Abstract

Cooling is a process integral to the operation of every computer in existence and many electronic circuits. The reasoning for this importance lies in the connection between component temperature and performance. This fact leads to the question in focus: To what extent does temperature affect computer performance? Research, experimentation, and analysis of collected data show that the computer does function better when cooling power is increased. These findings directly affect businesses that rely heavily on computers. Through the use of upgraded computer cooling systems, especially simple liquid cooling setups, companies may increase computer longevity and decrease maintenance and turnover costs.
1 Introduction

In the ever-growing world of modern technology, one of the most integral pieces of equipment is the personal computer. Personal computers have come a long way from the very first electro-mechanical binary programmable computer in 1936 and the first personal computer in 1953 [2]. Computers have changed the ways in which people do work, learn, access information, live, and interact. However, even such machines of great power and ability lack perfection.

Computers put off heat. As mechanical and electrical objects, this is to be expected. However, every mechanical and electrical device has a point at which the temperature in and around it begins to cause issues. Even prior to this point, performance may be affected by increased amounts of heat [3]. This is the key focus of this work: the affect of temperature on computer performance.

“Computer cooling is vital for proper function and longevity of electronic components” [25]. The practical application of cooling will be discussed in section two, including specifics for where and how cooling should be applied. However, the implications of this “proper function and longevity” go beyond simple home computer usage.

In 2002, a study found that, of the more than one billion personal computers sold since the 1970s, seventy-five percent of these were for work and professional use [10]. While this number has risen since its discovery thanks to the growing number of businesses, these 2002-numbers are sufficient to prove the point here: any problems that may resolve in a computer, in regards to function or longevity, would have a greater impact upon professional users as compared to home users. It would also be reasonable to assume that a computer owner who uses their machine for the purpose of making a living stands to lose much more from a malfunction than does an owner whose livelihood is not tied up in their computer.

Before examining the data surrounding impact costs and related issues, it is important to discuss the theory and methods of cooling computers in order to provide a proper background for the experiment detailed in this paper. This will be followed by a description of the experiment and the results collected from the tests. Finally, the connections between these tests and the business environment will be drawn and future developments for this project will be listed.

2 Background

In the following subsections, descriptions will be given for the practical applications of cooling computers. It is important to note that not all of these locations need a cooling solution above what is typically provided with the stock parts. However, for many of these locations, improved cooling does lead to improved performance.

2.1 Important Places to Cool

A glance at the website of any retailer of computer cooling equipment makes it obvious that the greatest number of cooling solutions available on the market are aimed toward use on the Central Processing Unit [29]. Also known as the CPU, this component is the brain of the computer. Any problems with the CPU bring assurances of computer malfunction. A faulty CPU cooler, or
the lack of a CPU cooler, can cause instantaneous CPU overheating and immediate computer shutdown [4].

While the cooling solutions need not be as intense and powerful as those for the CPU, it is nonetheless very important to cool the Graphics Processing Unit. The GPU may take the form of an integrated graphics unit on the motherboard or a separate graphics card. Often, the separate graphics cards contain their own cooling mechanisms, integrated with the card and not able to be modified.

The north and south bridges handle all communications on the motherboard. This includes communication between integrated components and motherboard peripheral [9]. Some type of cooling setup is almost always utilized for these two areas. Upgraded cooling solutions may be used, but they are not commonly available [29].

The power supply unit of the computer generates a lot of heat during the transfer of electricity. All power supply units contain their own solutions for cooling the internal components. These are not typically modified for greater cooling, as they are primarily self-contained units.

Hard disk drives and RAM (Random Access Memory) are oftentimes left uncooled. However, even cooling these components will provide some measure of improved performance. Aftermarket parts are available for purchase that provide cooling solutions for these areas [29].

2.2 Casing and Airflow Theory

An important distinction lies between the two genres of cooling solutions: active and passive. The difference between them is integral to the understanding of theories of cooling. Active cooling solutions are components such as fans or waterblocks, typically containing moving parts [4]. On the other hand, passive cooling involves non-mechanical methods of cooling, such as heat sinks, heat pipes, or even leaving the components open to the air [4]. These examples will be discussed in greater detail in section 2.3.

When looking to improve the cooling of a computer, it is important to take into consideration the component storage. Computer cases have been built from a large variety of materials, and each material has its own thermal conductivity. Acrylic, steel, and aluminum cases are popular options. Acrylic, while attractive, tends to have a much lower conductivity than steel, which has a lower conductivity than aluminum. The lower the conductivity, the more heat will be contained passively by the case [25]. This excess heat will need to be moved away
from internal components, which can be accomplished in large part by active cooling solutions.

There are considerations to be made within the case as well. Airflow can significantly affect the cooling of a computer if heat is not properly dispersed from around the components. The following diagram shows the theoretical flow of air through a standard-size computer case, which is equipped with air cooling solutions, taking into account scientific properties of heat (in this case, convection) [14].

![Diagram of theoretical computer airflow](image)

Figure 2. Diagram of theoretical computer airflow [6].

As can be seen above, ambient temperature air enters the front of the case and begins passing over the components. Some of this air is used to cool the central processing at the rotational arrow. The now heated air is often carried out the back or top of the case by means of a fan. Some air is additionally drawn up through the power supply unit at the rear back of the case and ejected from the back.

The amount of air being drawn into the case and ejected from it affects the ambient case temperature. When more air is being drawn into the case than ejected, a positive pressure system is created [25]. The advantages of positive pressure in the computer case have nothing to do with cooling, and this system will decrease the cooling effectiveness of any cooling solutions being used. However, a case with negative pressure will more effectively cool the contained components, as this system maintains a constant flow of air through the case [25].

2.3 Methods of Computer Cooling

While certainly the most common of all methods of computer cooling, fans are only the tip of the iceberg when it comes to solutions for lowering component temperature. In the following sections, a brief overview will be given to showcase some of the myriad options. Air cooling is by far the most common and, thus, the foremost discussed.

2.3.1 Air Cooling

Choices for computer fans cover a vast range, as a number of variables combine to create the options. Fans may vary by size, speed (and whether or not they are variable speed), decibel level, and the number of fins [25]. Additionally, the airflow of the fan may be different depending on how it is designed. Axial-flow fans are by far the most common and can by likened to a ceiling fan. Centrifugal fans use impellers to draw air into themselves and force it in another direction [23]. Cross-flow fans also work with impellers to move air without the direction change [7].

The reasoning behind the variables in
computer fans often remains situational. The size of a fan is often determined by its placement in the computer case or with the component. Higher fan speeds are typically desired in server setups, computers for gaming, or computers that are used for heavy graphics processing. Utilizing fans with variable speeds may save energy, allowing the user to employ higher speeds during times of heavier usage. The speed of the fan also has an impact on the decibel level of the fan’s ambient noise. This may be an additional reason for utilizing variable speed fans. Consequently, some users desire quieter computer setups and are willing to sacrifice money and/or performance to gain lower noise levels [4].

2.3.2 Liquid Cooling

In recent years, there has been a growth in another area of computer cooling: the use of liquid coolants to lower component temperatures. Liquid cooling systems work much like the cooling systems in automobiles as coolant is passed over vital components, draws away heat, has this heat dispersed by means of a radiator, and continues through the cooling circuit again. When liquid cooling systems were relatively new technology, it was necessary to assemble all of the components individually, fit them into the machine, and tune everything manually [12]. However, as liquid cooling increases in popularity, other options have arisen that make this cooling solution more viable for those who are less technically inclined.

Custom liquid cooling setups remain the best friend of those looking to lower their component temperatures by a great degree. Nearly all of the components, mentioned previously as important places, can be cooled with a single liquid system setup. However, these setups typically require larger amounts of space in which to fit the radiator, coolant tubes, cooling mounts (the mechanisms by which components are directly cooled), and sometimes a coolant reservoir or separate power supply [24]. They also require a certain high level of technical knowledge to acquire the necessary components and assemble them properly [12].

For those whose liquid cooling needs are less intensive or those whose technical expertise is not at the level of assembling a custom liquid system, simpler liquid cooling setups exist. These systems are closed loops comprised of a cooling mount, several tubes, and the radiator apparatus. While they typically only cool the central processing unit, these liquid cooling kits are more cost-effective than purchasing separate components [26]. The skills necessary to install one of these closed-loop systems are also much less technical than those with a custom setup [4].

2.3.3 Miscellaneous Active Cooling

Air and liquid solutions are not the only methods of active cooling. However, they are the most common on account of other methods being more expensive, less feasible, or aimed at more specialized setups and situations. In the fairness of presenting a broad overview of computer cooling, some of these other methods are worth mentioning.

Full-immersion cooling setups involve submerging all of the computer components (except the harddrive) into non-conductive coolant and then allowing the ambient air or a radiator carry away the heat generated
from the components. This setup is essentially liquid cooling for the entire computer. While it may look impressive, as it is often built in an aquarium tank with colored lights, it is also an expensive solution, as the most popular liquid coolant to use is mineral oil, which is difficult to acquire in many areas [18].

The use of dry ice, liquid nitrogen, and liquid helium in computer cooling falls in the realm of “extreme cooling.” Because of the short lifespan of such materials as coolants, they are typically only used for short overclocking sessions. Overclocking is the process of pushing computer components to their limits in order to benchmark the extent to which these components can perform. Each of these three coolants tends to provide incredibly low temperatures with liquid nitrogen performing better than dry ice and liquid helium lowering temperatures further than the other two. As previously mentioned, their short lifespan makes them of little use for anything other than benchmarking. Additionally, the cost factor and difficulty of implementation would make regular use incredibly inefficient [1].

Phase change cooling involves the use of basic refrigeration principles to cool computer components, especially the central processing unit. Using either evaporators or special liquid-chilling units, the temperature of the coolant is dropped below freezing to provide an even greater boost to component cooling. Aside from cost, the primary trouble with phase change systems is that they are quite noisy on account of the special components used [1].

2.3.4 Passive Cooling
A number of passive cooling solutions exist that are to be used in conjunction with various active cooling systems. Even in stock computers, some of these solutions may be seen in conjuction with fans or liquid setups [4]. In fact, even when attempting to achieve benchmark scores through the more extreme methods of active cooling, various passive cooling solutions are still integrated into the setup as a whole [1].

Heatsinks are designed to transfer heat into themselves from components and dissipate it into the surrounding air. They are typically designed with a large surface area-to-volume ratio, using materials that are high in thermal conductivity. Heatsinks must also have perfect contact with the component for the best heat transfer [20]. This point in particular will be discussed in section 2.3.5.

Heat pipes are typically used in conjunction with heatsinks, where the heat pipes syphon heat off a component and transfer it to another heatsink. They are designed as thin pipes with water running through the hollow center. Using laws of heat transfer, heat pipes raise the thermal conductivity of the cooling system many times more than it would be otherwise. However, heat production does not take place in heat pipes. Therefore, achieving temperatures lower than the ambient level is impossible via heat pipe alone [19]. On the other hand, producing heat and consuming energy is part of another method of passive cooling, known as Peltier, or thermoelectric, cooling.

Peltier cooling utilizes the Peltier effect to cool components, hence the name. The Peltier effect involves using a voltage and
thermocouples (dissimilar metals connected in such a way that there is a temperature differential between them) to create a sort of heat pump. When several of these setups are put in series, they form the basis for a thermoelectric, or Peltier, cooling mechanism. As the usage of voltage technically causes Peltier setups to become active cooling solutions, the base components are passive devices. Peltier coolers have no moving parts, require low maintenance, and having cooling capabilities that are on par with larger and more complicated active solutions, such as phase change cooling. Despite these advantages, they are very complicated to set up and properly tune to the computer [21].

Heat spreaders serve to do just as their name suggests: spread the heat from a component over a larger surface area. This improves the dissipation of said heat. Typically found on modules of RAM (random access memory), heat spreaders are a cost-effective solution to increased RAM cooling [11].

“Open bench” computers are designed to leave all of the components open to the surrounding air. Instead of residing in a computer case, the components are mounted on a skeletal rack so that they are all visible and to allow air to more freely pass through them. Various active cooling solutions are used in conjunction with this setup. [4].

2.3.5 Cooling Modifications

Various cooling solutions for computer components may be further modified in order to increase their efficiency. While these are not strictly necessary, many of them have been implemented by companies in the computer cooling industry. The intention of these companies is to further improve upon their own products beyond their stock implementations.

Thermal compound, also known as thermal paste, thermal grease, or more technically, “Thermal Interface Material,” serves to improve the movement of heat from the central processing unit or other computer component to the heatsink or other cooling interface. The reason for using thermal compound is that the surfaces of cooling interfaces and computer components are not perfectly flat and even. A small application of thermal grease between these surfaces serves to fill the miniscule air pockets and form a more conductive contact between those same surfaces [22].

As previously mentioned, heatsinks must have perfect contact with the component for the best heat transfer. While thermal compound helps to “fill in the gaps, another option is often utilized, especially by computer cooling enthusiasts. Known as heatsink lapping, the process essentially involves utilizing sandpaper of multiple grits to flatten and polish the contact surface of the heatsink to a more perfect degree. Often, this process provides a decent drop in component temperatures at a relatively low cost [15].

The idiom of “cleanliness is next to godliness” applies to computing as well. However, properly managing all of the cabling within the computer case will provide benefits beyond merely looking nice. Cable management will improve the airflow within the case and keep components cooler. In addition to properly managing cables, using rounded cables instead of flat or ribbon-style cables will prove beneficial [4].
2.3.6 Electronic Cooling Settings

Lower computer component temperatures may also be acquired without the use of physical setups. The process of “soft cooling,” as these methods are often termed, varies based on the components. Some components may be undervolted. The process of undervolting involves lowering the voltage provided to the component [8]. While this may decrease performance, less voltage in the component will result in less heat being emitted [4]. Underclocking is another form of soft cooling. This lowers the central processing unit’s speed [8]. The reduced workload may result in some decreased performance, but it will also cause the CPU run at a lower temperature [4]. Occasionally, “control of halt” instructions can be utilized to stop or pause unnecessary computer components, reducing heat through reduced activity [8].

2.4 Other Applications of Cooling

The cooling of electronic components extends beyond the use in desktop computers. Laptop computers are another obvious application. Additionally, the rise of video game consoles has lead to a new niche in component cooling as people strive for the best performance possible in their video games.

2.4.1 Laptops

There are far fewer options for the cooling of laptop computers than for desktop computers because of the smaller enclosure of the components. Typically, laptops utilize combinations of heatsinks, heat pipes, and air cooling to disperse heat. However, some laptop components are intentionally brought into contact with the laptop casing in order to dissipate heat passively [4].

2.4.2 Video Game Consoles

Video game console cooling solutions are sought by hardcore gaming enthusiasts. Because modern video game consoles are essentially computers inside, many of the same cooling solutions for computers can be adapted to video game consoles. Heatsink modifications, air cooling upgrades, and liquid cooling setups are sold for such consoles as the Microsoft Xbox, Nintendo Wii, and Sony PS3 [27, 28].

3 Experiment

“What impact does computer cooling have on businesses, and what affect might this have on maintenance and turnover costs?”

This project intended to investigate the effect of temperature on computer performance. Having covered a broad overview of the integral components to be cooled and the methods by which this could be accomplished, this information was then put into practice. The intention was to collect solid data regarding the effectiveness, and importance, of various computer cooling solutions. To narrow the field of investigation and to make it more relevant to real world issues, the question above was the focus of the experiment.

3.1 Tests

In order to more closely adhere to the parameters of the question under investigation, all of the variables were chosen to be as
closely representative of a real work environment as possible, while allowing for certain limitations of resources and requirements for control.

3.1.1 Setup

The experiment was performed in an enclosed, 10’ by 12’ room. The size room was representative of many office workspaces, and the reason for enclosure lies in the lack of proper air circulation in some professional environments. A consistent temperature of 76 °F was maintained in the room so that any environmental change came from the computers themselves. Aside from the primary computer on which tests were being run, there were four other running computers in this room: three desktops and a laptop [4]. Again, the purpose in adding these extra computers was to simulate a realistic work environment.

The fifth computer in the room was the computer on which the cooling tests were to be performed. This computer was a custom-built machine in a DiabloTek CPA-0280 Elite ATX Mid Tower Case. The motherboard was a GIGABYTE GA-880GM-USB3 REV3.1 AMD 8 Series AM3+ with an AMD Phenom II X6 1035T processor and 4GB of DDR3-1333MHz RAM. The hard drive was a Seagate Barracuda 7200 RPM 500GB hard disk drive.

3.1.2 Description

For the purpose of maintaining a control setup and investigate multiple solutions, three different variations on the same hardware were used. From one test to another, the only things that varied were the active cooling solutions. Heatsinks, heat spreaders, and the arrangement of components and cables within the case were not changed from between tests. The following are the three test cases.

1. Stock Air-Cooled System
2. Modified Air-Cooled System
3. Basic Liquid-Cooled System

The stock air-cooled system utilizes no additional cooling solutions other than those that were already built-in to the computer components. Therefore, the components in this setup are all passively cooled with the exception of the CPU, as the heatsink has an integrated cooling fan.

In the modified air-cooled system, the air-cooling was upgraded to improve the cooling efficiency. Two Masscool 120mm fans were added to the case. One was placed in the front of the computer case in order to draw in more air. The second was affixed in the upper rear of the case to exhaust warm air.

The third setup changes directions away from air cooling. Both of the case fans were removed. The CPU heatsink with its integrated fan was exchanged for a Corsair CW-9060001-WW Hydro H40 CPU liquid cooler.

Each setup was chosen for specific reasons. The stock setup carries the same amount of cooling that many business-class computers have as standard. Upgrading the air cooling is an inexpensive modification performed on many computers. The liquid cooler takes the cooling to the next level. This Corsair H40 was chosen for a number of reasons, all of which would prove beneficial to a business. It is easy to install; fully-enclosed, requiring no maintenance; and cost
effective. It promises a level of performance that is sufficient for many business-class applications and hardware setups [4].

3.2 Computing and Business

Four different software programs were used in testing the setups: OCCT, PassMark PerformanceTest x64, SuperPi + CoreTemp, and PassMark BurnInTest Pro x64. All four utilized different methods of stress-testing the computer, pushing the components to their limits, thereby generating the most heat possible. The heat and corresponding performance of the computer were the items under investigation through this project. For the following data charts, Setup 1 refers to the stock air-cooled setup, Setup 2 is the modified air-cooled setup, and the liquid-cooled setup is labelled as Setup 3. “Idle CPU” refers to the temperature of the CPU before the test was run, and “Load CPU” is the maximum temperature reached by the CPU over the course of the test.

In OCCT, the Automatic Test was run for one hour, configured to use a large data set. This test pushes the CPU to its full capacity for one hour while running various calculations and processes. Temperatures are measured utilizing a thermometer built into the motherboard. The results were as follows:

- **Idle CPU**
  - Setup 1: 21 °C
  - Setup 2: 21 °C
  - Setup 3: 10 °C

- **Load CPU**
  - Setup 1: 41.5 °C

### OCCT Results

![OCCT Results](image)

The PassMark PerformanceTest x64 runs a suite of tests against the CPU, graphics card, hard drive, RAM, and optical drive. The program gives a result as a number rating, which is a compilation of the scores. Typically, higher numbers are better. The results from PerformanceTest are not as high overall for these three setups as they could be, thanks to the lack of a separate graphics card (the graphics processing unit in this setup is integrated into the motherboard).

- **Rating**
  - Setup 1: 883.5
  - Setup 2: 885.3
  - Setup 3: 893.9

### PassMark PerformanceTest x64 Results

![PassMark PerformanceTest x64 Results](image)
The third test that was run utilized two different programs. SuperPi is a program that calculates the number pi to a specified number of digits. The highest number of decimals that could be calculated was thirty-two million. During the process of running SuperPi, the program, CoreTemp, was used to track the change in temperature of the CPU throughout the SuperPi run. SuperPi also reports the length of time it took to calculate the specified number of decimals. For all three setups, the length of time used was approximately twenty-three minutes. There was very little variation in time.

- Idle CPU
  - Setup 1: 22 °C
  - Setup 2: 19 °C
  - Setup 3: 13 °C

- Load CPU
  - Setup 1: 32 °C
  - Setup 2: 26 °C
  - Setup 3: 20 °C

- Time
  - Setup 1: 23 minutes, 12 seconds
  - Setup 2: 23 minutes, 11 seconds
  - Setup 3: 23 minutes, 11 seconds

PassMark BurnInTest Pro x64 is designed to push computer components to a certain degree in order to get them past the “burn-in” time period. This period is during which any components suffering from manufacturer defects or other damages are bound to fail [17]. Essentially exercising the components, BurnInTest Pro stresses the “CPU, hard drives, RAM, CD-ROMs, CD burners, DVDs, sound cards, 2D graphics, 3D graphic, network connection, printers, video playback” [16]. During the execution of the tests, the highest temperatures were tracked. The results were as follows:

- Idle CPU
  - Setup 1: 23 °C
  - Setup 2: 19 °C
  - Setup 3: 12 °C

- Load CPU
  - Setup 1: 32 °C
  - Setup 2: 29 °C
  - Setup 3: 20 °C
3.3 Test Conclusions

Following the tests, conclusions were drawn from the collected data. Typically, while the CPU was idle, having an upgraded air-cooled system did not improve the CPU's temperature to a large degree. The difference in temperatures for an idle CPU was much more noticeable when comparing the stock air-cooled system and the upgraded air-cooled system to the liquid-cooled system. Idle CPU temperatures with the liquid-cooled system were always close to half of the idle CPU temperatures for the stock air-cooled system.

When the CPU is under load, the advantages of a better cooling setup shines through in the data. In a majority of the tests, the upgraded air-cooled system performed moderately better than the stock air-cooled system. However, the liquid-cooled system performed over three times as well as the stock air-cooled system in a majority of the tests.

3.3.1 Other Findings for Consideration

Throughout the process of testing, several other discoveries were made. Each of the three setups varied in the level of sound they produced. Between the upgraded and stock air-cooled systems, the addition of more fans increased the ambient noise level around the computer by a great degree. While no data was collected in regard to decibel levels, the difference was noticeable. In the stock air-cooled system, the fan integrated into the CPU heatsink was the only noise source. When the computer case was closed, the noise level was not very noticeable with the computer case at a distance of one and a half feet from the user. Any noise coming from the power supply unit was quiet enough as to be nearly negligible. During the tests involving the liquid setup, the noise level was lower than that during the stock air-cooled system tests. While the liquid cooling mechanism does include a fan in the radiator setup, the relative noise of this fan was quieter than that of the heatsink and fan combination CPU cooler.

Another finding of the testing was related to the relative temperature of the testing environment. Because all heat from the computer was eventually exhausted from the computer case, whether passively (stock air-cooled system) or actively (upgraded air-cooled system and the radiator of the liquid-cooled system), the temperature of the testing environment varied from one setup to the next. Subjectively, it seemed that the temperature of the testing environment was cooler during the liquid-cooled system tests than during the stock air-cooled system tests. The environmental temperature during those stock air-cooled tests was several degrees warmer than the initially measured room temperature of 76 °F. However, during the liquid-cooled system trial, the temperature varied little from the initial reading. Additionally, the environment also seemed cooler during the stock air-cooled system tests than while the upgraded air-cooled system tests were being performed. The addition of more fans to the cooling system lead to the exhaustion of greater amounts of component heat into the testing environment.
4 Business Economics

The importance of these findings applies to businesses and individuals alike. However, most of the aforementioned do not investigate into improved computer cooling, much less know of the possibilities for their machines. This is what they should know.

4.1 Current Business Use of Cooling

Computer cooling plays an important role in many businesses today. Without proper cooling, high-powered machines and applications would not run to their full potential, nor would they last as long without maintenance. “Too much” cooling is an impossibility, and no harmful effects will come from the utilization of large amounts of cooling components, even to extreme degrees. It may be argued that any business that invests in advanced cooling systems for their computers will not see detrimental performance on account of the change in setup.

4.2 Connecting Conclusions and Business

Empirical data regarding the cost of electricity for air conditioning varies widely within individual cities. Thus, a direct comparison of the cost of the air conditioning portion of an electricity bill (from a business) to the cost of computer cooling upgrades within that same business would be inaccurate and partial speculation. However, the general logic of such a comparison should be sufficient illuminate the point. The comparison would have to be between the electricity used to cool the area occupied by the computer and the extra electricity drawn upon by the computer in order to a liquid-cooled system instead of a stock air-cooled system. It should be pointed out that this extra electricity is nearly negligible, considering that the power supply unit of the computer draws a certain amount of electricity regardless of the use [4].

The environmental cost plays a role in this comparison. The use of less electricity is friendlier to the environment. This fact cannot be disputed. It would follow that, if all of the components (computer cooling system and air conditioning) draw less electricity, as they would if a liquid-cooled system was in use, the liquid-cooled computer setup has a lower environmental cost than a stock air-cooled computer setup.

While not applicable to all businesses, productivity cost from noise level may play a roll for some users. As previously reported, the relative noise level was noticeably diminished through the use of the liquid-cooled system, as compared to the stock air-cooled setup.

4.3 Summarizing the Project

The topic of computer cooling is an unseen and confusing component of computer systems for many people. Few people fully understand the combination of physics, chemistry, and engineering behind computer cooling setups. However, the advantages of advanced computer cooling can be acquired even by those without a mastery of the topic!

In summary, this goal of this project was to make the concepts behind the cooling of computers more accessible to those who do not necessarily need or want an engineer-level comprehension of the background principles. The research portion aimed to give a
broad overview of the myriad of topics and methods for applied computer cooling. Experiments were performed to collect some empirical data. This data compared three different computer cooling setups mainly on the grounds of performance. The results of the experiments were then connected to their meaning for business users. Based on these connections, the ultimate conclusion for businesses with computers was drawn (and it will be shared!)

4.4 What Can Be Taken Away

The advantages of advanced computer cooling can be acquired with a lot of investment. For many computer users, even those with high power machines, an enclosed liquid cooling system will be sufficient. The setup used in this experiment, the Corsair CW-9060001-WW Hydro H40 CPU liquid cooler, retails for approximately $50 USD, a price that appears to be well worth the benefits provided. Additionally, while this project focused most of its work on business computer users, many of the same conclusions can be applied to personal computer use.

5 Related Work

It should be noted that this project is not the first work of its kind. Many technology websites create comparison tests of computer cooling components, typically grouped by type of component (heatsink, liquid CPU cooler, fan, etc). Xoxide, Tom’s Hardware, FrostyTech, TechSpot, and Benchmark Reviews are among the most prominent groups involved in component analysis. The intentions of such tests are often to pit one component against others of its kind in order to determine the “top” setup, usually in terms of performance [4]. However, comparisons between these “top component” tests and the results of this project would produce no relevant data for several reasons. First, component comparison tests always look at differences among a group of like components (i.e. all fans, all liquid coolers, all heatsinks, etc.). The other reason is that component performance tests often do not place as much emphasis on cost-effectiveness as this project has [4].

Considering the business implications of computer cooling choices rarely occurs. Often, the comparison studies are geared toward computer enthusiasts and avid computer gamers whose livelihood is not so intimately connected with their systems. Additionally, very few measurements have been performed to include components of various genres, whether working in tandem or one-versus-another [4].

6 Conclusion

To conclude this project, a disclaimer must first be made regarding this work. None of the experiments were performed under pristine conditions. The accuracy of the empirical data that was collected may have been compromised in any number of ways, especially including changes in environmental conditions from one test to the next. However, the validity of the conclusion remains: liquid-cooled computer systems perform better than their air-cooled counterparts, and the use of liquid-cooled computer systems would be advantageous for businesses.
7 Future Work

This project is only the tip of a large iceberg of computer cooling methodology and systems. From this work, two distinct lines of expansion have been wrought, each taking certain approaches to greater extents.

First is the expansion on the background and overview of computer cooling. The topic of methodology and process is far more vast than that which is covered in the beginning sections of this paper. At this time, no guidebook to computer cooling exists, but the potential for such a manual exists here.

The second area in which this project might broaden its horizons is practical testing in a true business environment. Being able to perform a long-term test of the implementation feasibility, financial advantage, improvements to computer performance and longevity in a professional environment would lend great weight to the validity of the conclusions of this paper. Additionally, establishing these comparisons within companies of various industries would provide the grounds for analyzing the extent to which different cooling systems are advantageous for varying levels of computer usage.

“Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.” -Sir Winston Churchill, 1942

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Webpage of Wii and PS3 console mods.

Webpage of Xbox 360 console mods.


The homepage of the Xoxide company. Specific focus on the top navigation bar.