An Expansion on Applied Computer Cooling

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LAES 400

November 29, 2012

Abstract

In the world of professional technology, many businesses utilize servers and Apple products in their day-to-day work, relying upon these machines for the livelihood of their operations. However, the technology being used is limited by a single, ever-important factor: heat. The key to improved performance, increased computer longevity, and lower upkeep costs lies in managing machine temperatures. Previously, this topic was investigated for the world of PCs. In this paper, modifications, upgrades, and available components that improve cooling are discussed in regard to servers and Apple products. Through the use of these methodologies, the aformentioned improvements may be achieved.

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1 Introduction

"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

Six months ago, the author completed a research, analysis, and experimentation paper. Entitled "Applied Computer Cooling," the paper ended with the above quote from Sir Winston Churchill. In this paper, methods for managing temperatures in PCs were investigated. Over the months since that paper's publishing, a number of feedback comments and results have pointed to a desire for more information on cooling. Specifically, a large number of people were interested in information pertaining to the cooling of servers and Apple products. In the same way that the original paper was intended to serve as a guide for users with computer knowledge at all levels, this work will follow a similar structure of clear and concise examples coupled with straight-forward definitions. While this paper may be seen as a standalone work, some concepts will be more clear following the reading of "Applied Computer Cooling" [16].

It is the hope of the author that this paper will provide the reader with a greater depth of knowledge regarding the available options for the cooling of servers and Apple products. The following information is meant as a broad overview of the available options and not as an exhaustive listing. Education on these options will lead to better decision making and increased returns.

Background information will introduce the reader to the topics at hand and the aspects that are being examined. Next, servers will be covered, the research discussing both freestanding and rack mount servers, as their differences are significant. The topics of this paper then make a transition to Apple products, touching upon the difficulties in improving cooling for Apple machines, as well as individual investigations of the iMac, Mac Pro, Mac Mini, Apple TV, and MacBook. Sections on business economics, related work, and the potential for future work will help bring context to the technical research and will explain the impact of the information that was found.

2 Background

In many cases, businesses use servers as they are sold, with no modification, following the initial setup. Yet, the similarities between a great deal of server architecture and that of PCs invite the possibility that cooling components for one may be able to be used for the other, albeit with minor modifications [15]. To clarify this terminology, computer architecture is defined as "the structure, behaviour, and design of computers" [12]. This, in turn, includes all internal components, such as the motherboard, RAM, harddrives, and cooling devices. It is on account of these points that the concept of improved cooling for servers is, more often than not, unrealized and unexplored.

This same lack of realization may be applied to Apple products. An entirely different culture surrounds Apple and their user base, as compared to that of PC users, whether they be Windows gamers, Linux power users, or simply computer owners, who had no desire to pay the typically-higher cost for a machine based on Apple's Mac OS X operating system. This Apple culture

tends to settle (not necessarily in a negative manner) for that which is offered and provided by Apple for their customers. Many customers are entirely satisfied with their experience and with the usage and functionality of their machines. However, for some more advanced users, questions, regarding unadvertised and greater ranges of performance, have been raised. In addition, some owners of Apple computers simply have the desire for their machines to work better than when they were first built.

In "Applied Computer Cooling," the author discussed primarily air, liquid, and passive cooling. Air cooling involves utilizing fans to push cool air across hot components and/or pull hot air away from components. Often, these components are mounted with heatsinks and other heat dissipation devices, and it is from these devices that the air carries away heat. Liquid cooling combines a passive heat transfer, usually from the central processing unit (CPU) to a plate called the "water block." This water block connects to a radiator via hoses that shuttle coolant across the block, drawing away the heat. Passive cooling, then, is essentially a non-electronic utilization of part of these previous two methods. Heatsinks and other devices for dissipating heat are mounted to computer components, and the ambient air carries away that heat, which has been produced in the operation of the computer [16]. These topics will be discussed in the context of server and Apple computer architecture.

3 Servers

The argument might be made by some that a section on the cooling of servers is completely unnecessary. However, despite servers being much the same as computers, for all intents and purposes of consideration, the exception lies in their cooling, because the primary difference is in their architectures in most cases. In order to be clear, in this section, the hardware side of a server is being discussed, as "server" can also refer to the software running on such a machine or a remote service accessible via the Internet [11].

The differences between servers and computers may still seem minuscule and irrelevant; however, servers run for long periods of time without interruption, requiring reliable and efficient cooling to be used, especially when it has such a huge impact on energy consumption. According to the president of the prominent microprocessor company, ARM, "...servers themselves account for around 2.5 percet of the US energy bill, and cooling them accounts for as much again" [4]. Different servers perform different tasks, but, rather than get into server purposes, two main server hardware types, the freestanding server and the rack mount server, will be addressed, along with methods of cooling for each.

The front line of defense for many servers against high temperatures is climate control. This typically takes the form of special air conditioners for the room in which the server is located. As these rooms are typically enclosed and sequestered from sight, it is important that they are maintained at a safe temperature to decrease the likelihood of heat-related issues. Airflow throughout the server area and low humidity levels are also critical and can be maintained using special cooling equipment meant for use with servers [3]. For small business servers or

home servers, a full-sized, special cooling unit may not be necessary. However, maintaining low temperatures, low humidity, and constant airflow should still be a priority, in much the same way that this plays an important role in the functionality of desktop computers [15].

3.1 Freestanding

While a freestanding server may look a lot like a typical desktop, the architecture of the motherboard itself, as well as much of the other components, differs in order to support multiple users, etc. Server motherboards require much more RAM and processing power in order to handle multiple sources of draw on their resources. Because of this, freestanding servers need cooling options that can handle these differences. Some of the available desktop computer modifications can be retrofitted to be appropriate for use in a freestanding server. These include heatsink lapping, heatsink upgrades, and fan upgrades [15].

As it was with desktop computers, one of the best cooling upgrades that can be made to a freestanding server is the addition of liquid cooling. Unlike with desktop computers, liquid cooling kits for servers are not as prominent and popular. However, the components to set up liquid cooling on a freestanding server do exist. Most liquid cooling kits can be modified to fit the different motherboard architecture [15]. The drawback lies with the necessity of using kits of individual components, rather than being able to utilize standalone, closed-loop systems, such as were part of past experimets [16]. Custom-built liquid cooling systems allow users to incorporate numerous waterblocks into the setup. A pump that is powerful enough to cycle the liquid through the extra tubing distance added by the addition of one or more additional CPUs will be necessary. Additionally, most waterblocks are not sold with the mounting options for server motherboards, which are different than those of most desktop computers. Thus, mounts that match the server processor type must be purchased and used [13]. While this sounds like a complicated process, the returns of performance increase and electricity consumption decrease are worth the effort.

3.2 Rack Mount

Rack mounted servers differ from freestanding servers in their physical appearance and how they are stored. Rather than being contained in a single upright case, these servers have their components arranged in shallow, tray-like cases, which are mounted in upright cabinet racks. These servers are especially utilized, when an organization has multiple servers, and space is at a premium [15].

Dell has implemented a number of advances that are meant to improve power and cooling efficiency in their latest PowerEdge servers. It may be possible to modify other servers to include these advanced components. Power supplies with improved energy efficiency will also lower temperatures within the server, as will better ventilation and airflow. These PowerEdge servers also utilize low-flow fan technology to keep air moving will minimizing power consumption [14].

Asetek is another company that has made great improvements in the area of server cooling. They have implemented a methodology of cooling rack-mounted servers that involves the use of liquid CPU

coolers much like those used in desktop computers. However, these systems allow for the cooling of numerous CPUs utilizing a single coolant loop, thus reducing the need for multiple radiators. Their company has developed several different variations on this cooling modification [8].

The first variation is a system, by which all water blocks, on each CPU, in a single shelf are on the same coolant circuit. This circuit, along with those of the other shelves, then feeds into a greater circuit, which is built into the sides of the cabinet. Using only ambient air and no radiator, the heat is bled off the cooling system. Without the use of a radiator fan, the power savings are quite large [9]. Additionally, as has been previously discussed and proven, the use of liquid cooling will improve the performance of the server itself [16].

Asetek's second variation on server rack liquid cooling closely resembles a rack mount server-version of the standard liquid CPU cooler used in desktop computers. In fact, the components are the same, as the closed loop is comprised of a waterblock; a radiator fitted with fans, which are made for rack-mounted servers; and tubes to carry the coolant through the system [7]

The third liquid cooling setup from Asetek for rack mount servers is a bit more complicated than the other two. Utilizing a concept that Asetek calls the "sealed server," this setup endeavors to eliminate the need for any air conditioning, or other cooling unit for the server room itself, by isolating the server components from that ambient air. In this variation, the entire server shelf is completely enclosed. Water blocks cool the CPUs and a heat exchanger draws heat from the air within the case. All of this heat is then carried out of the shelf via the coolant lines and dissipated in the same way as the first variation, without the use of a radiator fan. By cooling the air around the components on this small scale, rather than with an air conditioning unit for the entire server room, a great deal of energy is saved, thereby also saving large amounts of money [10].

What was once a cooling method attempted only by extreme computer cooling enthusiasts with their desktops, mineral oil has seen a rise in popularity in the world of server cooling, thanks to the Intel corporation. In this setup, their server rack shelves are mounted horizontally, on their sides, in large tub-like, liquid-filled enclosures. The design almost appears as though someone tipped a rack mount server cabinet onto its front. The standard server cables are all that emerge from above the surface of the mineral oil, which completely covers the servers themselves [19]. Intel is using a setup developed by Green Revolution, a company claiming that the use of their mineral oil cooling will lead to huge energy savings, because the oil has 1,200 times more heat capacity than air [18]. While this is certainly a strong supporting point and one that would lower costs immensely, it does require a certain commitment to the setup, as space must be found for the purpose of installing the immersion tanks. In general, these tanks will consume more floor space than a standard rack mount server cabinet, as the server shelves are rotated 90 degrees from their typical orientation [19]. However, for companies that can front the initial cost of setup, the reduced maintenance (relative to other liquid cooling methods for servers) will be a huge bonus [18].

One final methodology for server cooling does not involve liquid cooling. Rather, this method attempts to use air conditioning to the fullest possible extent of its efficiency. In-rack cooling, developed by 42U, situates a special air conditioning unit between two server rack cabinets. This unit forces the cool air through the racks and the warm air into a heat exchanger. By only applying the air conditioning to the servers themselves and creating a microclimate (unaffected by and neutral to the rest of the room), the efficiency of the energy usage is increased [1].

4 Apple Products

Difficulties exist that dissuade many users from modifying their Apple products. Despite this, upgrades are possible on many Apple devices. These devices with potential include Mac desktops (the iMac and the Mac Pro), the Mac Mini, the Apple TV, and the MacBook.

4.1 Difficulties

For years, one of the most prominent complaints the author has heard, regarding Apple computers, centers around their tendency toward high temperatures and, occasionally, overheating [15]. Users, who are more familiar with PCs, may first consider upgrading the cooling systems on these Apple computers in order that some of those cooling issues may be addressed. However, two specific difficulties exist that make the effort of acquiring and installing improved cooling systems into a trial - changing architecture and case design.

The architecture of Apple systems tends toward being very tightly controlled. These restrictions serve to make modifications and the use of third party components more difficult than it would be with a PC equivalent [15]. Additionally, the use of BIOS with PCs allows for easier and more open changes to be made than the Extensible Firmware Interface (EFI) used by Apple [24].

The high level of aesthetic design that dominates many of Apple's computers also reduces the options for increased cooling. One excellent example of this is the Mac Mini, a desktop computer with a very small form. Several laptop-style heatsinks and a single fan comprise the internal cooling setup for the generation of Mac Mini from mid-2010 [20]. While the noise level of these components is very minimal and thus would not be worth attempting to improve, the possibility for increased cooling capability due to changing the internal setup is very small [15].

4.2 Mac Desktops

The aesthetic design also plays an important role in the cooling capabilities of Apple's desktop computers, including the iMac and the Mac Pro. (The previously mentioned Mac Mini will be discussed in another section.) Designs for these desktops vary from one generation of computers to the next, in most cases. For example, an advanced cooling solution that may apply to the most recent line of iMacs, from mid-2011, may or may not also apply to those from the generations released in mid-2010 and late-2009. All three of these generations maintained the same external casing but varied in their internal configurations. The implications of

this will be discussed shortly [5].

Unless otherwise specified, the discussion will focus on available (and theoretical, to a degree) solutions for the most current generation. Yet, with the great similarities that often exist from one product version to the next, there is little doubt that similar modifications could be extrapolated for older computers [5]. Indeed, these may have already been developed.

4.2.1 iMac

The iMac all-in-one computer presents an interesting challenge for cooling upgrades, as the thin design with all components located behind the screen limits the amount of space available for modification of the existing cooling system. Without physically changing any part of the machine, the program smcFanControl allows users to manually raise the speed of the fan in their computer [27]. While this will certainly increase cooling, it should be noted that doing so will also raise power consumption by the iMac.

The heatsink on the CPU cooler should, in theory, be lappable. Lapping is a process by which better surface contact between the processor and the heatsink is achieved through the smoothing of these contact surfaces [16].

Component upgrades are another option, to a degree. Some websites, such as Newegg, do sell third-party CPU coolers and fans for machines like the iMac [29]. However, these third-party components for Apple computers are typically very rare in comparison to their PC counterparts. If they can be acquired, these parts may provide such upgrades as increased cooling efficiency, quieter fans, or less power consumption.

Externally, fans could be added to the case of the iMac to achieve some increases in cooling efficiency. Inward-pointing fans mounted on the air intake vents would increase the flow of air through the iMac case; however, this methodology could also cause turbulence within the computer, leading to increased fan noise and potential problems with the original computer fans. Another option would be mounting outward-pointing fans on the exhaust ports. This modification serves to draw heat away from the iMac at a faster rate than could be accomplished otherwise [15].

4.2.2 Mac Pro

Back in 2004, the then-named "Power Mac G5" utilized a liquid cooling system that was incredibly prone to leaking. While it was updated in the generation of Power Mac G5s that were released the next year, the rise of processors with better heat management led to Apple's discontinuation of including liquid cooling systems in their line of full-sized desktops, now known as "Mac Pro" [23]. Liquid cooling in the Mac Pro remains possible, along with nearly every desktop cooling modification discussed in "Applied Computer Cooling." This includes such modifications as upgraded fans, liquid CPU cooling, and heatsink lapping [16].

The difficulty in implementing some of these modifications lies in the lack of available parts. Third party fans for Mac Pros are difficult to obtain because very few are actually produced. Currently, no liquid CPU coolers exist for Apple products; however, these can be made custom [15]. Asetek, a company specializing in the liquid cooling of data centers, modified the

mount for the water block of a liquid cooler in order that it might properly be affixed upon the motherboard of a dual-processor Mac Pro, which also involved making some motherboard modifications and combining parts of two separate liquid cooling kits [6]. This successful modification allowed for increased system functionality (through both liquid cooling and an overclock) and much less noise being produced by the computer. However, this custom job involved a great deal of time spent by professional technicians and an estimated minimum cost of around $200 for the parts [28]. (See the Related Work section for more details.)

4.3 Mac Mini

Much of the popularity of the Mac Mini, since its first inception, has been derived from its small form factor. This allows owners to utilize the Mac Mini in locations where normal desktops would not fit, even those utilizing one of the famously-compact MicroATX-size motherboards, as is the case of the primary experimentation computer in "Applied Computer Cooling" [22]. However, as previously mentioned, the components used internally for cooling the Mac Mini are essentially of the same design, as would be found in a large laptop. This continues to be true in the most recent Mac Mini release [21]. This extremely limits the options for upgrading these components and thus improving the cooling capabilities of the machine.

Despite these limitations, a few modifications could still be made that do not involve replacing components. First, this case might be modified to increase the ambient airflow. While this may sound like a ridiculous idea, consider that most desktops do, in fact, have grating, of some sort, somewhere on the case for this very reason. Another method for increasing the cooling capabilities of the Mac Mini is a software-based solution, such as smcFanControl. However, it should again be noted that setting the fans to higher speeds will raise the computer's power consumption. Finally, heatsink lapping could be utilized, though it is unclear as to whether this might have detrimental effects on the laptop-style heatsink employed in the Mac Mini.

4.4 Apple TV

The Apple TV may not be considered a computer by some. However, once the technical specifications are examined, it becomes obvious that the Apple TV is nothing more than a micro-computer. The most current version utilizes a processor and graphics chip that are almost identical to those present in certain versions of the Apple iPhone and iPad [5]. While this may raise questions regarding cooling possibilities, users have developed various modifications that allow for better performance through increased cooling. The first cooling modification is not truly a modification so much as it is an addition. The Apple TV has a single USB port, which was intended for use in diagnostic work. However, any USB accessories may be plugged into this port with success, including cooling pads that are typically meant for use with laptops. This may increase the cooling of the Apple TV immensely, as some users have found [31]. Because of the shape and size of the Apple TV, a cooling pad with a single large fan set in the middle would be more effective than those designed with two,

or more, smaller fans arranged in a symmetrical (or other) pattern [15].

In addition to the cooling pad, another laptop cooling technique may be applied to the Apple TV. Raising it off the surface on which it rests, by a greater height than what the built-in feet would typically lift it, will serve to allow a greater airflow below the device, facilitating increased cooling. This technique may be used in conjunction with the fan in the pad for a more effective solution [15]. Modifying the device to include a fan on top may also be helpful, especially with earlier generations of Apple TVs, which had a greater surface area on the top and bottom (providing more surface for cooling). When one user combined this with lifting the machine, the Apple TV showed a drastic decrease in temperature [2].

On the extreme end of modifying the Apple TV for better temperatures lies a method that involves directly addressing the Apple TV's small case. As the heat radiating from the components gathers inside the case, it will cause the internal temperature to rise, thus further increasing the temperatures of those components. An Apple TV owner from the MacRumors forum modified the storage mechanism of his device in order to bring the harddrive outside of the case [26]. This, in turn, removes one of the major sources of heat generation from within the Apple TV enclosure and will, subsequently, lower internal temperatures and their effect on the other components. Locating the storage medium outside the case also allows for greater ambient cooling of this component[15].

4.5 MacBook

The available options for cooling a MacBook, MacBook Pro, or MacBook Air are much the same as those for cooling any laptop - virtually nonexistent. The best option for decreasing temperatures and increasing performance is a laptop cooling pad. There are many options, yet any of them will dissipate heat from the case and improve cooling [15]. The previously mentioned software, smcFanControl, could be used on any of these Apple laptops. However, changing settings on laptop fans can have a negative effect on more than the power consumption, and doing so is not recommended.

5 Business Economics

Severs and Apple machines maintain a large presence in many businesses around the world. To this end, the financial impact of cooling modifications is an important point that must be included in professional technological decisions. While changes to the cooling of servers will have a greater impact on costs for business, Apple products are still important for companies' IT specialists to take into consideration.

5.1 Servers

"Servers" refers machines used for a wide variety of operations, typically hosting a body of information, which can then be remotely accessed via a local network or the Internet. This information includes email, files, websites, and video games [11]. The uses are varied and numerous, and it is for these reasons, and more, that a large number of businesses employ servers in their technological

infrastructure [15].

Maintaining a server involves a large financial cost on account of the standard cooling measures that are typically employed - specialized air conditioning units that are up-sized variations on those used to cool homes and businesses around the world [3]. This cost increases exponentially with the size of the company, as this almost assuredly brings an increase in server size. With large companies often running their servers at their maximum capability, regardless of the necessity, or lack thereof, the use (and waste of electricity) can be staggering - and these numbers compound to enormous electricity bills. Actually imparting the size of the numbers is difficult, but one example is the use of electricity by the servers at data centers (whose entire business revolves around them) in 2010. Two percent of the entire electricity usage in the United States for all of that year went to data centers [17].

With these massive draws of electricity, the reduction of those numbers can only be beneficial to those, who lessen their costs. The foremost, and most effective, method of doing so would be to improve the cooling methodologies used with servers. Many of the modifications mentioned in the section on server cooling may be scaled to a data center of any size. Upgrades can only pay for themselves in savings, time and time again.

5.2 Apple

A number of professions, such as graphic designers, publishers, video editors, and musicians, use Apple computers almost exclusively in their work on account of compatibility, usability, program necessity, and other reasons. Personal preference also drives many businesses to choose Apple for their workstations. Sometimes, these companies might use Macs and PCs together, but they will still expect a high level of performance from their machines. The cost of Apple machines is notoriously high, which may cause businesses to question the need for additional costs when the reason for them is the improvement of something that Apple advertises as being top-of-the-line [5]. However, the truth is twofold. Increases in technology will bring about components that run at higher temperatures than those of their precursors. This being said, increases in technology will also give rise to increased cooling technology within the components. The catch is that the improvements in integrated cooling technology are not increasing at the same rate as the temperature levels of more powerful components [15].

While Apple has reportedly been working on the development of a liquid cooling system since 2006, such a setup has yet to be made available for retail purchase [30]. With reported temperatures for new processors, such as Intel's i7, reaching very high levels, it is logical that cooling these components would result in higher performance [25]. This is not to say that, without upgraded cooling, these computers will experience detrimental effects (though it is a possibility), rather that the full extent of their capabilities may not be realized with a stock setup.

6 Related Work

The engineers at Asetek specialize in liquid cooling solutions for servers, desktops, and laptops [8]. In a project moderately related

to the research of the author of this paper, Asetek delved into the possibilities of using a liquid cooling solution for a Mac Pro. While their intentions were intially to quiet the relatively loud computer (and thus improve productivity within the work environment in which it was located), their results were even more spectacular [6].

The machine being modified was an 8-core, 2.8GHz Mac Pro. A 120mm radiator was fitted with two low-noise fans. This apparatus was then connected to two waterblocks, situated on the two CPUs. The whole system was connected by tubing to form a single cooling loop. It should be noted that most of the parts were taken from multiple liquid cooling kits in order to be combined for this single, custom system [6].

After the cooling modification had been installed, the engineers ran performance tests, comparing the modified machine to a stock, air-cooled 8-core, 3.2GHz Mac Pro. This second machine had a much higher cost (for the increased stock performance). Another modification that had been performed on the 2.8GHz Mac Pro was overclocking, which is the process of electronically increasing performance by changing component settings. Overclocking typically causes greater heat generation by the computer. Thus, it is typically necessary for upgraded cooling to be used in conjunction with an overclocked computer. After the overclocking, the 2.8GHz Mac Pro was running at 3.16GHz, just short of the stock Mac Pro's 3.2GHz. The results were conclusive: the addition of liquid cooling absolutely improved performance. After running the same performance tests on both machines, it was found that the overclocked Mac Pro ran quieter than the stock, air-cooled Mac Pro. They both maintained the same level of performance and temperatures throughout the testing [6].

While the results of the testing may seem to be inconclusive, the difference reveals itself in a cost comparison. The primary specification difference between the machines is the processor. One machine contained two quad-core Intel Xeon processors, originally running at 2.8GHz. The other computer (the stock, air-cooled machine) contained two quad-core Intel Xeon processors, running at 3.2GHz. According to Asetek, the cost of the first computer, including the liquid cooling upgrade, was less than that of the second machine [6]. While these processors are no longer being sold in Apple machines, an inspection of the current generation of the current generation of Mac Pro machines shows that similar processor performance increase would cost approximately $1,200 for the additional 0.4GHz [5].

7 Conclusion

Many people do not have a familiarity with the cooling of servers and Apple products, nor do they realize the importance of this topic. This paper has provided a broad overview of the methodologies and reasoning behind the use of advanced cooling with these technologies. Upgrades are available for both freestanding and rack mount servers. From minor modifications, such as heatsink lapping, better heatsinks, and improved fans; to major component additions, including custom liquid-cooling systems for freestanding servers and the immersion/full-integration rack-mount systems; a number of both established and experimental

server cooling methodologies could be implemented.

Advanced cooling for Apple products does not fall under the one-size-fits-all mentality. With the iMac, Mac Pro, Mac Mini, Apple TV, and MacBook all maintaining different architectures, cooling components and their availability are just as different. Many non-basic cooling solutions for Apple machines are custom-built and/or rare.

However, the subject of cooling Apple computers has risen in popularity. As shown in the section on related work, Asetek has taken it upon themselves to devise this same type of custom system. They demonstrated how it was, in fact, superior to the stock Apple product, in a number of ways. Asetek may have a great amount of resources available for projects, such as these, but their work is sure to inspire future enthusiasts to homebrew their own advanced setups.

The importance of this advanced cooling cannot be stressed enough, especially in the world of business. Every new computer, every new server, and every successive data center places a greater drain on the resources of the business, and the power resources, than ever before. Upgrading the cooling systems can only help, as it will improve performance, extend computer longevity, and lower upkeep costs. The choice will never be clearer.

"Information technology and business are becoming inextricably interwoven. I don't think anybody can talk meaningfully about one without the talking about the other." -Bill Gates, Chairman of Microsoft

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