Technical white paper

HP Z Coolers

3D Vapor Chamber and Staggered Hex Fin cooling on the HP Z440 and HP Z840 Workstations

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Overview

Personal workstations have provided users with a substantial increase in processing power over the past decade. Advancements in memory size, graphics capability, mass storage capacity, and processor performance have all contributed to creating more powerful desktop and desk-side systems.

These evolutionary changes in system performance have brought with them increased power and consequently higher heat dissipation requirements. For example, the high frequency Intel single processor family has increased from 95 W (Intel® Core™ 2 Quad Q9650) to 140 W (Intel® Xeon® E5-1680 v3) in just a few generations.

To keep these processors and other critical components cool, traditional cooling systems add multiple fans to dissipate the heat to the environment outside of the workstation chassis. HP places great emphasis on employing the latest technology in personal workstations, and the realm of cooling systems is no exception. While HP Z Workstations are already quiet, the new and innovative HP Z Coolers for the HP Z440 Workstation and HP Z840 Workstation use 3D Vapor Chamber phase-change cooling with Staggered Hex Fin Heat Exchangers to further reduce acoustic noise and increase processor performance.

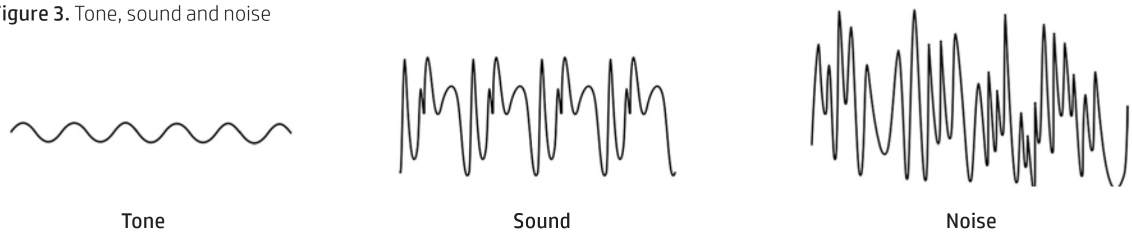
Figure 1. HP Z Cooler for Z440

Figure 2. HP Z Cooler for Z840

What is acoustic noise?

Pressure waves produced from a vibrating source create sound. The pressure waves are detected and translated into electrical signals by the human ear. Acoustic noise is generally regarded as an irregular aperiodic vibration as opposed to a sinusoidal wave (a tone) or a combination of several tones (a sound) — see Figure 3.

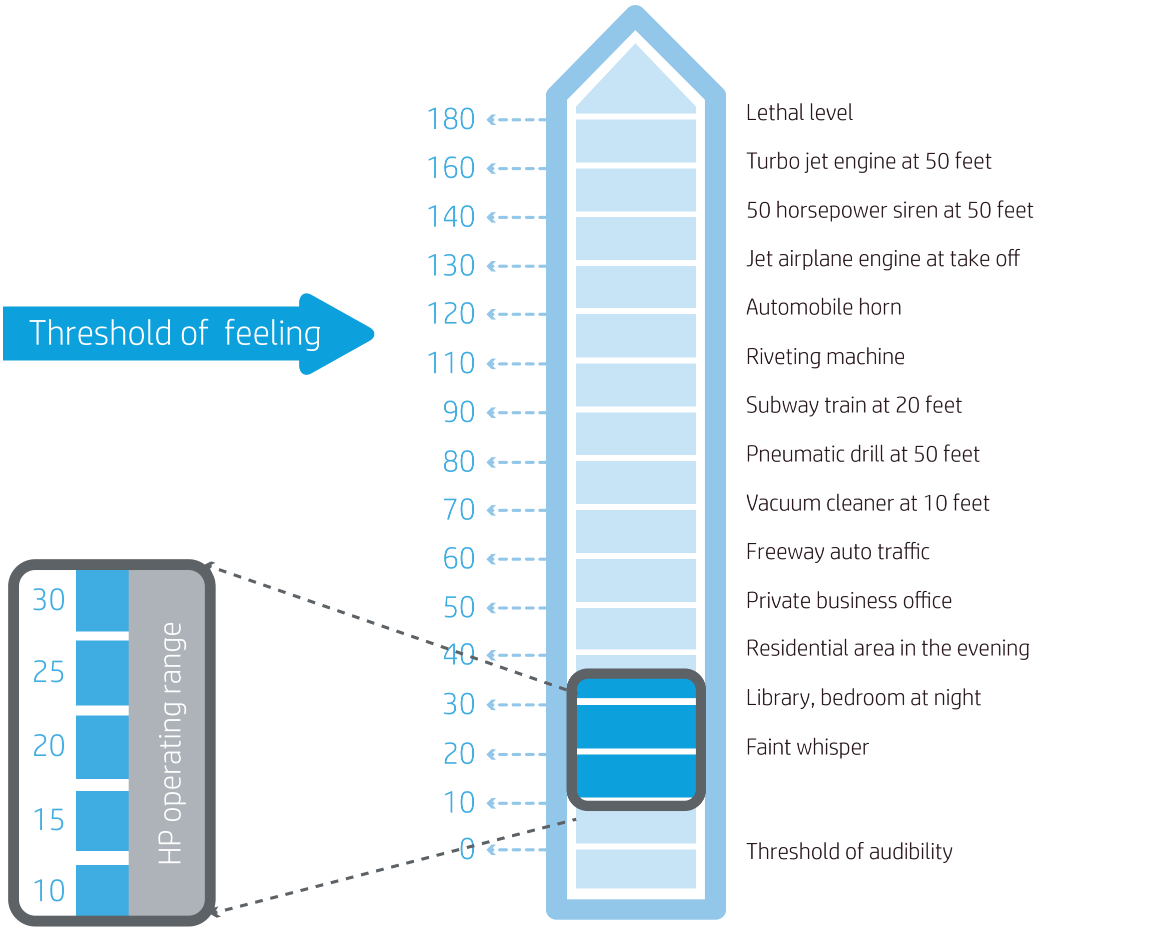
Figure 3. Tone, sound and noise



Acoustic noise is often measured as A-weighted sound pressure in decibels (dBA). A-weighting attempts to account for the fact the human ear perceives certain frequencies to be louder or softer than others. The decibel is a logarithmic scale where 10 decibels (dBA) equates to a 10x change in the sound pressure. An increase of 10 dBA in a sound is generally perceived as that sound becoming twice as loud.

The typical operating range for HP Z440 and Z840 Workstations is 10 dBA to 35 dBA. The scale in Figure 4 shows the decibel level for some common sounds.

Figure 4. Common sound pressure levels in decibels (dBA)



Acoustic noise in personal workstations

Acoustic noise is generated by multiple components within a workstation, such as hard disk drives (HDDs), optical disk drives (ODDs), liquid cooling pumps, fans, and blowers. Fans and blowers are often significant producers of acoustic noise. Workstations commonly contain multiple fans and blowers with various functions. Some may be used to exhaust air from the interior of the chassis, others may provide cooling for graphics cards, memory, and processors. The speed at which a fan or blower operates depends upon the cooling requirements. To remove excess heat, fan speeds are increased, causing a corresponding increase in acoustic noise.

Reducing acoustic noise

Fan speed, and thereby acoustic noise, can be reduced in two ways: decrease the amount of heat produced or use more efficient cooling mechanisms. For example, lowering processor frequency or decreasing the number of active processor cores are some ways to reduce generated heat. However, doing this results in lower system performance. Reduced performance is not acceptable since performance is a critical value proposition for workstations. Thus, more efficient cooling systems are usually the most effective way to lower acoustics.

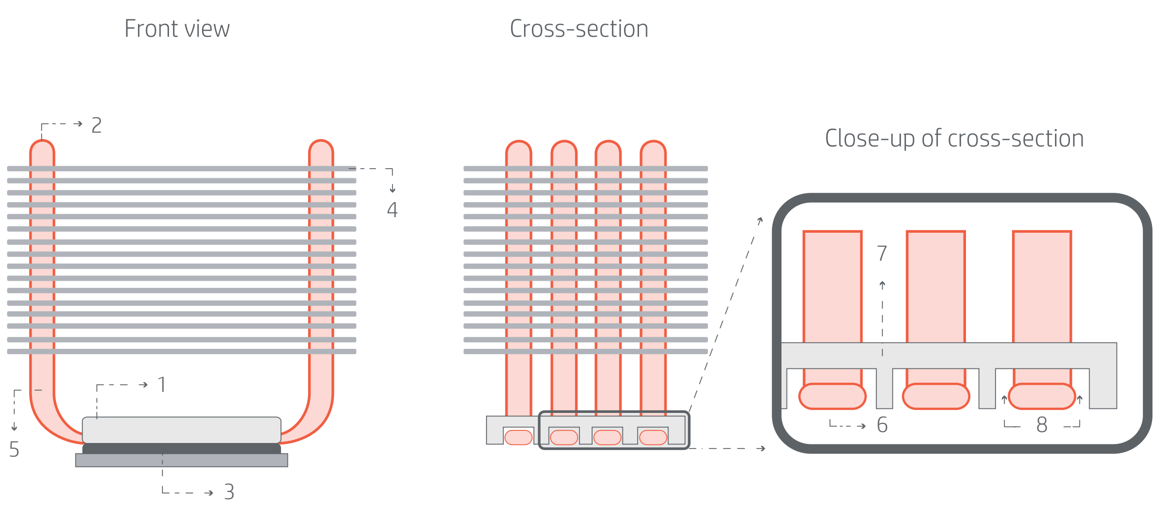
Cooling technologies

Traditional cooling

Traditional processor coolers (see Figure 5) use a heat spreader such as an aluminum block (#1) with heat pipes (#2) press-fit or soldered on to remove heat from the top of the processor (#3). The opposite ends of the heat pipes (#2) pass through a heat exchanger (#4), also called a "fin stack," to release heat. The main disadvantages to this design are:

- The heat pipes must be bent (#5) to transition between a horizontal state across the processor to a vertical state through the fin stack. Bending reduces the thermal capacity of the heat pipes, sometimes as much as 50 percent.
- The heat pipes are tubular and must be flattened (#6) to increase the contact area with the processor. Flattening reduces the thermal capacity of the heat pipes, sometimes as much as 50 percent.
- The heat pipes have gaps between them (#7) that limit the contact area with the top of the processor, hence the use of the heat spreader.
- The heat spreader has thermal conductivity 10x to 100x lower than the heat pipes, so the larger the heat spreader the lower the overall thermal conductivity of the assembly.
- There are inherent air gaps around the heat pipes (#8). Air is a poor thermal conductor that has thermal conductivity several orders of magnitude lower than metal. In order to improve efficiency in the heat transfer between the heat spreader and the heat pipes, these gaps must be filled with metal (e.g. solder) or another thermal conductor (e.g. thermal grease). These air gaps, even when filled, contribute to hot spots on the top of the processor.

Figure 5. Traditional heat pipe cooler

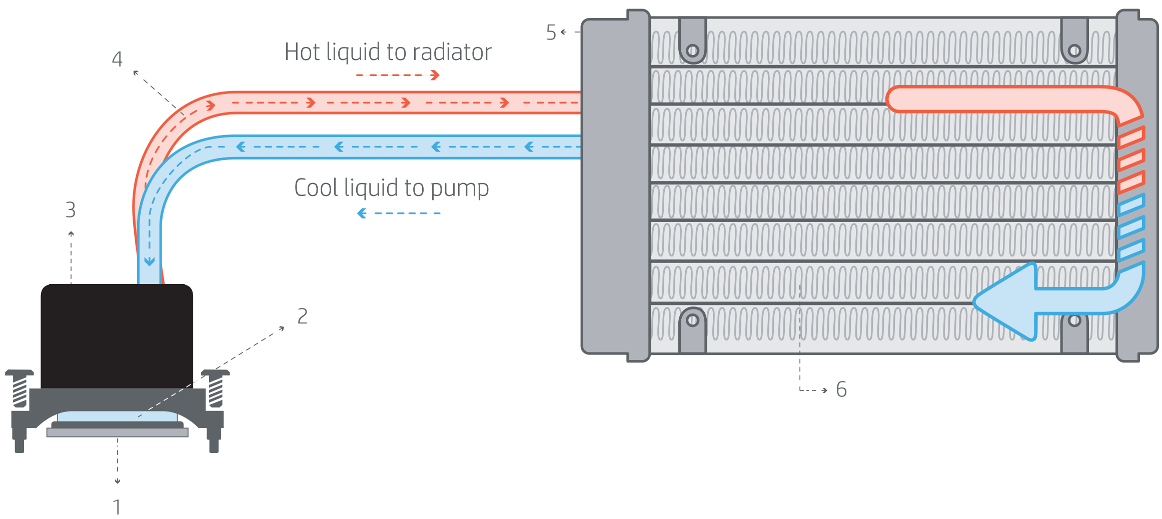


Liquid cooling

In a pump-driven liquid cooling system (see Figure 6), the heat spreader in contact with the processor (#1) is referred to as a “cold plate.” The cold plate (#2) is a metal block that has channels through which liquid can circulate. A pump (#3) pushes liquid through the cold plate to pick up heat and then circulates the liquid through hoses (#4) to a heat exchanger (#5) to release heat. The main disadvantages to this design are:

- It is a complex assembly of cold plate (#2), pump (#3), hoses (#4), and heat exchanger (#5).
- The heat exchanger, also called a radiator, is constructed much like a miniature automobile radiator. It typically has many rows of tightly spaced fins (#6) with a high resistance to airflow. Increased airflow resistance typically results in higher acoustic noise from the cooling fans.
- The radiator is often large and occupies valuable space within the chassis.
- The pump and hose connections are added points of potential failure.
- The pump can only move a liquid. If the liquid changes phase (evaporates or freezes), the pump stops operating as expected and is often damaged.

Figure 6. Pump-driven liquid cooling system



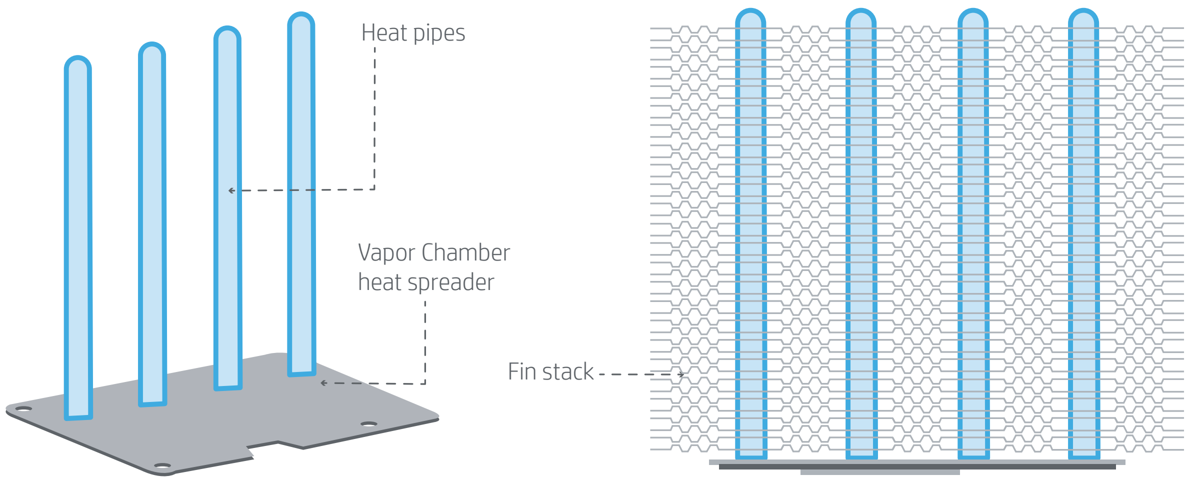
3D Vapor Chamber

In the case of the HP Z Coolers, the heat spreader and heat pipes (or cold plate and pump) assembly are replaced with a single 3D Vapor Chamber.

What is a 3D Vapor Chamber?

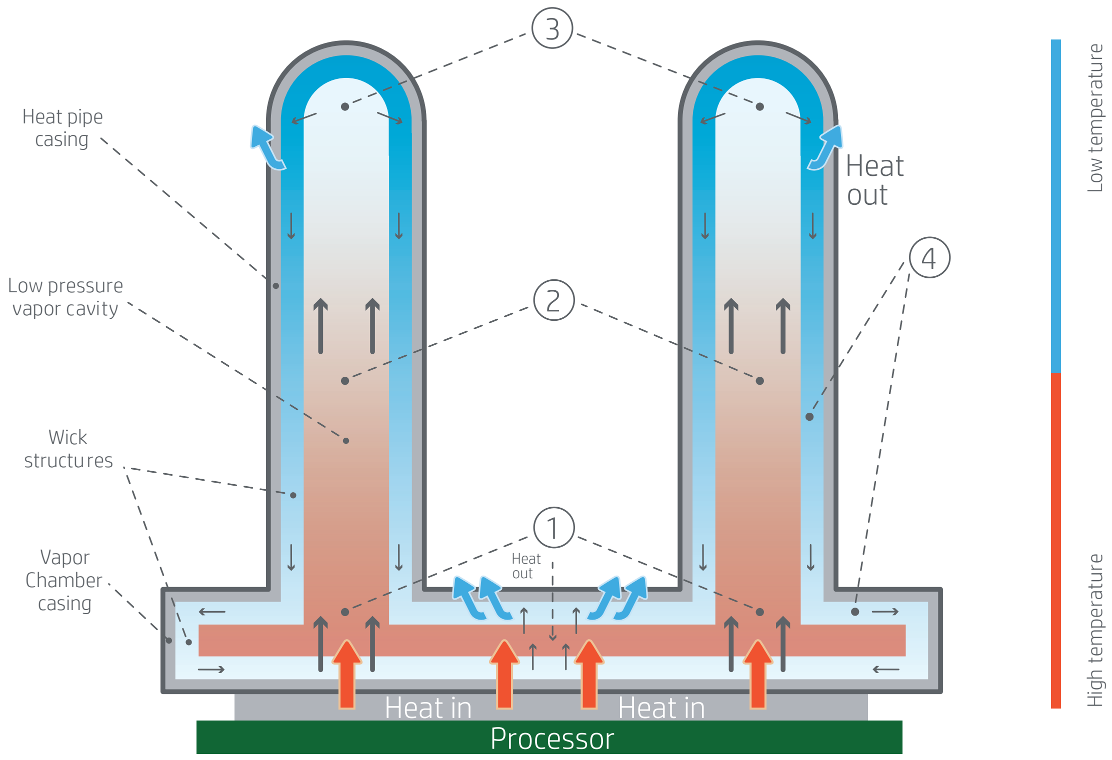
A 3D Vapor Chamber is a hybrid of a Vapor Chamber heat spreader with one or more heat pipes (see Figure 7), joined into a single unit sharing the same thermal cycle (evaporation/condensation — see Figure 8).

Figure 7. 3D Vapor Chamber and fin stack



How does a 3D Vapor Chamber work?

Figure 8. 3D Vapor Chamber operation



The 3D Vapor Chamber thermal cycle

1. At the high temperature side of the Vapor Chamber the working fluid evaporates, absorbing energy and creating a pressure gradient.
2. The pressure gradient causes the vapor to migrate across the Vapor Chamber cavity to the low temperature side. The vapor also migrates along the low pressure cavity of each heat pipe to the low temperature end.
3. The vapor condenses and is absorbed by the wick structures, releasing energy.
4. Capillary forces move the working fluid back through the wick structures to the high temperature side of the Vapor Chamber where the thermal cycle repeats.

What are the advantages of a 3D Vapor Chamber?

Using a Vapor Chamber instead of a solid metal block as the heat spreader can significantly increase heat transfer from the processor. Due to the phase change of the liquid inside, the Vapor Chamber has thermal conductivity 10x to 100x greater than solid metal.

The large Vapor Chamber Heat Spreader completely covers the processor, creating an isothermal (uniform temperature) surface that eliminates hot spots and improves heat transfer.

The heat pipes are an integral part of the Vapor Chamber, sharing the same working fluid and thermal cycle (evaporation/condensation). By eliminating mechanical interfaces between the heat spreader and the heat pipes, heat transfer into the heat pipes is improved when compared to traditional cooling methods.

The heat pipes are naturally perpendicular to the heat spreader; no bending is required. This improves the heat pipe efficiency when compared to bent pipes and helps optimise the heat pipe placement within the heat exchanger.

The 3D Vapor Chamber is a single hermetically sealed unit with no pumps or hoses, so it has the simplicity and reliability of traditional heat pipes with better thermal performance than a liquid cooling system.

Hex Fin (honeycomb) Heat Exchanger

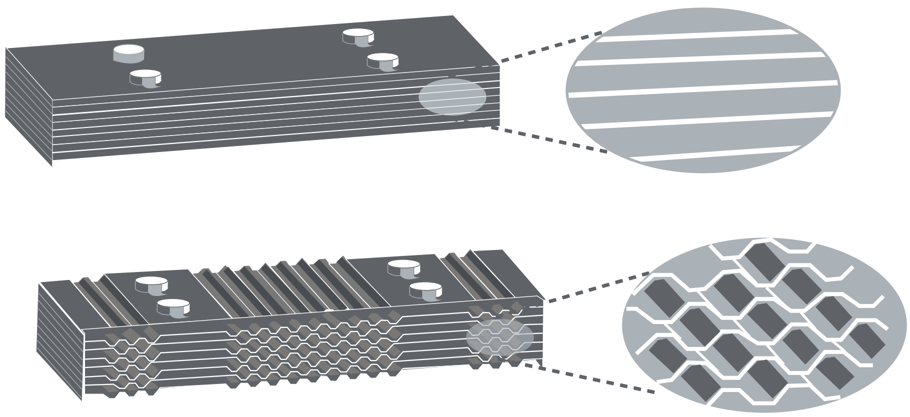
After heat has been removed from the processor, it needs to be transferred to the surrounding air so it can be removed from the chassis; this is done via a heat exchanger. In a traditional processor cooler, the heat exchanger is a series of flat parallel metal plates known as a “fin stack.”

In a pump-driven liquid cooling system, the heat exchanger looks like a miniature automobile radiator with alternating rows of liquid tubes and tightly spaced fins.

The efficiency of heat transfer into the ambient air highly depends upon the airflow through the heat exchanger and the surface area available for heat transfer. These factors tend to work against one another in that adding fins to increase surface area also increases the airflow resistance (impedance), thereby reducing the total airflow.

In order to optimise the balance between surface area and airflow, a new HP fin design has been created. The HP Z Coolers use specially designed fins with an alternating pattern that forms a series of hexagonal “tubes” similar to a honeycomb (see Figure 9).

Figure 9. Flat fin stack vs. Hex (honeycomb) Fins



Staggered Fin Edges

As air flows into the hexagonal "tubes" formed by the Hex Fins, boundary layers are formed along the walls of the tube. A boundary layer is a region where the velocity is less than the maximum speed of the air stream (see Figure 10). Eventually the boundary layers from each wall reach one another and the flow is considered "fully developed." Fully developed airflow has better heat transfer than partially developed airflow. In order to encourage fully developed flow to occur sooner, the HP Z Cooler hex fins have a specially designed HP Staggered Edge for the entrance to each tube (see Figure 11).

Figure 10. Boundary layer and flow formation in a normal tube

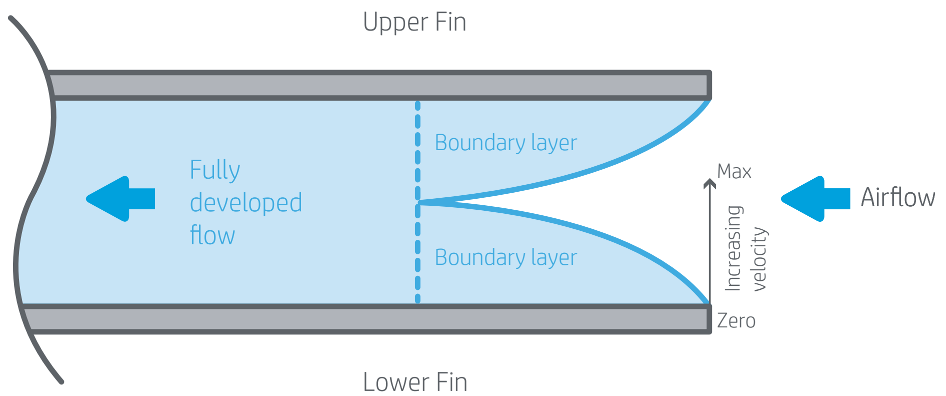
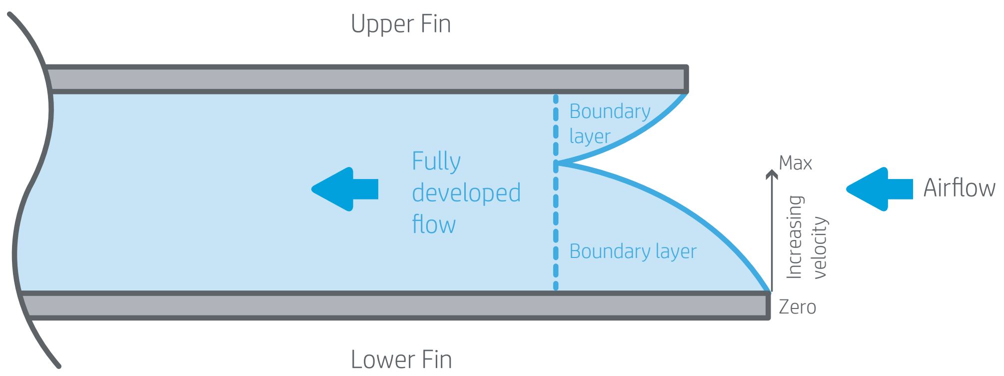


Figure 11. Boundary layer and flow formation in a Staggered Edge tube



Acoustic benefits of the HP Z Coolers

The superior thermal efficiency of the HP Z Coolers helps deliver lower processor-induced acoustic noise than traditional cooling methods at high frequency, high power processor operating states. In fact, HP R&D laboratory projections for acoustic improvements when comparing the HP Z Cooler to the standard cooler are reductions of up to 5 dBA (perceived as 30 percent quieter) on the HP Z440 Workstation and up to 4 dBA (perceived as 25 percent quieter) on the HP Z840 Workstation. These reductions in system noise create a more comfortable and productive work environment without sacrificing application performance.

In addition, studies have shown certain kinds of acoustic noise are more distracting than others, especially higher frequencies and irregular modulations. When a workstation executes a heavy cyclic processor workload, the fan(s) may ramp up and down rapidly with the workload, creating these irregular modulations. The high thermal capacity of the HP Z Coolers helps to reduce these bothersome changes in fan speed, delivering a pleasant user experience even under the most demanding processor use.

Environmentally friendly

HP is committed to environmental sustainability. The HP Workstation design team has taken a proactive approach beyond industry regulations to improve system recyclability and implement materials that are safe and environmentally friendly. HP Z Coolers are recyclable, constructed with low halogen materials and use non-hazardous de-ionised water as the working fluid resulting in a fully recyclable cooling solution.

Conclusion

As a technology leader, HP continues to innovate in the area of thermal management to improve the user's experience and productivity. HP is using its extensive experience and expertise in thermal management and workstation engineering to develop today's high performance, quiet and environmentally friendly workstations while innovating for tomorrow's more powerful generation.

For more information
hp.com/go/whitepapers
hp.com/go/workstations
https://en.wikipedia.org/wiki/Sound

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