Beat the Heat in Notebooks with Software

Computational fluid dynamics software can help you solve system-level thermal packaging problems.

Pentium-class portables present significant packaging problems. The heat generated inside a notebook not only reduces microprocessor reliability, but the reliability of peripheries such as hard drives and video chips. Although the processor is the primary heat-generating source, it isn't always the component least tolerant of temperature.

You can turn to sophisticated analysis tools to help find a solution to your excess heat problems. Computational fluid dynamics (CFD) software, especially, can determine the interaction of system components inside enclosures that have virtually no empty space. Interaction simulation can help you manage heat distribution throughout your design.

Notebook requirements

Determining thermal resistance requirements includes understanding the chassis and component power levels, layout, and reliability. Each notebook computer can require a different thermal solution.

Let's look at chassis requirements first. Basically, cooling electronic enclosures requires removing heat from the system. For portable enclosures, the problem becomes more challenging, since the temperature of the chassis must be managed so that the end user doesn't get burned! A skin temperature of 45°C is a common design goal. That's only 5 degrees above the maximum external air temperature of 40°C.

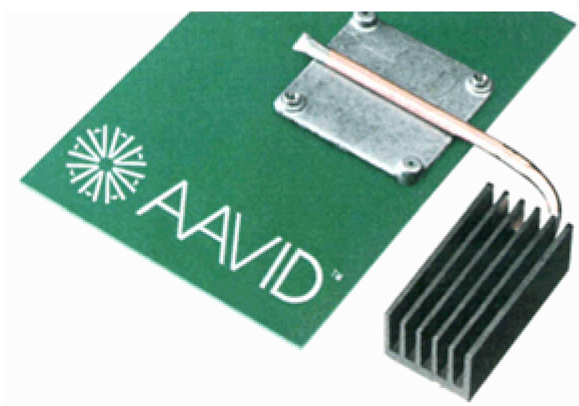

Figure 1. A simple notebook computer thermal solution consisting of a heat pipe and an extruded heat sink. This specific design is for a CPU module that has a thermal plate assembled on top of the microprocessor.

A notebook may also be used in a docking station with its lid closed. Or it might be used with the lid tilted when resting on someone's lap. These situations affect how efficiently heat is removed from the chassis. Heat must be evenly distributed throughout the system so that hot spots, which can seriously affect reliability, aren't created. Ultra-thin notebooks and subnotebooks require even smaller solutions.

An upgrade strategy

An examination of component power levels is beneficial. Because system performance and features are important to gain a competitive advantage in the marketplace, product variances complicate system thermal problems. Adopting an upgrade strategy allows higher-end-component drop-in without having to change the package.

Faster microprocessors generate more heat that must be removed. Typical Pentium power levels range from 5 W to 15 W, depending on the type of package. Next-generation processors will run at levels between 12 W and 17 W. New components such as DVDs, AGP chipsets, and sound synthesizers also dissipate heat in a system, further complicating thermal design.

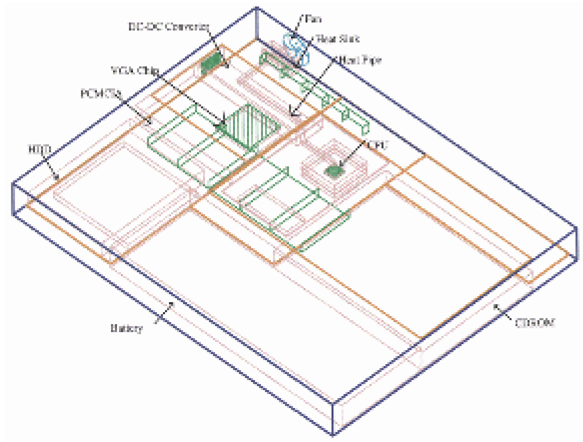

Figure 2. The CAD geometry of a notebook computer imported into Icepak.

Component layout

Let's turn our attention to component layout. The placement of components within a system is determined by end-user requirements. For example, a popular keyboard layout is close to a notebook's LCD, creating a flat section where hands can be rested during typing. Similarly, PCMCIA slots generally are sited on the right-hand edge of a notebook. Likewise, battery and CD-ROM locations need to be accessible. In fact, many notebooks have an extra drive bay that can accept either a second battery or a CD-ROM.

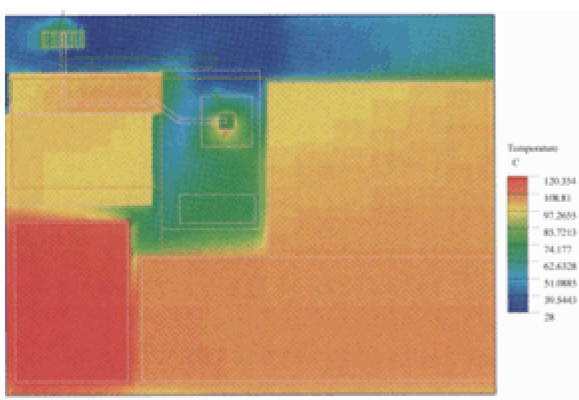

Figure 3. Temperature profile of the notebook computer where the red hot spot is the hard disk drive.

Once an initial periphery layout is created, a thermal analysis can be done. Each device has a maximum temperature spec that must be met by a thermal solution. The microprocessor, which dissipates the most heat, requires temperatures less than 85°C on average, but different package styles will have different temperature limits. Hard drives with a capacity greater than 2.4 Gbytes require thermal cooling, since maximum temperature limits can be as low as 55°C.

Multicomponent assemblies

Thermal solutions are typically multicomponent assemblies, too. For low-end systems that dissipate a total of 18 W (8 W from a CPU), you can use cast heat sinks and fan heat sinks located directly above the microprocessor. As system power increases up to 25 W (12 W from a CPU), heat pipes can be used to move heat to an area where there are vents or a fan. Heat pipes are commonly attached to small stamped plates that conduct heat into the backside of a keyboard.

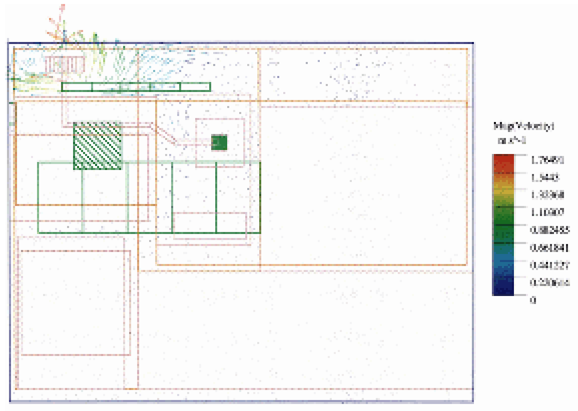

Figure 4. Air flow profile throughout the notebook computer.
Notice how the airflow is localized at the heat sink with no air near the hard drive.

For high-end systems where dissipation is greater than 30 W (15 W-plus from the CPU), a fan is typically required to control system-level air temperatures. Heat pipes, plates, and extruded heat sinks must move the heat to the fan where it's then removed from the computer.

Venting is therefore a consideration. The location of air vents can be determined at initial thermal analysis. Reducing the distance that a thermal solution needs to move the heat greatly impacts cost and size. For some low-power systems, a fan isn't required. Natural air currents can draw the heat out of the system—if properly designed

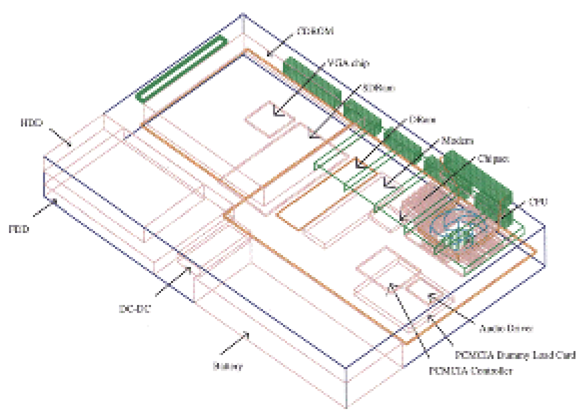

Figure 5. A notebook design with multimedia components with a fan heat sink used as the thermal solution.

Fan selection needs to be based on volumetric flow rate and power. Due to very small spaces, the 25 x 25 x 10-mm fan is the industry standard. Larger fans don't work efficiently, as pressure drops are too high due to the lack of headroom. Moreover, in a notebook, battery life is very important, and a cooling fan must not reduce it. System fans can therefore be controlled with a temperature sensor that turns the fan on only when needed to conserve power.

A heat pipe is another device that can be used to move heat from one place to another. It's an evacuated sealed tube, typically made of copper. Inside the pipe, there's a small amount of fluid that vaporizes when heat is applied. The vapor moves immediately to the other end of the pipe where the heat is removed and the vapor condenses.

On the inside wall of the tube, there's a porous wick that recirculates the liquid to the hot end. Because the fluid changes phase, heat can be absorbed and moved very efficiently. Heat pipes are six times more effective than conducting heat through aluminum. However, bends and flat sections in a heat pipe reduce efficiency. Notebook computers typically use pipes 3 mm and 4 mm in diameter. This size can effectively move as much as 20 W.

Stamp it out

For low-end systems, aluminum plates are a cost-effective way to transfer heat throughout a notebook. When used with heat pipes, plates can move heat directly to the backside of a keyboard. An additional metal plate on the keyboard can be designed to absorb as much as 4 W without significant temperature rise. For high-end systems, the plate can be used to take heat away from other heat dissipating devices, such as power supplies.

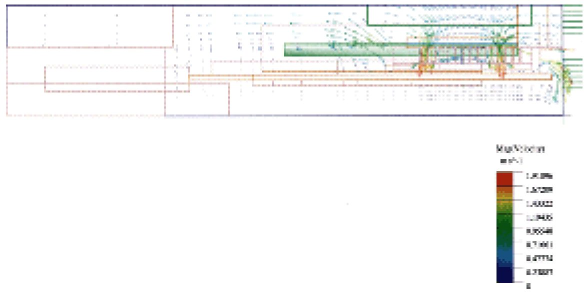

Figure 6. This air flow profile of the fan heat sink shows how the small space inside of a notebook computer, limits the area that is cooled by the fan

Consider extruded and cast heat sinks too. W
h en a system fan is used, a finned heat sink positioned in the air stream will dissipate the most amount of heat in the smallest space. A heat pipe is usually attached to the heat sink so that power from the microprocessor and other components can be transferred to the heat sink. This cooling technique manages total system power by quickly moving it out of your system.

CFD compares three notebooks

Three examples of actual notebooks modeled using IcePak, a CFD software package from Fluent (Lebanon, NH), shows how solid models, generated using CAD software, can be directly imported into IcePak. Once imported, each component was modeled using information about power dissipation and physical geometry.

Once the entire model is created, a simulation can be run to determine problem areas that are too hot. Once that's done, a thermal solution can be designed to solve the problem.

By changing the model to incorporate the thermal solution, a new simulation can indicate if the approach works. Several what-if scenarios can take into account different periphery placement and thermal management techniques; preliminary testing correlates well with thermal modeling, with accuracy between 80% and 95%.

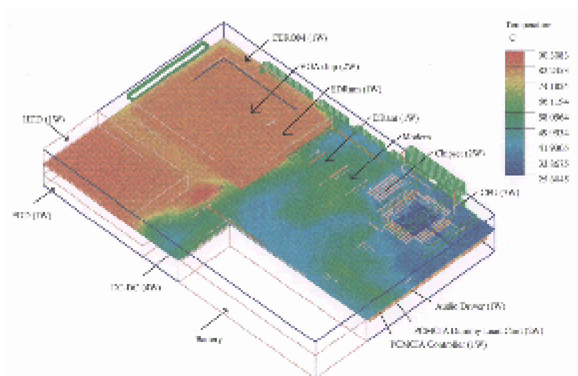

Figure 7. The final thermal profile of the notebooks shows how the fan heat sink cools the CPU and audio driver, but does little to manage the heat where the hard drive and CD ROM is located

Naturally, due to different sizes and features, thermal problems in notebooks differ for each model. However, once a model's created, what-if simulations can improve system packaging. Simulation doesn't replace system testing, but it can reduce the number of configurations tested. As product design cycles continue to shrink, CFD analysis can help you, as a product designer, to stay on schedule. Upgrade strategies can also be analyzed so that a thermal remedy can accommodate new components.

Actual designs

Let's look at how CFD was used to advantage in our three typical designs. In the first notebook, total system heat was 20 W, with 8 W coming from the CPU. Heat was also being dissipated from the notebook's video chip, CD-ROM, hard-disk drive, power supply, battery, and PCMCIA slots.

The thermal solution was a heat-pipe assembly to remove the heat from the CPU and transfer it to an extruded heat sink located in front of a system fan. In the illustration (a), vents are green.

Initial thermal plot analysis (b) shows a critical temperature on the hard-disk drive. The red area in the bottom left-hand corner of the diagram is revealing. Even though the CPU is cool, the disk drive is around 120°C—well over the recommended limit.

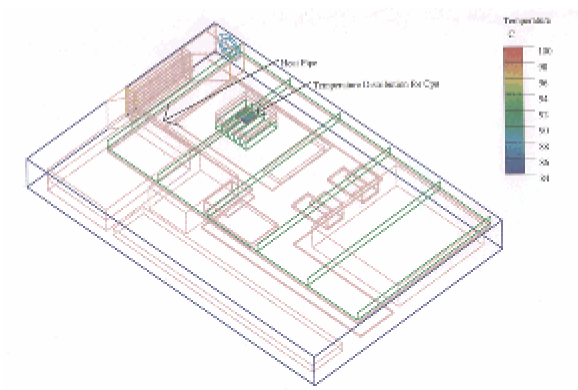

Figure 8. A new approach to cooling the next generation notebook computer uses a remote air duct used to manage the internal system temperature rise

Looking at system air flow (c), it's apparent that no air reaches the drive. Based on these results, the thermal solution was modified to include a plate that extends over the drive, reducing the temperature.

In our second notebook example (d), in addition to the components in the first notebook, there's an additional graphics chipset, a PCI chipset, a floppy drive, a PCMCIA controller, and an audio driver. The critical temperature is 70°C at the CPU, audio driver, and PCMCIA controller.

Since these components are located close to each other, an initial idea was to use a fan heat sink located on the CPU. The diagram (e) illustrates the airflow around the fan heat sink. Note the vent locations are well suited to permit air to cool the CPU and the adjacent audio driver. In the thermal analysis of the system using the fan heat sink (f), the area on the left is 30°C hotter than the side with the fan heat sink.

Even though this approach meets the specification, it shows how a fan heat sink only managed a localized area inside this notebook. A heat pipe with a plate attached to the fan heat sink can be used to spread the heat throughout the system.

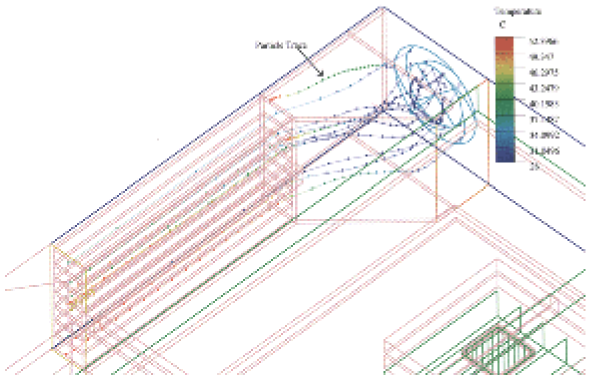

Figure 9. Looking at the air duct closely, we see that air entering into the fan is directed through the heat sink and the heated air is rejected outside of the system.

The third notebook studied represents the typical next-generation computer with a total system power of 30 W, with 15 W being dissipated from the CPU. Once system-level power increases above 25 W, the internal temperature rise can be greater than 10°C. This jeopardizes the ability to cool the system using internal system fans and heat pipes, as recirculating air tends to heat up the entire system. With this much power, a new concept in cooling was needed to manage temperature rise.

The approach was to use a separate air duct, fan, and extruded heat sink. In the figure (g), the top left side of the notebook shows this special cooling duct. Using heat pipes and an aluminum plate, the entire system's power can be moved to the extruded heat sink.

A close up of the cooling duct (h) illustrates how the air flows into the fan, through the heat sink, and out. Rejected air is removed from the notebook without heating the rest of the system. Looking at a temperature distribution of the plate (i), the maximum temperature difference is within 5°C

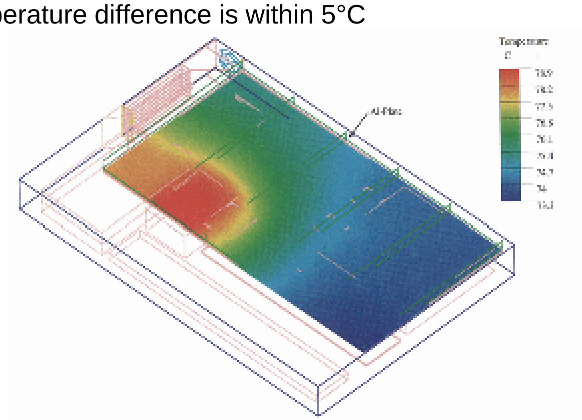

Figure 10. When used with a plate and heat pipes, the entire system heat can be managed by distributing the heat throughout the notebook. The temperature profile is within 5°C.