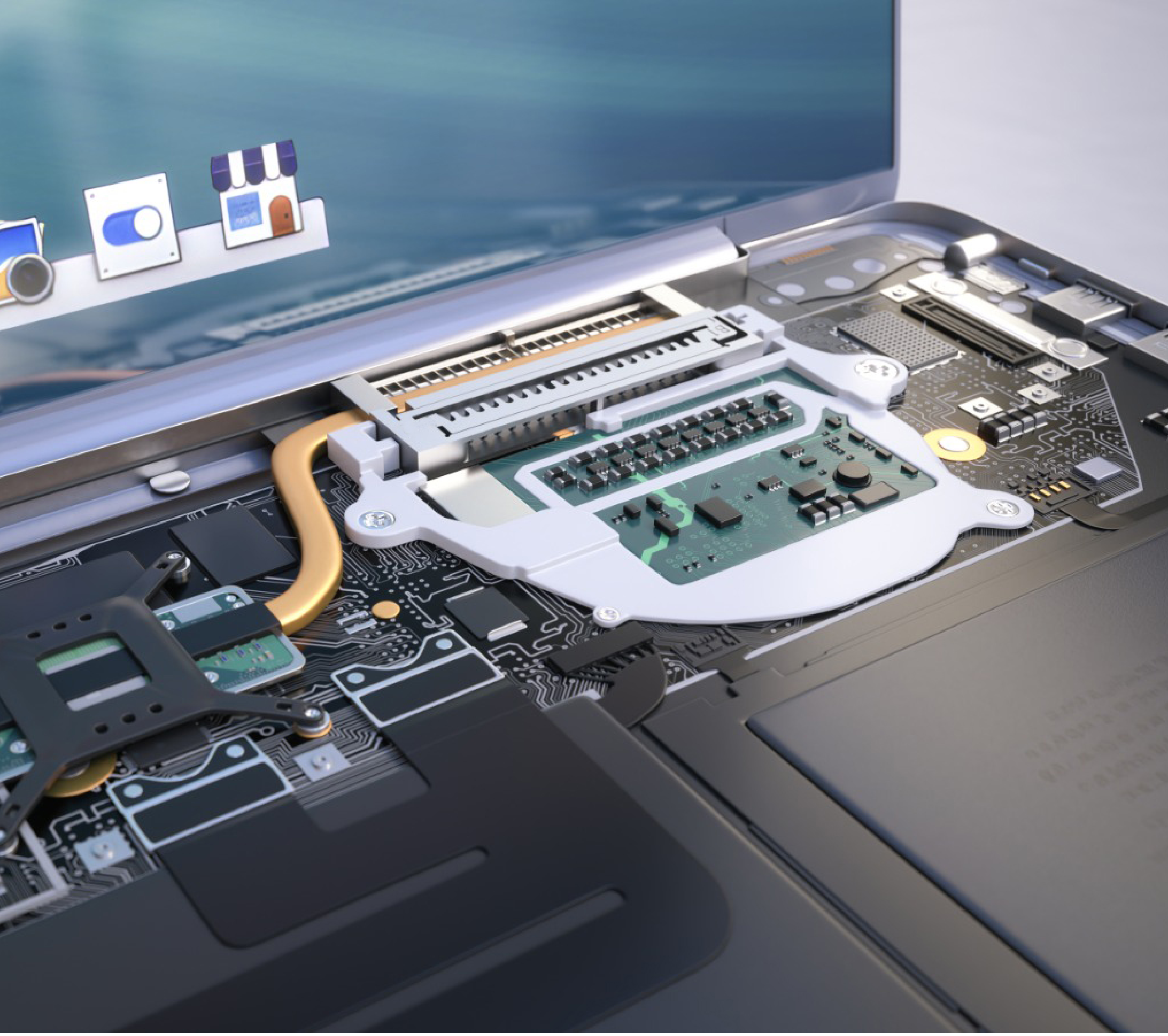


VENTIVA

Enabling High Performance Silent Computing:

A Breakthrough in Laptop Thermal Management

Executive Summary

The increasing thermal demands of modern processors pose significant challenges for compact laptop designs, particularly as manufacturers prioritize both performance and user experience. This white paper explores the critical balance between managing heat dissipation and achieving quiet laptop operation, while enabling top-of-the-line performance. As processors become more powerful, they generate higher thermal output, necessitating innovative cooling solutions that do not compromise form factor or acoustics. In this white paper, we will show how silent cooling solutions from Ventiva are the ideal answer.

Current heat management methods, such as heat pipes and advanced thermal interface materials, are examined alongside new offerings from Ventiva. Quiet operation has become essential in responding to user demand for a more pleasant computing environment, especially in professional and educational settings. This paper also highlights the importance of thermal management in maintaining system stability and in very small sizes, ensuring that modern laptops can meet performance expectations in thin, silent, form factors.

Ventiva has developed a novel thermal subsystem using ICE9® “air moving” devices. This subsystem can cool processor designs up to 40W thermal design power (TDP) while maintaining complete silence. This can cover almost the complete range of laptops for commercial and consumer customers, even while considering today’s most complex artificial intelligence (AI) workloads.

Introduction

Conventional cooling systems in laptops face several technical challenges. One significant issue is fan noise and vibration, which can disrupt the user experience, particularly in quiet environments or in use cases such as video calls or audio applications. Additionally, as laptop designs become lighter and thinner, these systems often have limited cooling capacity, making it challenging to manage the increased thermal output of modern, high-performance processors, including for new AI workloads.

As laptop manufacturers strive to improve cooling efficiency, the inclusion of fans typically leads to increased laptop sizes, counteracting the trend toward slimmer, more portable designs, or in compromises in battery size. The need for innovative solutions that effectively address these challenges while maintaining a compact form factor and silent operation has never been more critical.

Ventiva’s ICE9 thermal management solution is an ideal answer to the intertwined needs of silence and thinness.

Ventiva® ICE9: Fan-less Cooling for Thin, High-performance Laptop Designs

A fan uses mechanical energy to move air. Ventiva's patented Ionic Cooling Engine (ICE®) technology harnesses electrical energy to create the same effect, working on the principle of electrohydrodynamic flow. An electric field is created between two small electrodes. The electric field generated strips electrons from molecules of nitrogen, oxygen, argon (and other trace elements) in the air, creating ions that are repelled from the positively charged emitter. As positively charged ions move toward the collector, they collide with neutral air molecules. These collisions impart momentum to the neutral air molecules, causing them to move.

Ventiva's ICE9 thermal management solution combines the company's patented ICE technology with an innovative, software-controlled power supply. The power supply is driven by system voltages and designed to be easy to integrate. It uses the PWM that previously controlled the fan to control the system's ICE9 devices. A thermal designer only has to connect their existing system fan control to the ICE9 devices, letting the integral ICE power supply translate PWM outputs to the voltage and current levels required to make the system blow "harder" or "softer."

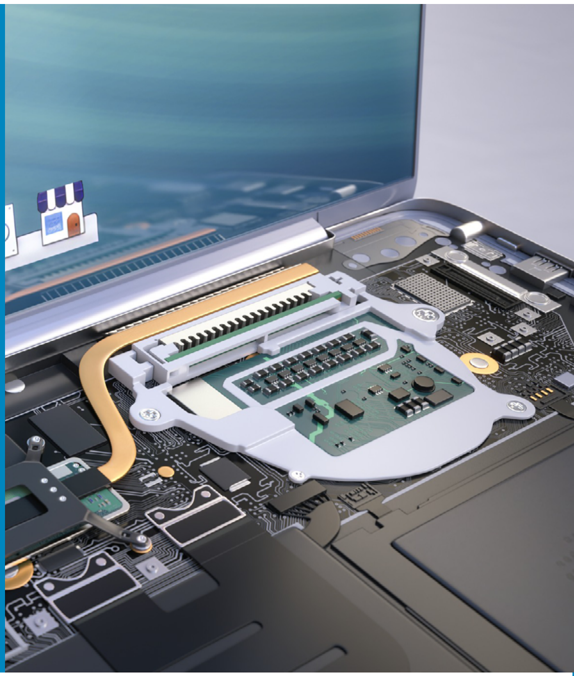
Unlike traditional fan-based thermal management solutions, the ICE9 device is designed to be small and modular. It is specifically designed so that a laptop thermal problem can be "broken up" into smaller pieces, each cooled by an ICE9 device. ICE9 thermal management solutions do not need a plenum—without an air gap, laptop designs become naturally thinner. Because the air movement is completely electrical, the ICE9 solution is completely silent.

The modular nature of the ICE9 device adds an additional level of design and form-factor flexibility. It can be arranged in different shapes, with each component a different length. The ICE9 solution is up to 80% smaller than a fan or blower, allowing laptop engineers to increase their battery sizes or add system functionality without changing the overall footprint dimensions of their machines.

The ICE9 device is a relatively lower pressure head air-moving device designed to enhance laptop thermal management. Its primary function is to facilitate efficient heat dissipation while maintaining a low flow resistance path, ensuring optimal performance and user comfort. By incorporating a direct air inlet at the bottom of the laptop, an ICE9-based laptop system has a steady flow of ambient air directly into the thermal management module. This approach maximizes airflow and heat removal efficiency.

Integration of Heat Pipe-Based Thermal Modules

A core element of the design involves using a heat pipe- or vapor chamber-based thermal module. Heat pipes and vapor chambers are highly efficient in transporting heat from the laptop's critical components, such as the CPU and GPU, to a finned heat sink assembly. These fins are strategically designed to maximize surface area, facilitating enhanced heat exchange with the incoming airflow provided by the ICE9 device. The key is in optimizing the fin design to maximize airflow and heat removal. This modular approach allows for precise control over the thermal profile of the ICE9 device, ensuring that heat is effectively and noiselessly removed even under high computational loads.



Direct Air Inlet Design

To optimize the performance of the ICE9 thermal management system, the laptop chassis is equipped with a direct air inlet at the bottom. This inlet allows unimpeded access for cooler ambient air to flow directly into the cooling system, eliminating reliance on preheated internal air. The design prioritizes airflow optimization, with careful attention to clearance and positioning to ensure a consistent and laminar flow. This inlet configuration is critical for minimizing thermal resistance and ensuring the ICE9 device operates at peak efficiency, even in compact laptop designs.

Thermal Modeling

Thermal modelling has been performed on a 14-inch clamshell notebook that includes simulation and component descriptions as follows:

1. System and Simulation Overview:
   - Model: 14-inch clamshell notebook. Notebook base size: 322mm x 212mm x 12.5mm
   - Cooling Mechanism: Forced convection with ICE9 devices
   - Ambient temperature: 35°C
   - Simulation domain size: 560mm x 300mm x 30mm

2. Thermal Module Configuration:
   - Components:
   - 2 x D6 flattened heat pipes (1.5mm thickness)
   - Aluminum fin area with optimized surface area for heat exchange
   - 5 ICE9 devices (65mm x 9.6mm x 3.6mm)
   - Copper plate and motherboard integration
   - High performance grease (5 W/mK, 30 micron thick)
   - Non-uniform heating of the CPU

Figures 1 and 2 show the bottom and the top view respectively of the laptop base assembly as modeled. **Figure 3** shows the thermal module as modeled. Fin parameters are also shown in **Figure 3.**

Fig. 1: Bottom View of the laptop with the base (D cover) transparent.

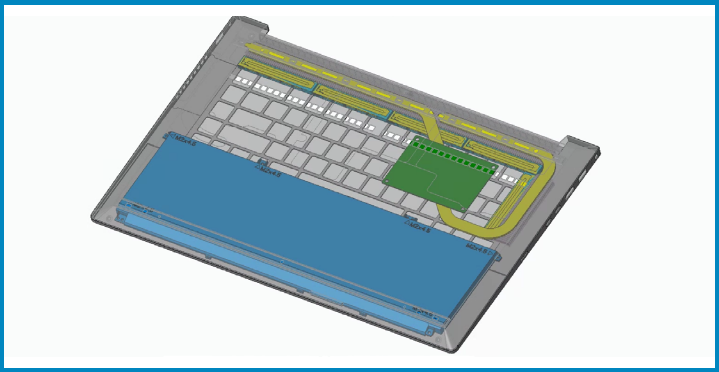
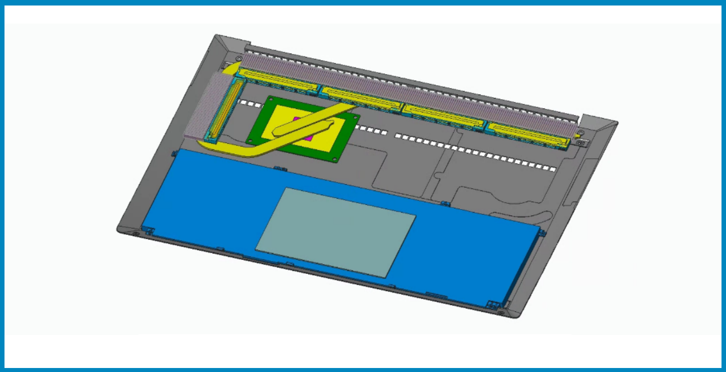


Fig. 2: Top view of the laptop with the keyboard area (C-cover) transparent.



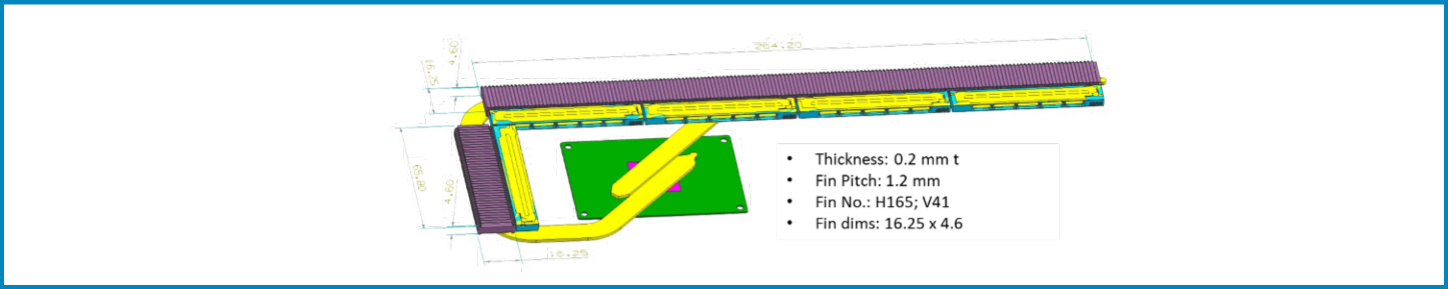


Fig. 3: Thermal module assembly with heat pipe, heat exchanger, and ICE devices.

We created a thermal model of the system described above using industry-standard thermal modeling software. For this analysis, the primary focus was on CPU cooling. No other heat source was modeled in the laptop system. Heat pipes were modeled using high effective conductivity, and ICE9 devices were modeled based upon its fan curve.

Industry-standard techniques such as grid sensitivity analysis and grid optimization were employed to refine the computational mesh, ensuring that the simulation results were not sensitive to grid size or resolution.

Modeling Results

For a 40W load from the CPU, based upon the conditions mentioned above, the CPU junction temperature was less than 82°C. The total flow through the system for these conditions was slightly more than 1.5 CFM. Although there were no other heat sources present, due to the thin system, the temperature of C and D covers in the immediate vicinity of the thermal module was approximately 50°C. No efforts were made to mitigate hot spots or slightly elevated skin temperatures. In a real system, a designer could employ spreaders like graphite to further mitigate those temperatures.

Figures 4 and 5 show the airflow pattern through the fins. Most of the air going into the fins is coming in from the inlet directly below the ICE9 devices. However, a small amount of air is also coming in from the connector openings. The airflow pattern shows that there is consistent flow through each of the ICE9 devices. The openings below each of the devices could be further expanded to improve the design. Furthermore, there is slight recirculation of air, pointing to further optimization opportunities.

Figures 5 and 6 also show the temperature along the thermal module. A vapor chamber-based design can further improve the cooling as there is a temperature drop of several degrees Celsius along the length of the thermal module to long heat pipes deployed to dissipate 40W.

Figure 6 shows the cross-section through the laptop base with a focus on the CPU and thermal module. The maximum CPU temperature in this plane is 81.3°C, and all other temperatures in the stack-up are as expected.

Fig. 4: Airflow pattern and various temperatures along the heat exchanger.

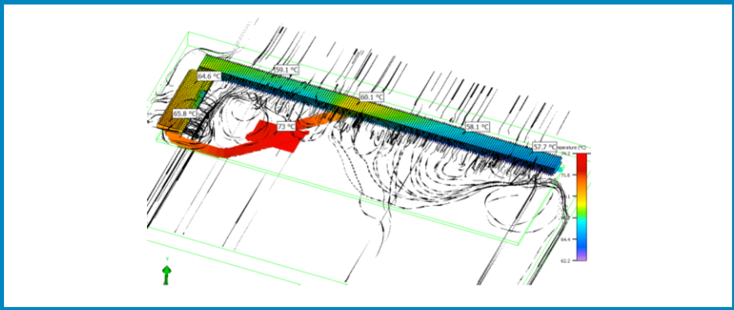
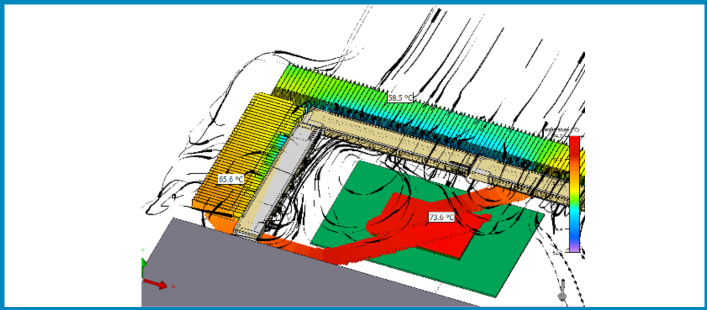


Fig. 5: Airflow patterns and temperature of thermal module at the heat source.



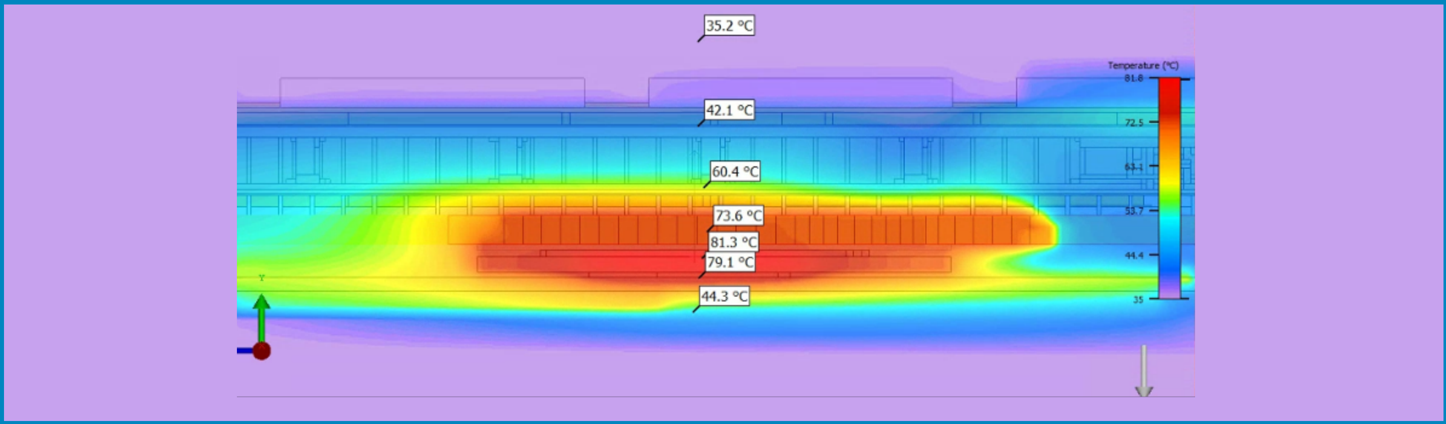


Fig. 6: Temperatures along the thickness cross-section of the laptop.

Experimental Validation

To validate the thermal modeling results, we built a system-level thermal test vehicle (TTV) utilizing the thermal solution and tested it in a 3D-printed laptop skin. **Figure 7** below shows the picture of the base of the laptop skin with the thermal module (**Figure 8**) incorporated for testing.

Fig. 7: Thermal Test Vehicle (TTV) consisting of the laptop base with the integrated thermal module.

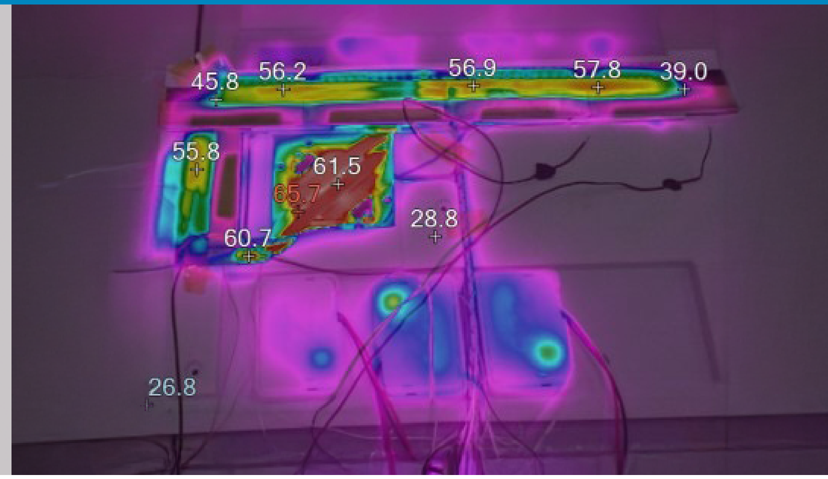
Fig.8: Thermal module (same as the thermal module that was used for modeling).

Five ICE devices were each powered at 5V into the power supply to run the devices. A thin film heater under a copper stub was used to simulate heat coming from the CPU. It was not possible to replicate the CPU non-uniform heating in the tests. CPU junction temperature, as well as ambient temperatures, were monitored using thermocouples. This testing was done in a natural circulation chamber with the chamber at 25°C. A picture of the unit under test is shown in **Figure 9** below. Thermocouples were used to monitor the heater temperature, representing the “junction temperature” or CPU T_j.

It takes approximately 1 hour to reach steady state and the CPU T_j at 40W of load was measured at 82°C in 25°C ambient temperature. **Figure 10** shows IR images of the entire laptop base. Scaled to 35°C ambient temperature, this will result in a CPU T_j of 92°C, still below the 100°C junction temperature specified for the CPU, which proves the design objective. Since ICE9 devices are configured to have relatively lower pressure head, additional optimization of flow inlet can further improve the cooling performance.

Fig. 9: Unit under test in a natural convection chamber at 25°C.

Fig. 10: IR image of the unit under test.



Conclusion

Ventiva's ICE9 thermal management solution offers a compelling solution for designing a 40W TDP laptop thermal system. Combining this innovative silent "air mover" with a heat pipe-based thermal module, a direct air inlet, and an optimized laptop design makes it possible to achieve efficient and silent cooling performance, even for the highest-performance AI-enabled laptops.

This approach enables laptop manufacturers to:

- Develop high-performance laptops with powerful processors without compromising user comfort or portability.
- Create slimmer and lighter designs, possibly with bigger batteries, by eliminating bulky fan assemblies.
- Enhance the end-user experience by providing a quiet, distraction-free computing environment.

The thermal modeling results and experimental validation prove the performance and effectiveness of this cooling solution. The Ventiva ICE9 thermal management solution represents a significant advancement in thermal management for laptops, paving the way for a new era of silent and powerful computing devices.

Ventiva can share detailed thermal models used in this study under an NDA.
For more information, contact sales@ventiva.com.

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