural convection for example, board-board radiation and radiation to the side panels of the subrack can significantly reduce the temperature variation across the rack preventing over-design of the cooling for centrally-located boards. Surface emissivity influences the heat loss and for metal enclosures it is worth testing the sensitivity of the simulation results to see if coating or painting the inside of the enclosure is worthwhile.

Solar radiation deserves a special mention at this point. For outdoor equipment that's exposed to sunlight, solar heating of the system can present a major challenge. Shielding the electronics from the heating effects of sunlight may require a dual skin design with ventilation that is controlled and with additional heating to prevent frost protection. Specialized cabinets are available for this purpose. It should be noted that the color of the enclosure is important as this affects the solar absorptivity.

11: CO-DESIGN OF ENCLOSURE AND ELECTRONICS

In this whitepaper we've talked about the design tasks associated with enclosure design. We have not yet talked about these tasks in the context of the overall product design process.

In conceptual design a very simple representation of the enclosure may be all that is possible, but the flip side is that there is very little constraint from other aspects of the design, so there is great scope for designing a highly thermally-efficient enclosure that has low design, manufacturing and operating costs. Doing so requires the enclosure design to be refined as other aspects of the design evolve. The enclosure design itself should be updated in the thermal model as soon as design details are committed to the CAD system, and updated thereafter in step with updates to the CAD geometry to ensure that these changes do not negatively impact the overall thermal design. The system-level model should be re-run whenever there is a change to the PCB layout and heatsinking arrangements for any components, and if information about the component powers changes. The aim should be to keep the thermal model of the system in sync with the design information held in main MCAD and EDA design flows.

12: DESIGN IN COOLING INTELLIGENCE

Increasingly it is both impractical and not cost effective to design cooling solutions for systems based on the maximum thermal load. For example, multicore computers and servers often spend periods of time running with relatively low workloads. Today's equipment is designed to draw little power when idle, so the cooling can be throttled back for much of the time.

In early design a representative Thermal Design Power [Ref. 4] can be used, allowing steady-state calculations to be used to investigate different aspects of the cooling solution discussed above. In the detailed design phase however, it may be necessary to consider different use cases, each having different power levels for the critical components and in some cases even different power distributions on the surface of some of the packaged dies, e.g. in high power density mobile applications.

The task is to optimize the cooling solution for a range of use cases and design the cooling solution to adapt to the different power levels it has to cool, thereby allowing the power required by the cooling solution to be minimized. In the simplest case this can be having the fan normally run at slow speed and increasing the fan speed when a component temperature exceeds a predefined value.

FloTHERM has the ability to run design variants, and supports the simulation of systems with dynamic cooling solutions such as temperature controlled variable speed fans.

CONCLUDING REMARKS

This whitepaper provides an overview of the key considerations in Enclosure Thermal Design. It is by no means exhaustive, with many details not covered. If you are responsible for enclosure-level thermal design and want to know how Mentor Graphics' thermal design software can help, and what is the right product for your application, then please contact us through the Mentor Graphics Mechanical Analysis web page www.mentor.com/mechanical

ACKNOWLEDGEMENTS

Dr John Parry, CEng, CITP, MBCS, MIEEE
Dr Ian Clark

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