Stealing Heat: How to cool a computer

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Why is cooling so important?

The modern world is almost exclusively reliant on computers. Computers, in turn, rely completely on their CPUs- their Central Processing Units. According to ARM, a processor architecture company, the Central Processing Unit (CPU) is the primary component of a computer that acts as its “control centre.”(ARM [online] Available From: https://www.arm.com/glossary/cpu [Date Accessed: 15/04/2024 10:01 GMT]) The CPU does all the mathematical operations and logical comparisons that the computer needs to run, and in the end, is solely responsible for decoding and carrying out the instructions given by the user.

Because computers use electrical signals in order to operate, the CPU of a computer has a large amount of power flowing through it while in operation. Most desktop CPUs use somewhere around 60-120 Watts of power (Watts being, of course, the product of Potential Difference * Current) (Anker [online] Available From: https://www.anker.com/blogs/chargers/how-much-wattage-does-my-pc-need [Date Accessed: 17/04/2024 13:10 GMT]), although this can change depending on the workload of the processor (it uses less power sitting on the desktop than it does performing mathematical calculations), and the specifications of the processor itself.

Processors typically run at a potential difference of around 1.2 Volts, with variable current depending on what the CPU is doing. The performance of a processor is measured, in part, by its “clock speed”. Measured in Hertz, it is a measure of how many instructions a computer can carry out per second: a CPU with a clock speed of 1.2 GHz can carry out 1.2 billion instructions every second. The higher the clock speed, the faster the processor can run programs, and therefore some users choose to boost the clock speed above its usual range. This process is called “overclocking”, and requires “overvolting”- increasing the potential difference that the processor runs at. This leads to a greater amount of power in the CPU (because power is proportional to the potential difference), and therefore the CPU needing to dissipate a greater amount of heat.

Because a lot of power is passing through such a small area (CPUs are typically slightly smaller than a credit card), a lot of the energy is lost as heat. This heat needs to be dissipated into the environment somehow, otherwise the CPU will melt, and become unusable. To help combat this, CPU manufacturers invented the concept of thermal throttling: when a CPU reaches a certain temperature, termed T_JMax, usually around 100°C .(Puget Systems [Online] Available From: https://www.pugetsystems.com/support/guides/thermal-throttling/#:~:text=This%20temperature%20limit%20is%20known,temperature%20should%20not%20approach%20this./ [Date Accessed: 17/04/2024 13:21 GMT]). If a CPU detects that is is approaching this temperature, it runs slower (and therefore decreases in performance), in order to generate less heat and prevent damage. This is bad for the user, because it means that the CPU runs slower under heavy loads.

You might notice how if, when you use it for an extended period of time, the back of your smartphone heats up. This is a prime example of a computer overheating, and if you notice that your smartphone runs slower while this is happening, then that’s thermal throttling. Of course, there’s a fine line between a slight increase in temperature that users are able to tolerate, and the smartphone getting hot enough to burn the user’s face.

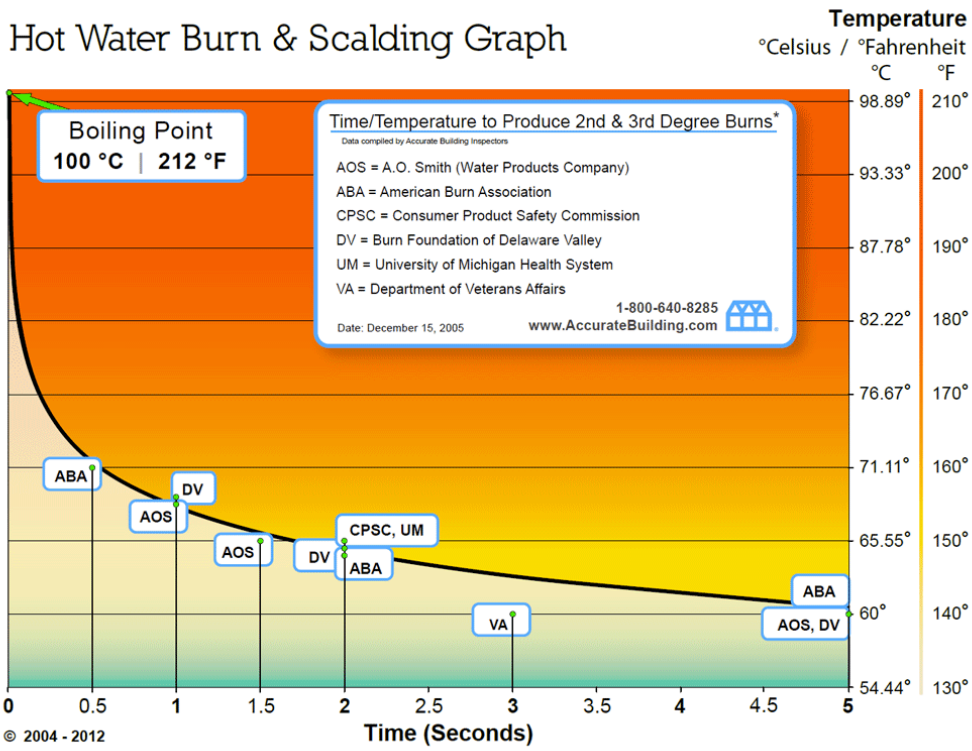


Image Credit: Accurate Building Inspectors

One thing that you can do at home to help cool your devices, particularly laptops, is to avoid putting them on soft surfaces, such as a blanket or a bed. This is because the weight of the laptop deforms the soft material, and the material blocks the air vents of the laptop. This means that hot air cannot be pushed out by the fans, and therefore the computer cools less effectively. While this is bad for the performance of your devices, this is also bad for your own safety, because of the fact that a soft material coming into close contact with hot air for extended periods of time is a huge fire risk.

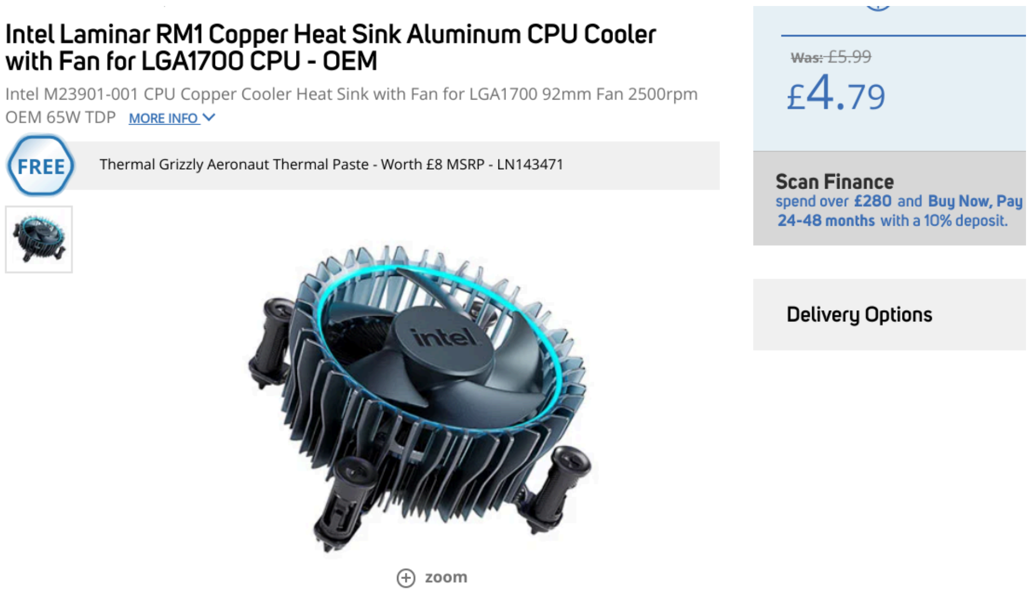
One reason that computers, particularly laptops, tend to run slower over their lifetimes is the fact that dust and grime gets into the cooling system. This means that fans get clogged, and remove hot air less efficiently, and it also means that dust covers the heat sinks, making them less able to dissipate heat, and making them less able to cool the CPU. This is a particular issue for laptops, as it is often very difficult to take them apart to remove the dust, and even if it is possible, many users neglect to do so. This contamination is one of the reasons why data centres (Places with lots of large computers all together in a room) operate like cleanrooms, with a negative pressure system in place to stop any contaminants from getting in.

What is the typical way that companies use to cool computers?

When choosing how to cool a product, the companies that make computers are forced to compromise between space, cost, and cooling capacity. They are able to choose from a wide selection of different cooling methods for their products, and are forced to make difficult choices in order to deliver a working product for a reasonable price.

Passive Cooling

The chromebooks we use at school are passively cooled. They include neither a fan nor a pump, and therefore the CPU inside them is limited. The CPU on the chromebooks in the All Saints RC Science department is the Intel Celeron N4020. This CPU is intended solely for mobile purposes, as is obvious by the fact that Intel does not sell it to consumers, only to OEMs (original equipment manufacturers) such as acer. A CPU like this is necessary, because a higher-end CPU would require active cooling. Nearly all consumer-grade Intel CPUs ship with a “stock” air cooler like this:



(Image Credit: SCAN)

A cooler like this would obviously not fit into a notebook laptop, and therefore mobile devices are forced to use much worse performing “mobile chips”. This results in worse performance, and is one of the main reasons that the smaller a computer needs to be, the more expensive it is.

Because an air cooler would be too expensive, loud, and bulky for many applications, many manufacturers opt for passive cooling, usually by using a heat sink. The goal of a heat sink, like all cooling methods, is to remove heat from a source and dissipate it to the environment. The performance (how much it cools) of a heat sink is given by the equation:
$Q_s = hA(T_s\text{-}T_{amb})$, where Q_s is the heat from the source being cooled (in this application, the CPU), h is the convection coefficient of the heat sink, A is the total surface area of the heat sink, T_s is the temperature of the source being cooled, and T_{amb} is the ambient temperature. This equation makes two things obvious: firstly, the higher the surface area of the heat sink, the better the performance, and secondly, the higher the ambient temperature of the environment, the worse the performance.

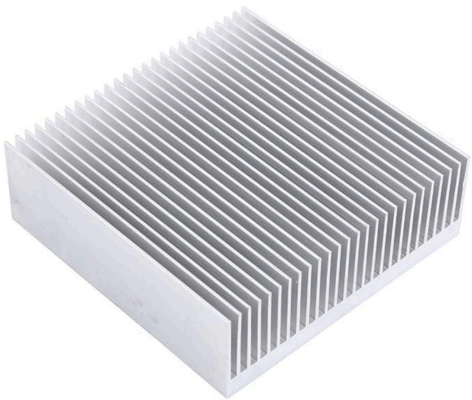


Image Credit: Amazon

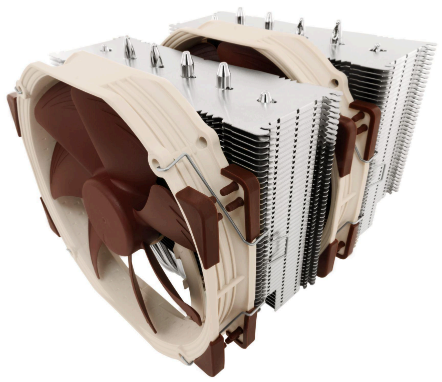
This second factor is a large reason why computers perform measurably worse in hotter environments, and is the reason why the Arctic World Archive is located in Svalbard- the extremely low ambient temperature of the arctic means that the energy needed to cool the facility is far lower (Arctic World Archive [online] Available From: https://arcticworldarchive.org/about/ [date accessed: 25/04/2024 10:39 GMT])

Combination Air/Passive Cooling

Something like the Raspberry Pi 5 (A SBC- Single Board Computer) can be both passively and actively cooled. The base computer is sold without a cooler, however an active cooler is sold by the manufacturer for work with “Heavy loads”. This active cooler includes a fan and a heatsink. The heatsink is a piece of thermally conductive metal, which conducts heat away from the CPU’s IHS (Integrated heat spreader- the piece of metal placed on top of the actual silicon chip to conduct heat away from it). The fan blows cool air past the heatsink, allowing the hot air to be released into the environment, and new cool air to be provided to the heat sink to conduct away more heat.

Air Cooling

Most desktop computers are air-cooled, using either a stock cooler (as pictured above), or an aftermarket cooler. Aftermarket coolers provide better cooling performance (and therefore less thermal throttling), but at a higher price. They do this by using larger heat sinks made of higher quality metal, and larger, more powerful fans. One such company that makes aftermarket air coolers is Noctua. One of their most popular products is the NH-D15, which is described on their website as “an elite-class dual tower cooler for the highest demands.” (Noctua [online] Available From: https://noctua.at/en/products/cpu-cooler-retail/nh-d15 [Date Accessed: 24/04/2024 13:11 GMT]).

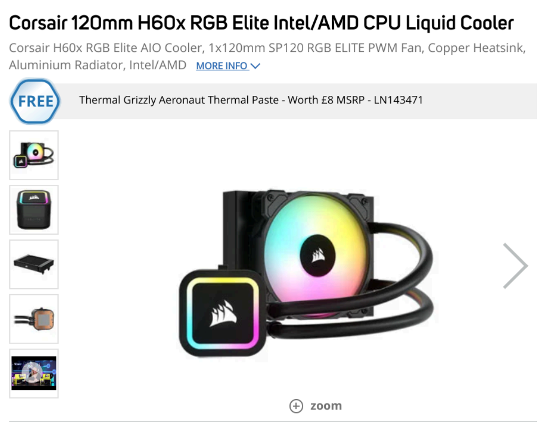


(Image Credit: Noctua)

As you can see, a good quality aftermarket cooler is significantly larger than a stock cooler. This results in the heat sinks having a much larger surface area, and therefore being able to dissipate more heat. Not only are there two fans instead of one, but the fans can run at much higher speeds (1500 RPM), and are much larger than the single fan on the stock cooler. This means that they can move a greater volume of air per second, and therefore can take away more heat. This also results in a greater rate of airflow in the computer as a whole, and therefore can improve the cooling of other components, such as the GPU as well.

Liquid Cooling

Some very high-end computers use liquid cooling. This can either be achieved by an AIO (All in One) cooler, as pictured below, or by using custom loop water cooling. Water cooling is significantly more expensive than air cooling, as it requires many more components.



In order to water cool a computer, you need a “water block” for each component you wish to water cool, a pump (to move the water around), a reservoir (to hold the coolant), and a radiator (to cool the coolant, and release the heat into the environment).

While it is typically called “Water cooling”, a wide range of coolants can be used in place of water, such as ethylene glycol and hexene. However, because of its cheapness and availability, by far the most common coolant is deionised water. The water needs to be deionised, because should it leak and spill onto the computer, the fact that it is deionised means that it can’t conduct electricity. This is because electric current is just a flow of charge, and if there are no charged particles that can move around, no current can flow- the water is not electrically conductive. Furthermore, it is important to use distilled water, because otherwise some of the minerals in the water could cause blockages in the cooling system.

What’s the theoretical best way to cool a computer?

The world record for the highest clock speed ever achieved is 9.117.75 GHz (9.117.75 billion clock cycles per second). This was achieved by a team from Asus, Intel and Elmor labs in March 2024. They used a top-of-the-range intel CPU, with liquid helium cooling, and the IHS removed. Removing the IHS is dangerous for most consumers, because while most of the CPU has temperature sensors, some parts of it get hotter than others. The effect of this is greatly reduced by the IHS, and without it, if the cooler is improperly installed, it is possible for parts of the CPU to melt without thermal throttling. Furthermore, liquid helium cooling is, of course, impractical to have in consumer PCs.

What is the best solution for most users?

For many applications, the best way to cool a computer is by passive cooling. It would be too bulky to include an air cooler in nearly all mobile applications, and with modern chip technology, the CPUs in mobile phones are easily powerful enough to run most of the applications they are needed for. For desktop and laptop computers, by far the most common and reliable method is air cooling. While it doesn’t provide the best performance overall, it is by far the most economical method of cooling, and has the advantage that it can be repaired by anyone, even someone who isn’t an expert in complex water cooling systems. However, one key disadvantage of air cooling is noise. Many users strongly dislike computers that are too loud, and this can in some cases encourage people to remove, or otherwise disable the fans that keep their devices cool. Furthermore, many applications need the devices to be silent, such as the projectors in a movie theatre, or a television, in which the noise of the fan might interfere with the audio of the content being shown, especially in a quiet scene.

Custom loop water cooling provides the best performance that is sustainable for long periods of time in a home environment. It can be tailored to the specific needs of the user and their computer, and it has the advantage over an AIO cooler that it can be modified to cool an entire system rather than just the CPU. This means that, theoretically, a custom loop water cooling system could be used to create an entirely silent PC (except noise from the pump), which in some situations can be extremely useful. Furthermore, because the heat from the CPU can be carried to a different location using the coolant, the heat can be recycled, to heat things like a swimming pool or a home. One such example of this is Linus Sebastian’s “Pool Watercooling” (https://www.youtube.com/watch?v=wjO6OLmZB9A), where the heat from his server rack (a rack filled with powerful computers) is used to partially heat a swimming pool in his back garden.

I would conclude that the actual best way to cool a computer, for most consumers, is AIO water cooling. The performance it provides is nearly as good as the performance of custom loop water cooling, and it is nearly as easy to install as an air cooler. Because of the fact that it is a sealed system, the user needs to be much less worried about leakage, and this makes it a much more reliable method of cooling a computer. In some ways, it is easier to use than an air cooler, because most of the space that it takes up within the case is taken up by the radiator, which can be mounted to the side of the case. This is in contrast to an air cooler, where the entire cooling system needs to be directly on top of the motherboard (the main circuit board that connects all the components of the computer together). This can make it difficult, or even impossible, to add, remove or maintain other components of the computer, and for this reason, AIO water cooling is significantly more convenient than air cooling.