DATA CENTER EFFICIENCY AND IT EQUIPMENT RELIABILITY AT WIDER OPERATING TEMPERATURE AND HUMIDITY RANGES

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Executive Summary

Extending the environmental operating parameters of a data center is one of the industry-accepted procedures for reducing overall energy consumption. Relaxing traditionally tight control over temperature and humidity should result in less power required to cool the data center. However, until recently, the impact of increased data center operating temperature on the information technology (IT) equipment installed in the data center has not been well understood. Historically, it has been widely presumed to be detrimental to the equipment's reliability and service availability.

Interest in the use of economization methods to cool data centers is helping to drive increased focus on extending the data center operating range to maximize the potential benefits of air-side and water-side economizers in general. With economizers, the greater the number of hours and days a year that they can be used, the less the mechanical chiller based cooling component of the infrastructure needs to operate. More importantly in some cases were economizers can be used, the benefits could be significant enough to reduce the mechanical cooling capacity or even eliminate it altogether. Yet what effect does increasing the operating envelope within the data center have on the reliability and energy consumption of the IT equipment itself? What if realizing savings in one area compromises reliability and increases energy usage in others?

The Green Grid works to improve the resource efficiency of IT and data centers throughout the world. The Green Grid developed this white paper to look at how the environmental parameters of temperature and humidity affect IT equipment, examining reliability and energy usage as the data center operating range is extended. Using recently published ASHRAE data, the paper seeks to address misconceptions related to the application of higher operating temperatures. In addition, it explores the hypothesis that data center efficiency can be further improved by employing a wider operational range without substantive impacts on reliability or service availability.

The paper concludes that many data centers can realize overall operational cost savings by leveraging looser environmental controls within the wider range of supported temperature and humidity limits as established by equipment manufacturers. Given current historical data available, data centers can achieve these reductions without substantively affecting IT reliability or service availability by adopting a suitable environmental control regime that mitigates the effects of short-duration operation at higher temperatures. Further, given recent industry improvements in IT equipment efficiency, operating at higher supported temperatures may have little or no overall impact on system reliability. Additionally, some of the emerging IT solutions are designed to operate at these higher temperatures with little or no increase in server fan energy consumption. How organizations deploy wider operating ranges may be influenced by procurement lifecycles and equipment selection decisions.

Table of Contents

I. Introduction

Data centers have historically used precision cooling to tightly control the environment inside the data center within strict limits. However, rising energy costs and impending carbon taxation are causing many organisations to re-examine data center energy efficiency and the assumptions driving their existing data center practices. The Green Grid Association works to improve the resource efficiency of information technology (IT) and data centers throughout the world. Measuring data center efficiency using The Green Grid's power usage efficiency (PUE™) metric reveals that the infrastructure overhead of precision cooling in a data center facility greatly affects overall efficiency. Therefore, solutions that can result in improved efficiency deserve increased focus and analysis.

Initial drivers for the implementation of precision cooling platforms within data centers have included the perceived tight thermal and humidity tolerances required by the IT network, server, and storage equipment vendors to guarantee the reliability of installed equipment. Historically, many of these perceived tight thermal and humidity tolerances were based on data center practices dating back to the 1950s. Over time, the IT industry has worked to widen acceptable thermal and humidity ranges. However, most data center operators have been reluctant to extend operating parameters due to concerns over hardware reliability affecting the availability of business services, higher temperatures reducing the leeway and response time to manage cooling failures, and other historical or contextual perceptions.

It is widely assumed that operating at temperatures higher than typical working conditions can have a negative impact on the reliability of electronics and electrical systems. However, the effect of operating environment conditions on the reliability and lifespan of IT systems has been poorly understood by operators and IT users. Moreover, until recently, any possible affects have rarely been quantified and analyzed.

Recent IT reliability studies show that, with an appropriate operating regime, a case can be made for the operation of data centers using a wider temperature range and relaxed humidity controls. Using a looser environmental envelope opens the door to a potential reduction in some of the capital costs associated with a data center's cooling subsystems. In particular, data centers that do not require a mechanical chiller based cooling plant and rely on economizers can prove significantly less expensive both to construct and operate.

II. History of IT Operating Ranges

For many years, a thermal range of between 20^{o}C and 22^{o}C has been generally considered the optimal operational temperature for IT equipment in most data centers. Yet the underlying motivation for this on-going close control of temperature and associated humidity is unclear. For instance, there is evidence that the operating range was initially selected on the suggestion that this choice would help avoid punch cards from becoming unusable. What is clear now, in hindsight, is that this type of tight thermal range was adopted based on:

- The perceived needs and usage patterns of IT technologies when they were first introduced
- The environment within which vendors and operators were willing to warrant operation and guarantee reliability of those technologies
- The gravity of any existing assumptions about the use of tight control ranges in an environment

This ad-hoc approach led to wide variability between vendors' supported thermal and humidity ranges across technologies, and it presented a significant challenge for users when operating multiple vendors' products within a single data center. Even when data center operators installed newer equipment that could support wider acceptable ranges, many of them did not modify the ambient operating conditions to better align with these widening tolerances.

To provide direction for the IT and data center facilities industry, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Technical Committee 9.9—Mission Critical Facilities, Technology Spaces, and Electronic Equipment—introduced its first guidance document in 2004. The operating ranges and guidance supplied within this seminal paper were agreed to by all IT equipment vendors that were on the ASHRAE committee. In 2008, this paper was revised to reflect new agreed-upon ranges, which are shown in Table 1.

Table 1. ASHRAE 2004 and 2008 environmental guidelines

	Recommended		Allowable	
Year	2004	2008	2004	2008
Temperature Range	20^oC - 25^oC	18^oC - 27^oC	15^oC - 32^oC	10^oC - 35^oC
Moisture Range	40% - 55% RH	5.5^oC DP - 60% RH	20% - 80% RH	20% - 80% RH

In its guidance, ASHRAE defined two operational ranges: "Recommended" and "Allowable." Operating in the Recommended range can provide maximum device reliability and lifespan, while minimizing device energy consumption, insofar as the ambient thermal and humidity conditions impact these factors. The Allowable range permits operation of IT equipment at wider tolerances, while accepting some potential reliability risks due to electro-static discharge (ESD), corrosion, or temperature-induced failures and while balancing the potential for increased IT power consumption as a result.

Many vendors support temperature and humidity ranges that are wider than the ASHRAE 2008 Allowable range. It is important to note that the ASHRAE 2008 guidance represents only the agreed-upon intersection between vendors, which enables multiple vendors' equipment to effectively run in the same data center under a single operating regime. ASHRAE updated its 2008 guidance[1] in 2011 to define two additional classes of operation, providing vendors and users with operating definitions that have higher Allowable temperature boundaries for operation, up to 40ºC and 45ºC respectively. At the time this white paper was written, there existed only a small number of devices available that supports the new ASHRAE 2011 class definitions, which are shown in Table 2.

Table 2. ASHRAE 2011 environmental classes

ASHRAE 2011 Equipment Environmental Specifications					
Classes	Product Operation				
	Dry-bulb temperature (ºC)	**Humidity range non-condensing**	**Maximum dew point (ºC)**	**Maximum elevation (m)**	**Maximum rate of change (ºC/hr)**
Recommended					
A1 to A4	18 to 27	5.5OC DP to 60% RH and 15OC DP			
Allowable					
A1	15 to 32	20 to 80% RH	17	3040	5/20
A2	10 to 35	20 to 80% RH	21	3040	5/20
A3	5 to 40	8 to 85% RH	24	3040	5/20
A4	5 to 45	8 to 90% RH	24	3040	5/20
B	5 to 35	8 to 85% RH	28	3040	NA
C	5 to 40	8 to 85% RH	28	3040	NA

ASHRAE now defines four environmental classes that are appropriate for data centers: A1 through A4. Classes B and C remain the same as in the previous 2008 ASHRAE guidance and relate to office or home IT equipment. A1 and A2 correspond to the original ASHRAE class 1 and class 2 definitions. A3 and A4 are new and provide operating definitions with higher Allowable operating temperatures, up to 40ºC and 45ºC respectively.

Although the 2011 guidance defines the new A3 and A4 classes that support higher and lower Allowable operating temperatures and humidity, vendor support alone for these ranges will not facilitate their adoption or enable exploitation of the Allowable ranges in the existing A1 and A2 classes. Adoption is dependent on the equipment's ability to maintain business service levels for overall reliability and availability. Typical concerns cited by data center operators regarding the wider, Allowable operational ranges include uncertainty over vendor warranties and support and lack of knowledge about the reliability and availability effects of such operation. These are issues that must be addressed by the industry.

In its guidance, ASHRAE has sought to provide assurance about reliability when applying the Recommended and Allowable ranges. It should be noted, however, that few users were in a position to quantify the risks or impact associated with operating within the 2004 or 2008 ASHRAE Allowable or even Recommended ranges. As a consequence, most data center operators have been wary of using the full scope of the ranges. Some may tend to use the upper boundaries to provide a degree of leeway in the event of cooling failures or to tolerate hot spots within the data center environment. A recent survey by The Green Grid on the implementation of the ASHRAE 2008 environmental guidelines in Japan[2] showed that over 90% of data centers have non-uniform air inlet temperatures and that the 2008 Allowable temperature range is being used to address the issues of poor airflow management.

The conservative approach to interpreting the ASHRAE guidelines on operating temperature and humidity has presented a hurdle to the application of energy efficiency measures in the data center in some areas. This hurdle has not necessarily stifled innovation, as operators have been addressing overall data center efficiency in multiple ways, but the available avenues for savings realization may have been narrowed as a result. The Green Grid White Paper #41, *Survey Results: Data Center Economizer Use*,[3] noted:

> The efficiency of data center cooling is being increased through better airflow management to reduce leakage of chilled air and increase return temperatures. Contained aisle solutions have been introduced to eliminate air mixing, recirculation, and bypass of cold air. These approaches, even within the restraints of tight environmental control, have eliminated hot spots and brought more uniform inlet temperatures. As a consequence, they have allowed higher ambient cold aisle supply temperatures without overall change in IT availability and reliability.
>
> Many operators are implementing direct air cooled, indirect air cooled, and indirect water economizers to reduce the number of hours that an energy-hungry chiller plant needs to be operated. The Green Grid survey of data center operators showed that use of economizers will result in saving an average of 20% of the money, energy, and carbon for cooling when compared to data center designs without economizers.

The increase in efficiency highlighted in White Paper #41 has largely occurred without any significant changes in the way IT equipment is operated and the data center's environmental characteristics are configured. Where uniform air distribution is implemented through the use of contained aisles or similar approaches, loose control within the boundaries of the ASHRAE Recommended range can potentially allow for increases in the number of hours of economizer operation available to the facility and drive further reductions in overall data center energy consumption and costs. Raising the supply temperature also provides the opportunity for greater exploitation of economizers in hotter climates, where previously the economic benefit was comparatively small due to the limited number of available operating hours. The Green Grid's free cooling maps[4] and web tools[5] published in 2009 illustrate that when operation at up to 27ºC in the Recommended range is allowed, air-side economization can be exploited more than 50% of the time in most worldwide geographies. In higher latitudes, this opportunity increases to at least 80% of the time.

The Green Grid's 2012 free cooling maps[6] illustrate operation up to the limits of the ASHRAE A2 Allowable range of 35ºC and demonstrate the potential for a greater impact of the use of economizers on energy efficiency. The maps show that 75% of North American locations could operate economizers for up to 8,500+ hours per year. In Europe, adoption of the A2 Allowable range would result in up to 99% of locations being able to use air-side economization all year.

Greater use of economizers also can drive down the potential capital cost of data centers by reducing the size of the chiller plant needed to support the building or by possibly eliminating the chiller plant entirely in locations where peak outside temperatures will not exceed economizers' supported environmental ranges.

Irrespective of the known benefits of raising supply temperatures, anecdotal evidence suggests that the average supply temperature of data centers has hardly changed in recent years. This conclusion is supported by the survey of Japanese implementation of ASHRAE 2008 environmental guidelines.[2] The principal reasons given for maintaining average supply temperatures around 20ºC to 22ºC are concerns about the effect of temperature and humidity on IT hardware reliability and about the corresponding impact on business service levels as the operating temperature is increased. Independently, operators also cite as a barrier the lack of clarity provided by vendors on product support and warranty factors when operating outside the Recommended range. The lack of reliable information on these topics has deterred many organizations from pursuing higher operating temperatures as a route to reduced energy costs.

III. Industry Change

The rise of cloud computing as a new IT service delivery model has been the catalyst for innovation across the whole spectrum of IT activities. This new model represents a conjunction of many existing and new technologies, strategies, and processes. For instance, cloud computing has brought together virtualization, automation, and provisioning technologies, as well as driven the standardization of applications, delivery processes, and support approaches. Combined, these technologies, services, and capabilities have triggered radical change in the way IT services are being delivered, and they have changed underlying cost structures and cost-benefit approaches in IT service delivery.

Early cloud innovators identified data center facilities as a major, if not prevailing, element of their service delivery costs. After all, when looking at cloud services and increasingly at big data and analytics operations, any opportunity to reduce overhead and facility costs can reduce net unit operating costs and potentially enable the data center to operate more economically. These savings can be used to increase the scale of the IT environment.

Inspired by their need for greater cost efficiencies related to supplying power and cooling for IT equipment, organizations operating at a cloud scale drove critical, innovative thought leadership. They were able to quickly demonstrate that air-side economizers and higher temperature data center operations did not have meaningful impacts on reliability and availability when measured against their service delivery targets. This latter point is important—the service levels offered in most cases were not necessarily the same as might be expected from an enterprise with a traditional IT model that assumes high infrastructure reliability and multiple component redundancy to deliver IT services.

The IT hardware used by some of these cloud services operators was typically custom built to their own specifications. Further, these cloud services operators were able to effectively decouple the services they offered from potential failures of individual compute or storage nodes and whole racks of IT equipment. They were even able to decouple the services from a complete failure of one (of several) data center facility. This type of abstraction from facility and IT hardware failure requires a very robust level of IT service maturity—a level that only recently is becoming a realistic target for most mainstream enterprise IT organizations. Nonetheless, the success of the cloud service organizations and their IT and business models has shown that there is room for innovation in more traditional data center operations and that previous assumptions about data center operation can be challenged.

Most organizations do not have the luxury of being able to specify and order custom-designed, custom-built IT equipment. Thus, any challenge to existing assumptions about data center operations has to occur within the confines of the available industry standard server (ISS) platforms across the industry. To help determine the viability of operating ISS platforms in a completely air-side-economized data center with a wider operating range than specified under ASHRAE 2008, Intel ran a proof of concept in a dry, temperate climate over a 10-month period, using 900 commercially available blade servers. Servers in the air-side-economized environment were subjected to considerable variation in temperature and humidity as well as relatively poor air quality. Even then, Intel observed no significant increase in server failures during their test period. “We observed no consistent increase in server failure rates as a result of the greater variation in temperature and humidity, and the decrease in air quality,” noted Intel in its August 2008 report.[7] While this was not a strictly scientific study, it did confirm that industry standard servers could be used in this fashion and that further study and use was appropriate.

The Green Grid has observed a slow but steady increase in the adoption of wider operating envelopes. For example, Deutsche Bank recently announced its construction of a production data center in New York City that is capable of handling nearly 100% of the cooling load by using year-round air-side economization. The bank is able to cool its data center with no mechanical cooling necessary for at least 99% of the time through a combination of facilities innovations and the willingness to operate IT equipment at an expanded environmental range.[8]

IV. Concerns over Higher Operating Temperatures

Even given the data from the Intel study and the general trend toward leveraging wider operating envelopes, concerns about reliability and possible service-level impacts are not without merit. The relationship between increased temperatures and failure rates of electronics is well known and widely used to reduce the time required to perform reliability testing. What is not as well understood is the effect of temperature on the long-term reliability of IT equipment, apart from anecdotal evidence that servers in hot spots fail more frequently. There also remains disagreement on the importance and definition of "long-term" for most organizations. Effects such as ESD, particulate contamination, and corrosion at higher humidity levels also need to be considered.

Even if the theoretical potential for meaningful increases in failure rates was discounted, there remain more practical and immediate considerations to address when looking at wider operating ranges, especially at the higher end of the thermal range. There is a relationship between temperatures above a certain point and an increase in server power utilization. This relationship is largely due to the increased server fan power required to cool components and, to a lesser extent, to an increase in silicon electrical leakage current when operating at higher ambient temperatures.[9]

Additional observations show that some traditional, mechanical chiller cooled data centers have a "sweet spot" where operators can minimize overall energy consumption. This point exists at the intersection between the mechanical cooling energy consumption (which decreases as the operating temperature increases) and the IT equipment energy consumption (which increases as ambient air temperature rises past a point). Whereas chiller efficiency improves with increasing inlet supply temperature and reduces energy consumption, the power consumption of the IT equipment increases with inlet temperature past a point, which can be expected to vary between device types.[10, 11]

Data center operators frequently cite the perceived potential impact of higher temperature operation on support and maintenance costs as a significant deterrent to adopting wider operating ranges. Most IT equipment vendors warrant recent equipment for operation in both the 2008 and 2011 Recommended and Allowable ranges of the ASHRAE classes. However, there is often some ambiguity as to any operating restrictions, and vendors do not necessarily clearly articulate the duration of supported operation at the limits of the ranges. In recognition of the lack of clarity on warranties, the European Union, in its 2012 update of the Code of Conduct for Data Centre Energy Efficiency,[12] added a requirement for vendors to clearly publish information that specifies any such limitations in the operation of IT equipment.

IT RELIABILITY AND TEMPERATURE

The lack of historical authoritative data on any change in reliability that may occur when operating IT equipment at wider thermal and humidity bands has been a stumbling block to change. This historical murkiness has stopped some users and operators from building models and business cases to demonstrate that an economized data center using higher temperatures is viable and will not meaningfully and negatively affect the level of business service offered.

The Intel study in 2008 was the first study made public that used industry standard servers to demonstrate that reliability is not significantly or materially affected by temperature and humidity. At the time the Intel study was released, this conclusion was met with surprise, although perhaps it should not have been unexpected. For many years, IT systems design specifications have required that high-power components be adequately cooled and kept within vendors' specifications across the equipment's supported operating range. ASHRAE published data in its 2008 guidance paper, *Environmental Guidelines for Datacom Equipment—Expanding the Recommended Environmental Envelope*, that documented the change of internal component temperature for a typical x86 server with variable speed fans as the inlet air temperature changed. (See Figure 1.)

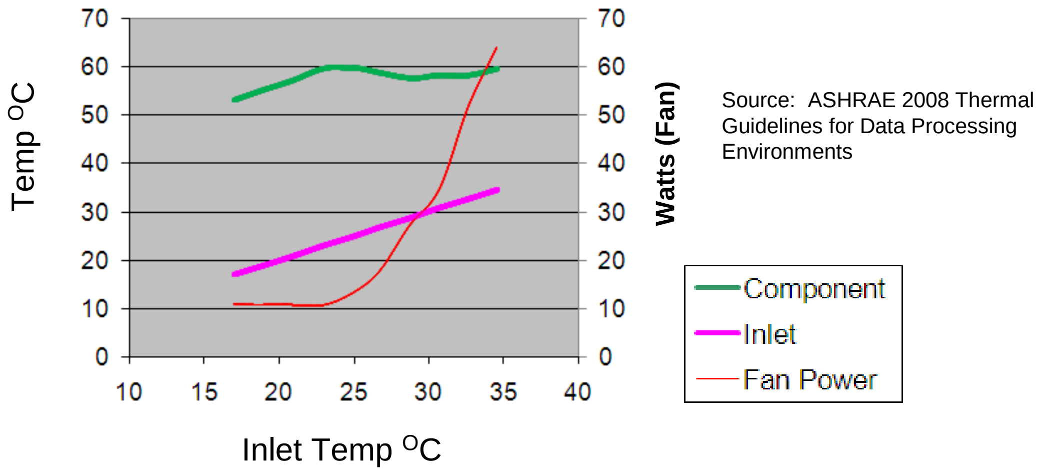

Figure 1. Internal component temperature and fan power against inlet temperature

The 2008 ASHRAE paper shows that the external temperature of the processor packaging (T_{CASE}) remains fairly constant and within its design specification, largely due to server fan speed increasing to mitigate the effect of the external temperature increase. As a consequence, the reliability of this component is not directly affected by inlet temperature. What can be established is that server design and airflow management are crucial influences on the reliability of server components, due to the change in operating temperature of these components, but the servers are designed to mitigate changes in inlet temperatures as long as those changes stay within the equipment's designated operating range.

What can also be seen from this data is that server fan power consumption rises rapidly to provide the necessary volume of air flowing through the processor heat sinks to maintain the component temperature within the allowed tolerance. Also note that the increase in fan power consumption only becomes meaningful past roughly 25°C, toward the limit of the Recommended range. Specifically, the increase in data center operating temperature had no impact on server power consumption until the inlet temperature reached this range. (Newer equipment and equipment designed to class A3 exhibits slightly different characteristics and will be discussed later.)

The industry's understandable focus on life cycle energy consumption for devices has driven a number of changes and innovations in more recent systems. Advancements in the design of these systems continue to reduce power consumption at many temperature levels, and the industry has continued to innovate in an attempt to drive down the required energy consumption as operating temperatures rise. However, the increased power and airflow associated with extended environmental ranges continue to be factors that need careful consideration. Additional implications of the increase in airflow will be discussed later.

In 2011, ASHRAE introduced its paper, *2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance*[1] to provide further guidance and direction for the IT and data center industries. One of the datasets presented in this ASHRAE paper was a normalized chart of relative server failure rates when evaluated against temperature, based on reliability data from multiple hardware vendors. Figure 2 is a plot of the change of the failure rate for multiple devices and vendors, showing the spread of variability between devices and the mean value at specific temperatures. This shows the change in the rate of server failures with temperature. Each data point is not the actual number of failures, but the relative change in failure rate among a heterogeneous sample of devices from multiple vendors.

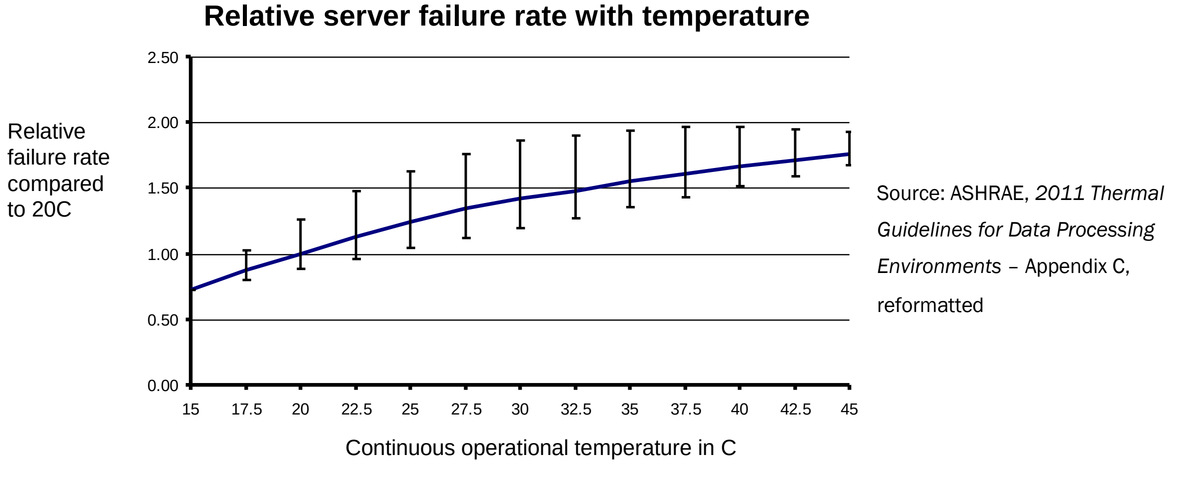

Figure 2. ASHRAE 2011 Relative failure rate with temperature for volume servers

The device failure rate shown above is normalized to 1 at 20ºC. Thus, Figure 2 demonstrates that for continuous operation at 35ºC, the failure rate is close to 1.6 times higher than for continuous operation at 20ºC.

Whether this increase is meaningful requires a bit of analysis. To illustrate the impact of this increase, consider a hypothetical data center with 1,000 servers. Assume that this data center typically expects an average of 10 servers to undergo some kind of failure within a given year when operating continuously at 20ºC. Given this baseline, if the example data center were to be operated continuously at 35ºC instead of 20ºC, one would expect to see an average of 16 server failures. This represents an average net increase of six server failures over the baseline rate, or simply six additional failures across a population of 1,000 installed servers.

In this example, continuous operation at 35ºC would represent a measurable impact on the availability of the population of servers when compared to continuous operation at 20ºC. If a more conservative approach is applied to the example data center, where it continuously operates at 27ºC (as opposed to 35ºC), an average increase of 2.5 failed servers could be expected across the 1,000-server population. More specifically, in this population of 1,000 servers, it would make sense to see an increase of failed servers from the baseline average of 10 per year at a continuous operation at 20ºC to 12.5 per year at a continuous operation at 27ºC.

The Relationship between Operation Duration and Failure Rates

It is important to note that the ASHRAE failure rate guidance and the example above both explicitly presume *continuous operation* at the given temperature. However, the application of the principles discussed here would tend to result in operations that are *discontinuous*. Specifically, it can be expected that most operations would result in a degree of floating ambient temperatures, where the actual ambient temperatures are more closely aligned with the capabilities of the economizers on a given day. For instance, operations at the upper portion of the selected thermal range would occur part of the year and likely only part of the day even on those days. Thus, while a number of operating hours can be expected at the upper temperature referred to in Figure 2, that operation would be discontinuous. The guidance provided by ASHRAE is that the maximum rate of change of operating temperature should not exceed 5ºC per hour where tape devices are used or 20ºC per hour where only disk devices are used. The actual rate of change for most environments will be significantly lower than the maximum permitted, in which case the effects of thermal stresses caused by changes in operating temperature may be discounted for the expected working life of a device. In short, the number of hours that a device operates at a given temperature within the allowable range is the prime determinant of its failure rate, and the effects caused by changes in temperature are themselves not a driver of failures during the device's useful life.

Consequently, the known data suggests that short-duration operations at or above 20ºC may only increase the failure rate for the particular duration, or they may have no measurable impact on failure rates for the expected lifespan of the installed equipment. The second point is that operation below 20ºC tends to decrease the failure rate. A potential scenario is a data center operating regime that combines floating operation both above and below 20ºC, weighted to follow the mathematical distribution shown in Figure 2. Short-duration operation at up to 27ºC could be balanced by longer-term operation at just below 20ºC to theoretically maintain the normalized failure rate of 1. This approach is discussed later in this paper.

The actual number of equipment failures for a given data center will depend on the individual level of reliability of the chosen hardware vendors and devices at corresponding points in the hardware's supported thermal operating range. In addition, the illustration above does not take into account the effects of preventative maintenance actions triggered by hardware-generated predictive failure alerts. Although these maintenance actions may be required more often, the likelihood of a server failing (resulting in unplanned downtime) is arguably reduced. Even more important is the understanding of what it means for a server to "fail." Different organizations would apply different definitions for a server failure; they may start the count from any unplanned component failure (fault) or, in contrast, start the count at a predictive failure alert. The significance of one approach versus the other would be organizationally specific.

Thus, each organization would need to look at the ASHRAE server failure rate model, understand its general nature, and apply the model to work within its specific context. For organizations with highly mature change and maintenance processes, the theoretical impact of any operating temperature increase may be tempered by the processes' ability to absorb the potential increase in failures. Moreover, organizations that leverage IT architectures that are largely abstracted from underlying hardware, such as in highly virtualized and cloud environments, may argue that there is no substantive impact to their IT operations availability or level of risk, given the resiliency built into their IT architectural models. In other words, the application of best practice IT platform design may, for some organizations, render any perceived or actual increase in failure rates (as described here) wholly inconsequential.

Other organizations may approach the equipment failure question in alternative ways. For instance, for some organizations, the cost savings derived from operating at higher ambient temperatures may easily pay for any potential increase in maintenance costs (such as component failures). As long as the equipment vendors support operation of their equipment at this higher temperature, and appropriate maintenance and/or warrantee contracts are maintained as typical, then the actual realized maintenance costs to an organization may be minimal. For these organizations, the cost impact may be as little as the labor used to execute the repair work and conceivably some accounting of the cost of scheduled and unscheduled downtime. Of course, this presumes that the IT organization is able to support its service level obligations and targets with a slightly elevated equipment failure rate; thus, all analyses would necessarily require some thought and planning to account for these and other organizationally specific needs and constraints.

Additional points can be drawn from ASHRAE's *2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance*. The normalized failure rate data[a] the paper presents is broken out by bin within Appendix C. (See Figure 2.) A "bin" is simply a five-degree range of temperatures, along with the number of hours of occurrence during a year. The observation here is that the anticipated rate of failure at a particular temperature is influenced by the number of operating hours at that point. Specifically, a bin breakout of the expected operating temperatures in a given data center can be used to establish a rough expected change in failure rates on the basis of the temperature distribution.

The overall consequence of these factors is that short-duration operation above 20ºC only increases the failure rate for that duration. In addition, operation below 20ºC decreases the failure rate for that corresponding duration. A potential scenario may involve a data center operating regime that combines operation at both above and below 20ºC, weighted to ensure no overall change in failure rate or even a reduction in likely failures, depending on the temperature of the data center as it stands today.

POWER CONSUMPTION INCREASE WITH TEMPERATURE RISE

As temperature rises past a point, one can expect the power consumption of the IT equipment to rise as well. There are two factors that primarily determine the increased demand for power in relation to a rise in temperature. The first is the increase in fan power that is used to boost the volume of airflow, which correspondingly provides adequate cooling of the processor and other components. The second factor is silicon leakage current in server components. Figure 3 illustrates the relationship between server power consumption and temperature for a range of industry standard servers.

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[a] It is important to note that ASHRAE describes this normalized failure rate as the "X-factor" in its discussion.

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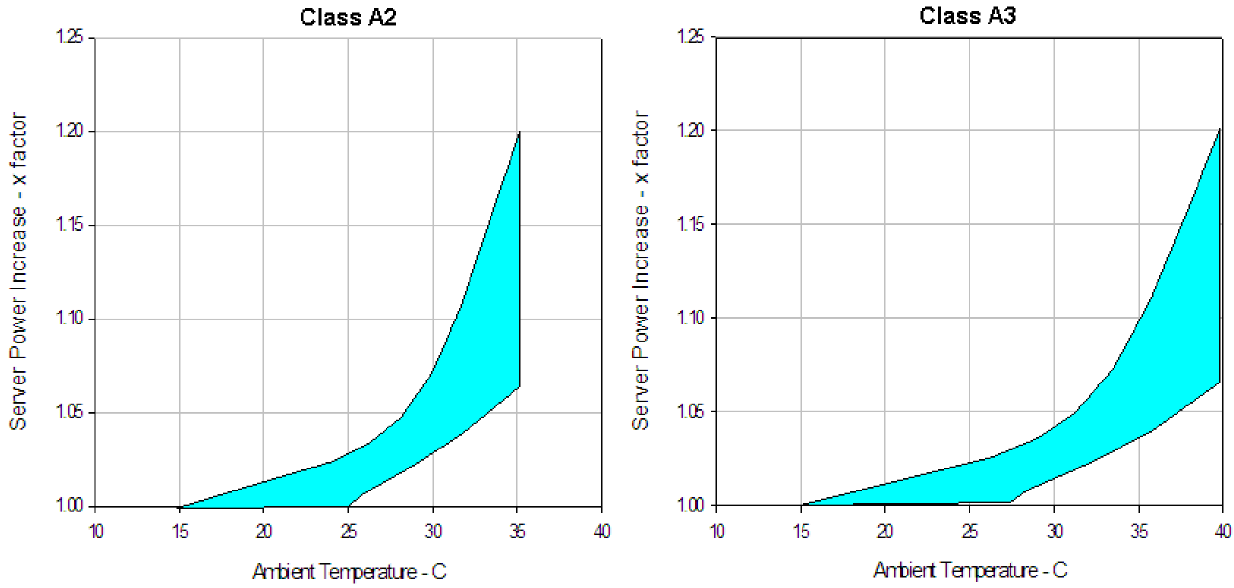


Source: ASHRAE 2012 Third Edition, Thermal Guidelines for Data Processing Environments

Figure 3. Relative increase in server power against inlet temperature for ASHRAE class A2 and A3 devices

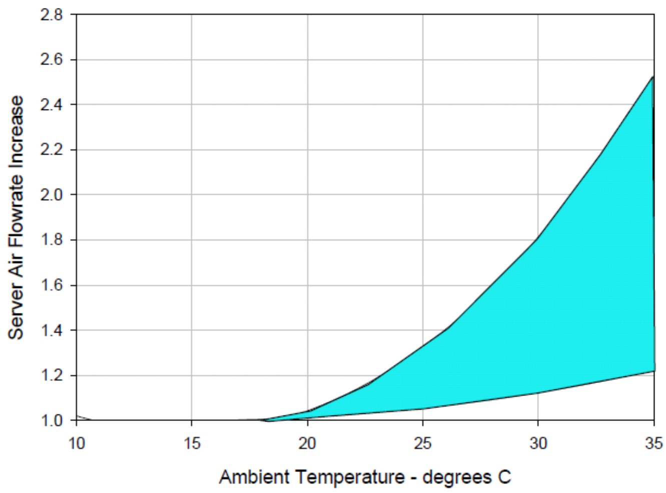
Figure 3 comes from the 2012 *Third Edition of the ASHRAE Thermal Guidelines for Data Processing Environments*.[13] It illustrates power consumption against temperature data for multiple vendors and devices, showing class A2 devices on the left and the more recently introduced class A3 devices on the right. A non-linear increase in power consumption is clearly evident in both charts. While leakage current rises linearly with temperature,[9] fan power consumption increases non-linearly with the desired airflow, increasing more rapidly than IT operating temperature as the speed of the fans is ramped up to maintain device component temperature within specification. Figure 3 shows that operating at the top of the Allowable range could cause devices to use up to 20% more power than operating at 20ºC. This effect needs to be factored into the power distribution design of a data center that solely uses economizers. Indeed, one of the reasons that ASHRAE identified its Recommended and Allowable ranges was the significant increase in server power consumption due to the increase in fan speeds as the supply temperature exceeds 25ºC to 27ºC.

The ASHRAE analysis also highlights the variation of power consumption among device models and vendors, potentially an important consideration when modeling the efficiency of a new data center. Similarly, the age of a given server is a noteworthy factor. Newer servers are likely to be able to handle increased inlet temperatures in a more efficient manner than older servers, and the distribution of old and new equipment within a given real-world data center will significantly influence expected and realized failure rates. Form factor can also be a consideration. For instance, 1U rack servers are at a disadvantage in that they tend to be less efficient than larger devices when handling higher inlet temperatures because of the smaller size and higher rotational speed of the fans used. Consequently, these servers are also more likely to exhibit higher increases in energy consumption due to the corresponding rises in inlet temperature. Blade servers and newer, modular form factor servers typically use larger fans at lower rotational speeds to achieve the same volume of airflow. Hence, they can be more efficient while demonstrating lower increases in power consumption as inlet temperature rises.

The industry's current innovation curve is steep; vendors are designing servers and other IT equipment to handle increased inlet temperatures better with each generation. As a result, the charts in Figure 3 show strong evidence of technology evolution since ASHRAE announced its A3 and A4 classes. The chart on the right shows that vendors of newly released class A3 devices are able to support operation at up to 40ºC with the same power characteristics as the previous class A2 devices operating at up to 35ºC, as shown on the left. There is obviously wide variation among devices and vendors, although a general observation is that, as the temperature rises, the increase in power consumption of a class A3 device is typically only 50% of that of a class A2 device.

The increased server fan power demands at higher temperatures have a distorting effect on IT power consumption at higher temperatures and therefore on overall data center PUE. For instance, the increased server power demands under these conditions result in the perverse effect of reducing the effective PUE at these higher temperatures—at the expense of increased absolute energy consumption. The PUE metric is intended to help operators understand a data center's overall efficiency and reduce energy consumption. Using the increased server power consumption to manipulate the presented PUE figure is an approach that is not advocated.

Along with the increase in fan power consumption, an even more important effect for data center designers is the change in the required airflow volume with changes in temperature. This relationship is shown in Figure 4.



Source: ASHRAE Whitepaper – 2011 Thermal Guidelines for Data Processing Environments

Figure 4. Relative change in server airflow with inlet temperature

Figure 4 shows that, compared to operation at 20ºC, operation at 35ºC in 2011 with A2 class servers could require more than twice the volume of airflow to maintain the correct internal component temperature. For data centers, this is a very different design point; airflow volume now becomes as important as temperature and humidity control. Similar to the increase in power consumption, it is expected that A3 class servers will show reduced airflow requirements compared to A2 class servers at the same temperature.

V. Exploiting Air-Side Economizer Cooling

To support the exploitation of economized cooling approaches, The Green Grid published two sets of free cooling maps, first in 2009 and again in 2012. The 2009 free cooling maps[4] and tools[5] enable data center operators in North America, Japan, and Europe to identify the level of benefit that air-side and water-side economized cooling would bring while working in the ASHRAE Recommended range of up to 27ºC. The 2009 map for Europe, Figure 5, uses light-to-dark blue shading to show that most European data centers could expect at least 7,000 hours a year of air-side economizer operation when the external temperature was less than 27ºC. This represents up to 80% of operating time.

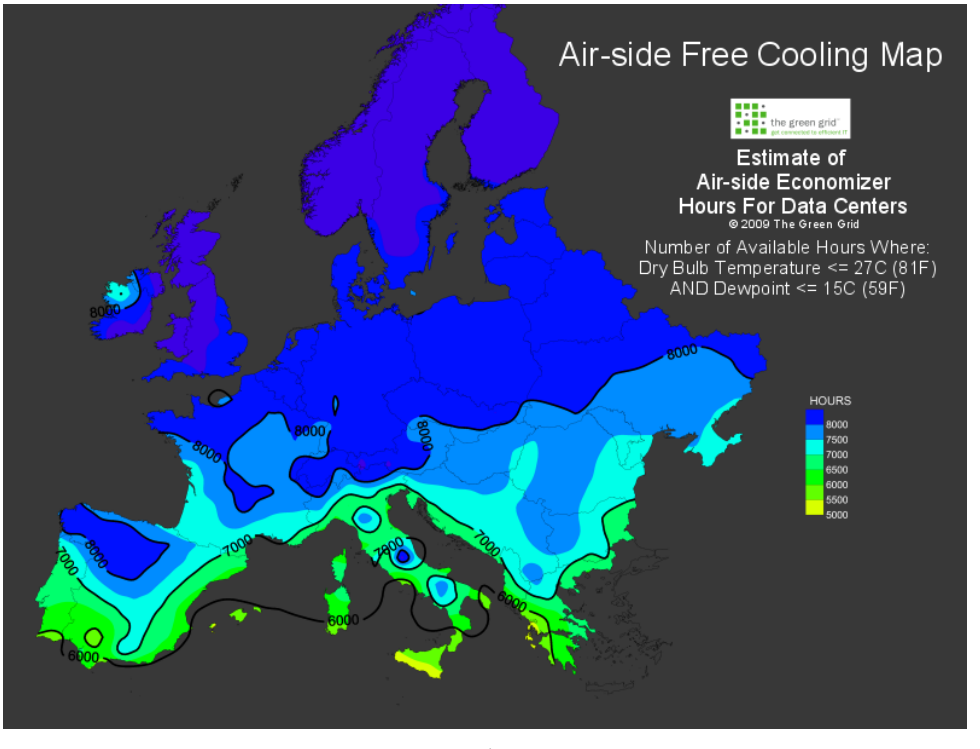


Figure 5. 2009 Europe free cooling map 27ºC

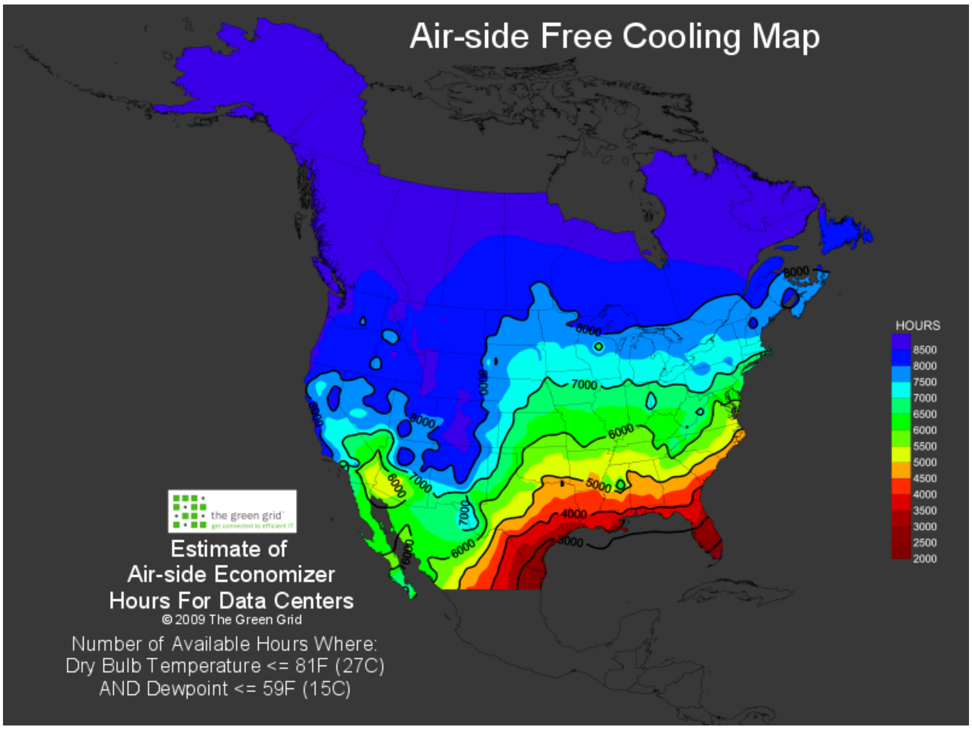


Figure 6. 2009 North America free cooling map 27°C

Figure 6 shows the corresponding map for North America, where the 7,000-hour line is more restricted due to the climate. That said, the 5,500-hour-and-above line (shaded in green to dark blue) represents 60% of operational time and covers much of the United States and Canada. This offers data centers significant potential for energy savings by operating up to the limits of the ASHRAE Recommended range of 27°C.

The Green Grid's 2012 maps[6] illustrate operation up to the limits of the ASHRAE A2 Allowable range of 35°C and show a potentially greater impact of the use of economizers. Figure 7 shows that 99% of locations in Europe can use the A2 Allowable range and take advantage of economizer mode cooling all year. Figure 8 illustrates that 75% of North American data centers can operate economizers up to 8,500+ hours per year.

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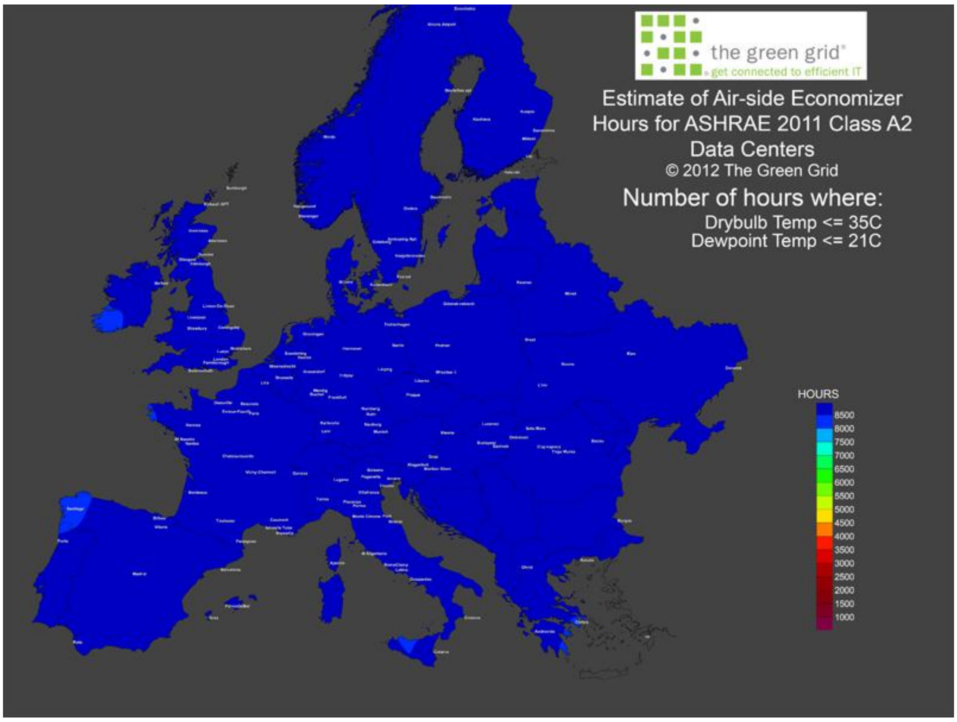


Figure 7. 2012 Europe free cooling map 35°C

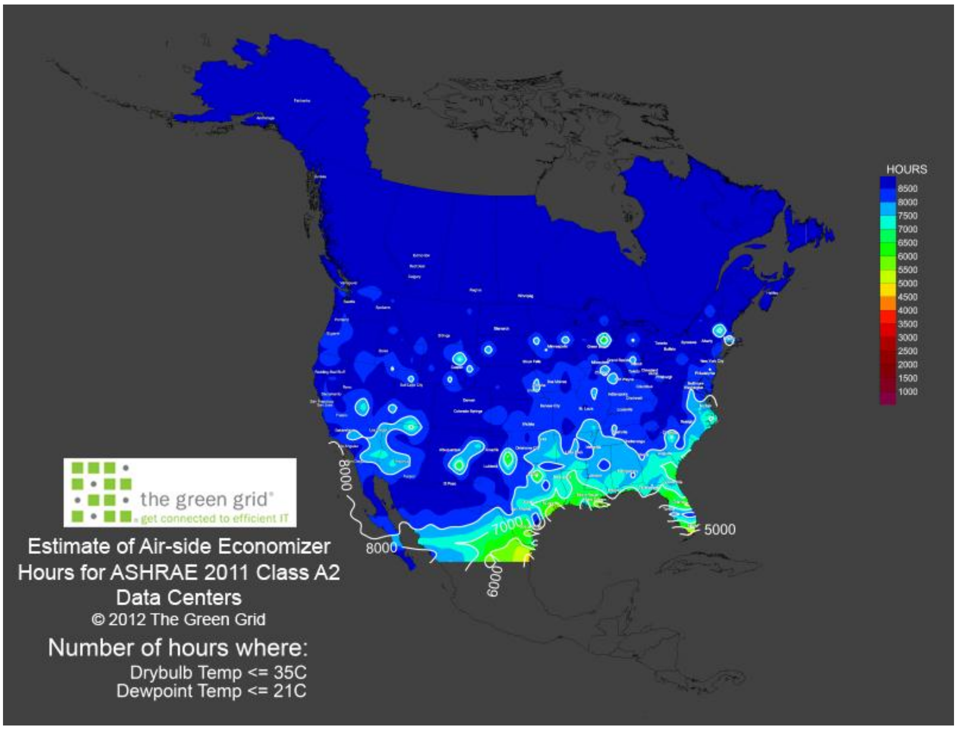


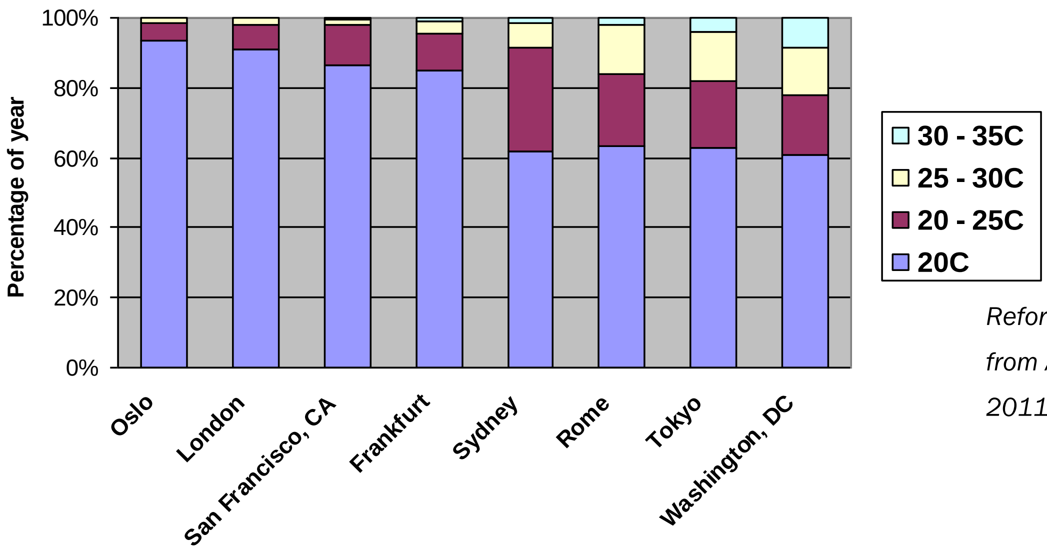
Figure 8. 2012 North America free cooling map 35°C

As noted earlier, many data centers are still operating with inlet temperatures in the 20°C to 22°C range. This greatly limits the duration that economizers can be used and the economic benefits that can be derived, although The Green Grid's recent economizer survey suggested even that limited operating range would result in 20% lower operating costs. Where good airflow practices are used—such as contained aisles to provide consistent supply temperatures to all devices irrespective of placement—the energy savings benefit from limited operation at up to 27ºC (as illustrated in The Green Grid free cooling tool) is significantly greater.

It is important to note that any increase in total server energy consumption resulting from a rise in inlet temperature in an air-side economized data center is likely to prove inconsequential in comparison to the data center build and running costs associated with a restricted operating range and the use of mechanical chiller based cooling. In other words, the incremental costs from operating an air-side-cooled data center, with occasional increased server energy consumption, are almost certainly lower than the extra cost associated with using mechanical cooling to maintain a constant supply temperature when external ambient temperatures are toward the top of the range. In most cases, where the supported environmental range is not exceeded, installing mechanical cooling to reduce the inlet temperature to achieve lower server energy consumption would not prove to be an overall cost- or energy-efficient approach.

THE EFFECT OF BROADENING OPERATING REGIMES

To explain the effect on reliability of higher supply temperatures, ASHRAE published data in its 2011 paper that shows the ambient temperature range for major international cities, as expressed in 5ºC-bin increments. This data illustrates the duration that devices would likely need to operate at above 20ºC in a data center with only air-side economization. The data includes a reasonable assumption of an increase in data center supply air temperature of 1.5ºC above the outdoor ambient temperature.



Reformatted from ASHRAE 2011

Figure 9. Percentage of the year during which major international cities' temperatures fall within the ASHRAE class A2 Allowable range

Figure 9 is an example of the ASHRAE 2011 data for cities across the world. The figure's blue shaded areas show the percentage of time that the data center can expect to operate with an external air supply temperature below 20ºC. The purple shaded area illustrates the percentage of operating time between 20ºC and 25ºC, and the figure continues to show the percentage of expected operating time, expressed in yellow and green, up to 35ºC. This data illustrates that, for some major international cities, the external temperature is only above 20ºC for less than 10% of the year. If the region up to 25ºC is included, the duration of time above 25ºC ranges from less than 20% down to less than 2%. Thus, the higher the allowable inlet temperature, the more geographic areas that can be considered for exclusively air-side economized data center cooling.

If the temperature duration data for a particular data center location is combined with the reliability data for each temperature increment (as presented earlier in Figure 2), the impact on overall reliability and failure rates for different operating regimes can be determined. This operating approach assumes that the supply temperature tracks the external temperature and that appropriate airflow management is implemented to avoid hot spots. Low external temperatures are mitigated by the reintroduction of hotter exhaust air (recirculation).

A number of different data center operating scenarios can be considered for economizer operation. The ASHRAE 2011 paper uses an example of a data center located in Chicago, where the temperature is below 20ºC for much of the year. Chicago reaches higher temperatures during the summer months, but only for limited periods. The supply temperature tracks the external air temperature down to a minimum of 15ºC and up to a maximum of 35ºC. From the prior discussion on the nature of the failure rate distribution, recall that the effect of server operations with inlet temperatures below 20ºC tends to reduce the failure rate. Correspondingly, operating at above 20ºC tends to increase the failure rate. The time the average data center server operates at a given temperature determines the actual expected failure rate within that data center. The aggregate failure rate for the example Chicago operating regime is calculated as 0.99, compared to a failure rate of 1 for this white paper's baseline: continuous operation at 20ºC.

Using this same approach, Figure 10 illustrates the effect on overall server reliability at a given data center for some select international cities. This figure uses the ASHRAE temperature data for those cities, along with the corresponding reliability data.

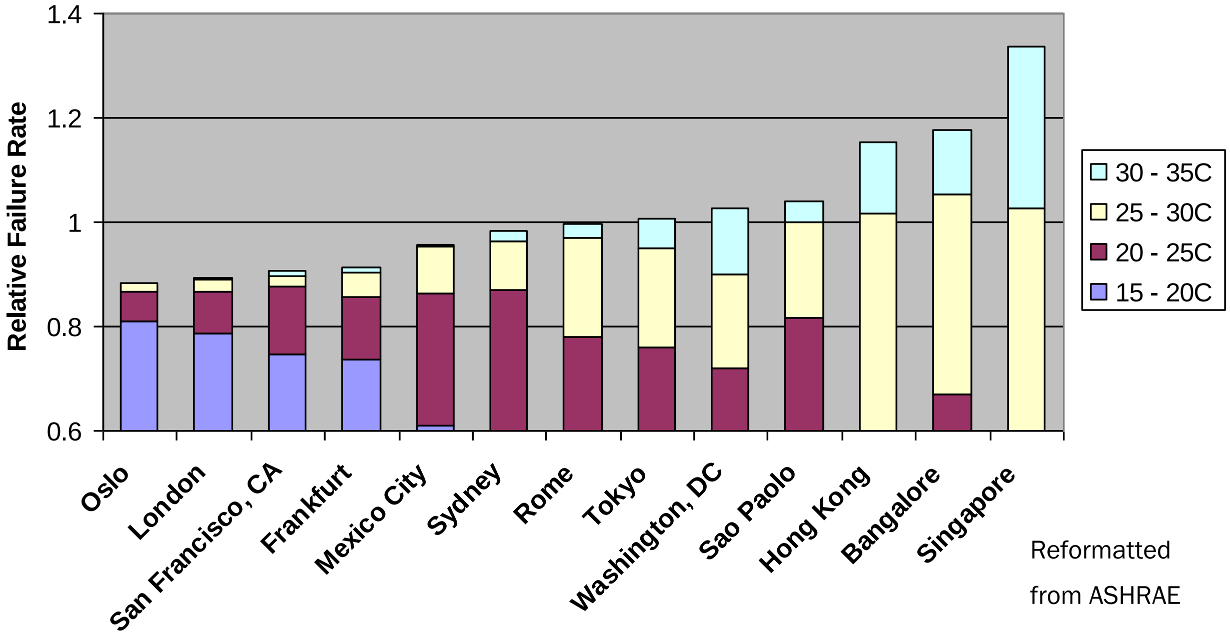


Figure 10. Change in failure rate for international cities with variable operation between 15°C and 35°C

In Figure 10, the vertical axis represents the relative failure rate compared to continuous operation at 20°C. The different colors in the bars represent the different contributions to the overall failure rate for the duration of operation within each 5°C temperature increment at each location. Figure 10 shows that for many cities where the external temperature is below 20°C for much of the year, using a minimum operating point of 15°C could actually increase overall reliability.

Multiple different operating regimes can be derived from the presented ASHRAE data and the effect on expected reliability can be determined. Figure 11 shows a restricted operating regime, where the data center maintains 20°C as its minimum temperature and operates up to the ASHRAE A2 limit of 35°C.

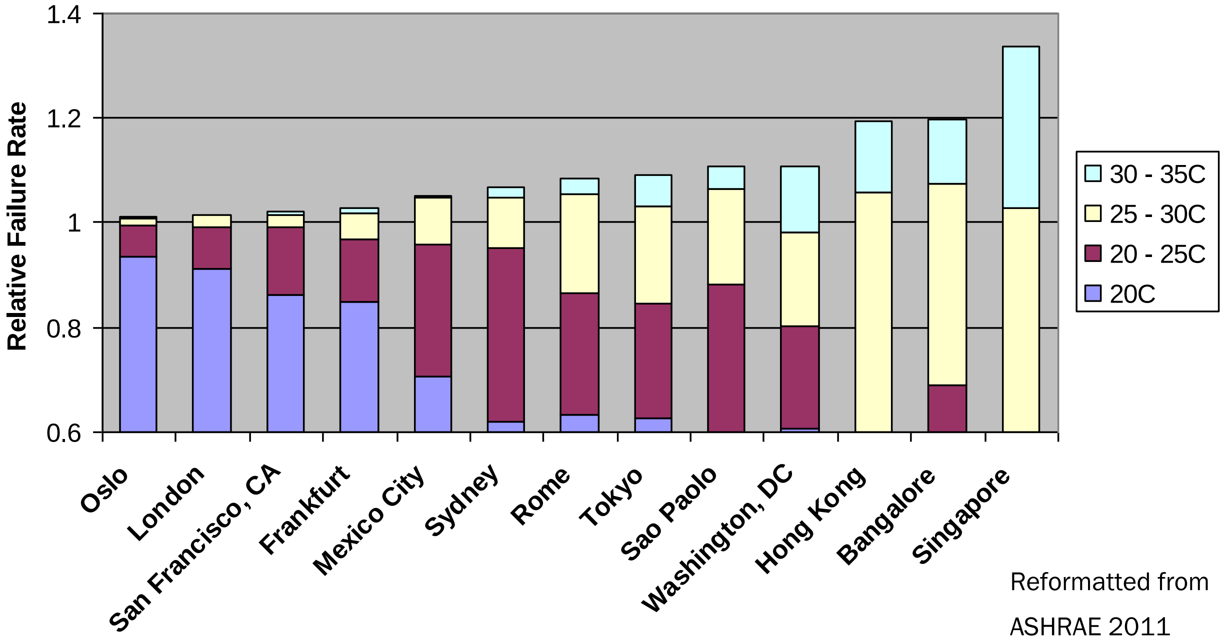


Figure 11. Change in failure rate for variable operation between 20°C and 35°C for international cities

Figure 11 reveals only a marginal increase in failure rate for many European cities compared to continuous operation at 20°C. Because the period when the supply temperature is above 20°C is of a relatively small duration, the effect on overall reliability from operating at this temperature is limited. For locations such as London, operating in this manner results in less than a 2% increase in the expected failure rate. Based on the example of 10 failures per year in the IT reliability and temperature subsection, the short duration equates to an additional 0.2 servers potentially failing per year.

This analysis of failure rates only considers temperature effects and does not consider the effect of long-term higher humidity and external contaminants that may be present when air-side economizers are used. In combination, high humidity and gaseous or particulate contaminants represent a serious threat to device reliability.[14,15] This threat may be mitigated by filtration, but industrial pollution may be a limiting factor in data center site selection where one plans to use air-side economizers.

The effect of thermal cycling on long-term device reliability is also a consideration with variable temperature operation. The regime presented in Figure 11 shows a relatively benign environment with a restricted range of operation. ASHRAE guidance suggests a rate of change of no more than 5°C per hour, which would require adoption of an appropriate environmental control system to maintain the rate of change within this limit.

CALCULATING THE EFFECT OF OPERATION IN THE ALLOWABLE RANGE

The reliability data provided by ASHRAE can be used to explore the effect of using the full ASHRAE Allowable range to maximize the benefits from economizers for a specific data center location. It goes without saying that a key pre-requisite is to implement appropriate airflow management best practices, thereby providing complete control over the environmental conditions within the data center. The following is a sample approach to calculating the net change in overall reliability for a specific location.

This calculation uses the relative change in equipment failure rate, or “X-factor,” at a specific temperature to calculate the “Net X-factor” for a location. The Net X-factor for a location is a measure of the impact on IT server reliability by allowing the operating temperature in the data center to track the external ambient temperature closely. An X-factor value of 1 is the reliability of IT servers in a data center that operates at 20ºC continuously. If the calculated Net X-factor is less than 1, then IT server reliability could increase compared to running the data center at 20ºC continuously. If the calculated Net X-factor is greater than 1, then reliability of the IT servers will be reduced compared to continuous operation at 20ºC. Rather than exploiting the entire range, data center operators may decide to manage the temperature range with the intent on realizing a Net X-factor below 1, while potentially achieving significant cooling-based energy savings. Note that the figures provided by ASHRAE only relate to volume industry standard servers. Device failure rates and temperature characteristics may well be different for other classes of devices deployed in a data center. Operators are advised to work with their respective device vendors to understand the temperature characteristics and potential failure rate distributions of all deployed devices at their sites. Table 3 is an illustration of how to calculate the Net X-factor for a specific location, with the final result presented at the bottom of Column F.

Table 3. Calculation of Net X-factor for a specific location

Column A Input	Column B	Column C Input	Column D	Column E Input	Column F Calculation
X-factor	**IT inlet temperature ºC**	**External to inlet increase ºC**	**External temperature ºC**	**% of hours at temperature**	**Contribution to X-factor**
0.72	Less than 15		Less than 13.5	35.1%	0.25
0.72	15	1.5	13.5	7.5%	0.05
0.80	16	1.5	14.5	6.8%	0.05
0.87	17	1.5	15.5	6.5%	0.06
0.91	18	1.5	16.5	6.1%	0.06
0.96	19	1.5	17.5	5.9%	0.06
1	20	1.5	18.5	5.1%	0.05
1.07	21	1.5	19.5	4.8%	0.05
1.13	22	1.5	20.5	3.5%	0.04
1.17	23	1.5	21.5	3.2%	0.04
1.20	24	1.5	22.5	3.1%	0.04
1.24	25	1.5	23.5	2.1%	0.03
1.29	26	1.5	24.5	1.8%	0.02
1.34	27	1.5	25.5	1.5%	0.02
1.37	28	1.5	26.5	1.7%	0.02
1.39	29	1.5	27.5	1.4%	0.02
1.42	30	1.5	28.5	1.2%	0.02
1.45	31	1.5	29.5	1.1%	0.02
1.48	32	1.5	30.5	0.9%	0.01
1.50	33	1.5	31.5	0.3%	0.00
1.53	34	1.5	32.5	0.2%	0.00
1.55	35	1.5	33.5	0.1%	0.00
1.55	Greater than 35	1.5	Greater than 33.5	0.1%	0.00
				Net X-factor	**0.91**

The X-factor values used in Column A are dependent on the risk profile adopted by the organization and come from Table 4. The lower boundary of the failure rate data should be used if the objective is to be more aggressive in saving energy and the upper boundary if the approach adopted is conservative with the objective of minimizing risk. The Table 3 example uses the “Average” numbers from Table 4. In Table 3 Column A, the **bold** figures are taken from Table 4, the figures in *italics* have been extrapolated from the ASHRAE data in Table 4. The X-factor values in Column A align with the “Inlet to IT Temperatures” in

Column B. The lowest operating temperature is **limited** to 15ºC, and the highest allowed operating temperature is 35ºC, aligning with ASHRAE class A2.

The temperature rise from external ambient air temperature to the IT inlet temperature is entered in Column C of Table 3. For an air-side-economized site, +1.5ºC is assumed due to mechanical air handling. For any given data center location, the hourly temperature bin data must be obtained. This can be sourced from the ASHRAE Weather Data Viewer[16] or from the relevant national weather bureau. This temperature bin data is used to populate Column E of the table. Column D specifies the (external) temperature "bin", the percentage of hours for the given location at the specified external air temperature as taken from the bin data is populated in Column E. Column F calculates the contribution to the Net X-factor by multiplying the X-factor from Column A with the percentage of hours in Column E. The Net X-factor is the summation of the values in Column F and is presented at the bottom of the column. In this Table 3 example, the Net X-factor is 0.91, which represents an overall reduction in the temperature-induced equipment failure rate.

Table 4. ASHRAE relative hardware failure rate X-factor for volume servers as a function of continuous (7 days x 24 hours x 365 days) operation air inlet temperature

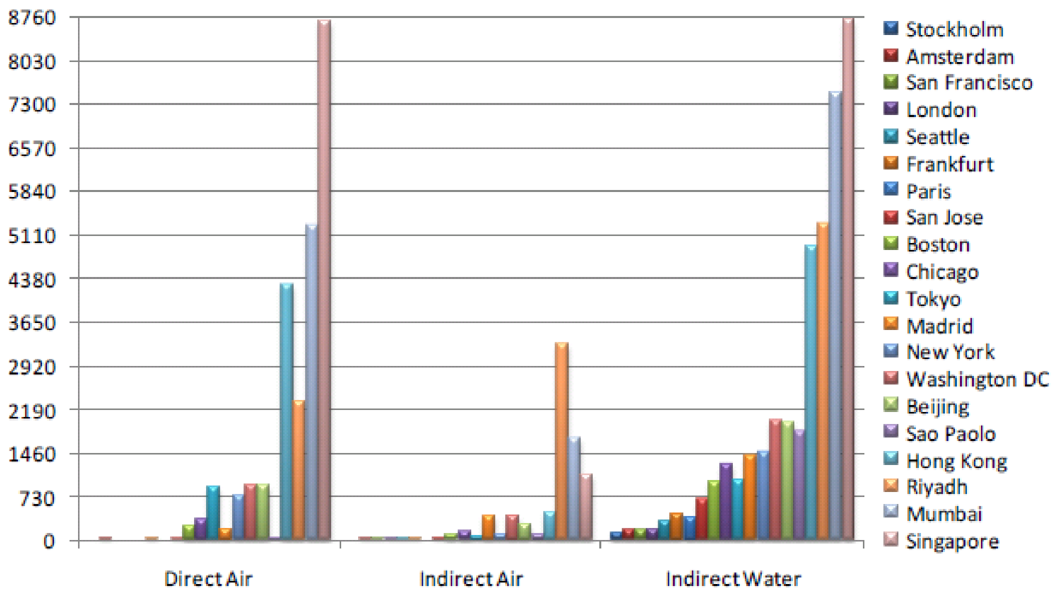
	Average	Aggressive	Conservative
Dry Bulb Temperature (C)	Average Failure Rate X-Factor	Lower Boundary of Failure Rate X-Factor	Upper Boundary of Failure Rate X-Factor
15	0.72	0.72	0.72
17.5	0.87	0.8	0.95
20	1.00	0.88	1.14
22.5	1.13	0.96	1.31
25	1.24	1.04	1.43
27.5	1.34	1.12	1.54
30	1.42	1.19	1.63
32.5	1.48	1.27	1.69
35	1.55	1.35	1.74
37.5	1.61	1.43	1.78
40	1.66	1.51	1.81
42.5	1.71	1.59	1.83
45	1.76	1.67	1.84

What impact does the change in the Net X-factor have on service availability and server failures? The average failure rate for IT servers at a Net X-factor of 1, operating continuously at 20ºC, is assumed to be between 2% and 4% a year. Hence, in a 1,000-server data center, there are likely to be 20 to 40 server failures a year, when operating at 20ºC continuously. If the temperature in the data center is allowed to track the external ambient temperature with the aim of achieving a Net X-factor of less than 1, then a reduction in server failures should be realized. In Table 3, the Net X-factor is 0.91, which means that, by allowing the data center to track the external temperature, the IT server failures should reduce by 9% for this location in contrast to the baseline. For a 1,000-server data center, this corresponds to 18 to 36 server failures. This number of failures is less than when operating at 20ºC continuously.

THE EFFECT ON DATA CENTER ENERGY CONSUMPTION

The choice of operating regime and exploitation of the Recommended or Allowable ranges, or even part of these ranges, has a considerable impact on energy consumption and overall data center operating costs. The data presented in The Green Grid free cooling maps in Figure 5, Figure 6, Figure 7, and Figure 8 illustrates the possible geographical exploitation of economizers and good airflow management, and it represents a large potential reduction in energy consumption.

The approach to energy reduction described in this white paper has also been explored by the Data Centre Specialist Group (DCSG) of the British Computing Society (BCS). In 2011, BCS published a white paper titled *IT environmental range and data centre cooling analysis*. This paper assessed the impact of IT inlet temperature and humidity ranges on data center cost and overall energy consumption.[17] To understand overall energy costs, the BCS analyzed the number of hours of chiller operation (mechanical cooling) that was required when using the full ASHRAE A2 Allowable range of temperature and humidity. Reproduced from the BCS paper, the data in Figure 12 illustrates the number of chiller hours required for three different cooling approaches in major international cities.



Source: BCS
IT environmental range and data centre cooling

Figure 12. Annual worldwide chiller hours necessary when using ASHRAE class A2 range with different cooling approaches

Figure 12 reveals that when a data center is designed and operated effectively, the hours per year during which any mechanical chiller cooling is required are minimal. Three different types of cooling economizer are represented here: direct air-side, indirect air-side, and indirect water-side. The analysis in the BCS paper shows that, for many locations, only a limited number of chiller hours are required if data center operators exploit the full ASHRAE A2 Allowable range up to 35^{O}C. However, the paper also shows that very high humidity levels in cities such as Mumbai and Singapore would seem to preclude the use of direct air cooling in those locations. The BCS paper concludes that operating at up to 35^{O}C is therefore effective in reducing the energy consumption associated with mechanical chiller–based cooling. Furthermore, by reducing that consumption to a small proportion of the data center's overall energy consumption, the data center reduces its PUE.

In addition, the BCS analysis shows that, where there is an available supply of water, adiabatic (evaporative) cooling can be used as a replacement for chillers. Direct evaporative cooling (DEC) injects water directly into the air supply and results in cooling of the intake air through vaporization of some of the water. It is an approach to cooling that is rapidly becoming accepted. For example, Facebook recently disclosed that it built a data center in Oregon[18] using direct evaporative cooling.

The BCS paper further concludes that completely eliminating mechanical chillers delivers benefits such as associated capital cost reduction and elimination of the chillers' supporting electrical equipment capacity in data center design. However, the elimination of chillers had no significant impact on operational costs, energy consumption, or PUE in the BCS analysis due to limited chiller operation in the explored scenario.

The decision to eliminate chillers entirely in a design is not to be taken lightly because of the risk of extreme climate events. The implementation of a closed-loop cooling design (with or without mechanical cooling) may also be a requirement in areas where there is risk of significant industrial pollution or airborne particulates.

EXTREME TEMPERATURE EVENTS

In addition to considering a location's average annual temperature and humidity profile to determine the appropriate operating regime, the occurrence of extreme temperature events must also be considered. The ASHRAE 2011 paper highlights this necessity, pointing out that peak temperatures may deviate significantly from a location's average figures. The BCS paper also identifies extreme temperature events as a consideration for whether chillers can be completely eliminated from data centers.

Temperatures as high as 50ºC have been recorded in some U.S. states and in Seville, Spain. Temperatures at this level will require data centers to use chillers or adiabatic/evaporative cooling in conjunction with economizers, irrespective of the environmental range supported by the IT hardware.

VI. Equipment Supporting Higher Operating Ranges

Telecommunications equipment for many years has conformed to the European Telecommunications Standards Institute (ETSI) EN 300 019 Class 3.1 standards or the equivalent Network Equipment Building System (NEBS) Level 3 standard in terms of supported environmental ranges. These standards enable deployment of ruggedized IT equipment in a wider range of physical environments than IT-orientated data centers. Among characteristics specific to operation within telecommunications sites, such as seismic mounting and optional 48V direct-current (DC) operation, telecommunications-rated IT equipment is required to operate at up to 40ºC and in exceptional conditions at up to 45ºC. Data center operators who want to exploit the ETSI or NEBS environmental characteristics to make greater use of economizers therefore face a restricted choice of devices, with potentially limited performance and largely higher costs.

Telecommunications-rated equipment typically comes at a cost premium compared with commercially available volume servers. To achieve the telecommunications design point at a reasonable cost, many vendors use commercially available off-the-shelf (COTS) server components, typically designed to support the ASHRAE A2 range. However, to enable standard heat sinks and fans to dissipate thermal energy at the higher peak NEBS/ETSI operating temperature, the vendors limit their equipment’s heat production by using lower-performance and lower-power processors. The available range of telecommunications-rated equipment is also only a fraction of the complete commercial range, as a consequence of the narrower market.

In recognition of operators’ desire for IT equipment that can improve efficiency and reduce data center capital and operational costs while maintaining existing standards of reliability, ASHRAE introduced the new A3 and A4 classes. Class A4 is largely equivalent to ETSI EN 300 019 Class 3.1 or NEBS Level 3. Introduction of these classes represents a departure by ASHRAE from previous practice in 2004 and 2008, where all vendors agreed to support class 1 or class 2. ASHRAE has moved to an approach that outlines a number of environmental ranges, where vendors can choose to release products supporting specific classes based on user requirements, demand, and feedback.

Product evolution is enabling this move; several vendors have released new product ranges that support the A3 class. Over time, natural hardware obsolescence and equipment replacement cycles will refresh entire data center inventories with A3 class or higher equipment.

However, to support data center operators in taking advantage of the wider Allowable range, IT vendors still need to provide more clarity around the duration of operation supported and warranties for operation within the Allowable range.

VII. Implications for the Design and Operation of Data Centers

Raising operational temperatures in a data center can affect more than its IT equipment. The following section discusses key data center design factors to consider when planning for extended environmental ranges. Higher-temperature operation, if only for limited durations, brings new operational challenges for data centers. It is highly unlikely that simply taking an existing data center and increasing its operating temperature will result in a successful transition. Several basic air-management and operational areas need to be reviewed for applicability, including:

- Health and safety concerns for operating personnel
- Airflow optimization throughout the data center's layout to avoid (very) hot spots
- Increased temperature in the hot aisle, which may extend beyond limits of cabling
- Increased temperature, humidity, and particulates effects
- PUE anomalies due to server fan power consumption at high temperatures

HEALTH AND SAFETY

Increasing the airflow driven through a server also has an effect on fan noise, with the sound level increasing at the 5th power of the rotational speed. European health and safety guidelines already dictate the maximum noise level for IT equipment, and any future server cooling improvements will have to be achieved within the same noise limits. An obvious solution to limit noise and increase airflow in servers is the use of larger fans and server form factors. Systems with small form factors, such as 1U servers, need to move similar volumes of air but with smaller fans, necessitating higher fan speeds to move the required amount of air. In addition to the extra power drawn, the subsequent increase in speed also amplifies the noise, resulting in increased background noise. Consideration should be given to working procedures associated with the increased noise that may result from higher operating temperatures.

A second health and safety consideration is the exhaust air temperature, which again may inhibit higher temperature operation. Exhaust temperature is dependent on inlet temperature, server power consumption, and airflow—in extreme cases, exhaust temperature can be 20°C more than inlet temperature. In a contained aisle configuration, this could result in hot aisle temperatures of over 50°C. Raised exhaust air temperature has significant implications for operational working practices within data centers with regard to maintenance and device installation.

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Both of the above considerations can be addressed by using service windows where the temperature is reduced through additional cooling; this occasional cooling necessitates the provision of plant and control capabilities to deliver it.

HIGHER TEMPERATURES AFFECT ALL ITEMS IN THE DATA CENTER

Increased temperature has implications for the selection of cabling and power distribution components in the hot aisle, where previously no temperature rating considerations were necessary. While limited research is available on the effect of temperature on power and network cables, there is some evidence that Category 6 cabling is affected by increased temperature. Category 5 and Category 6 cables have a temperature range of -10 to +60^{o}C, although beyond 40^{o}C, the bandwidth and signal-to-noise ratio reduce considerably.[19] More research is required to identify the effects of increased temperatures on all of the components of the data center. With increased inlet temperature, the hot aisle temperature needs to be monitored to ensure that the data center's overall temperature does not exceed the design parameters for all its peripheral equipment, cables, and hardware.

Other rack-based equipment such as power distribution units (PDUs) and network switches have distinct operating envelopes with an upper limit of around 45^{o}C. This limit can easily be exceeded if the inlet temperature rises above 35^{o}C.

AIRFLOW OPTIMIZATION

All data centers will normally have some variance of temperature throughout the layout of a rack or row. Enclosed aisles generally improve the distribution considerably, but care must still be taken during a data center's design and operation to ensure that hot spots are reduced. When increasing the overall server inlet temperature in a data center, those areas prone to hot spots need close monitoring to ensure that variations do not exceed the operational envelopes. Implementation of cooling best practices such as those in The Green Grid Data Center Maturity Model[20] and the EU Code of Conduct on Data Centre Efficiency[12] can ensure that any hot spots are mitigated. As discussed earlier in this paper, there is a tendency to use equipment's supported temperature envelope as a basis for mitigating the effect of changes in airflow and cooling due to alterations in data center layout. Care should be taken when implementing any changes in an existing data center to ensure that the supported temperature envelope has not been used in this fashion in any previous decisions on layout.

TEMPERATURE EVENTS

A cooling plant failure affects most data centers, whether the cooling is achieved by conventional methods or air handlers in a free-air environment. Temperature envelope monitoring is critical as the ambient temperature increases, because without a large plenum of air, the temperature can exceed system and infrastructure design envelopes in a short timeframe.

Data center operators should consider maintaining cooling plant operation via the uninterruptible power supply (UPS) circuit or backup power in order to overcome the risk of over temperature or thermal runaway. In this respect, air-economized data centers offer benefits over traditional closed-loop, mechanical chiller cooled environments, because the lower power consumption of the cooling facilities can allow operation from the UPS or backup power. Enclosed aisles can also help in this regard.

HUMIDITY CONSIDERATIONS

Relaxing humidity control can deliver substantial energy savings. Dew point maintenance is critical, however, as is ensuring that all equipment in the data center is suitable for the extended humidity ranges. This is similar to the due diligence required for those with extended temperature ranges.

DATA FLOOR DESIGN

The most effective method of harmonizing temperatures is normally to separate a data center's hot and cold aisles to prevent hot spots and hot air recycling. There are multiple arguments for hot or cold aisle enclosures, but whatever the decision on design, it is key to ensure that exhaust air is not allowed to mix with the supply air.

For equipment that has limited extended range operation, including tape devices or mission-critical hardware, suitable zoning within a data center or the provision of additional spot cooling/control may be an appropriate solution.

MEASUREMENT AND CONTROL

Data center infrastructure management (DCIM) is another factor requiring careful consideration when expanding the environmental ranges. When extending the upper and lower environmental boundaries, variations in airflow can significantly affect delivery of cool air. For example, cool air could be depleted through an increased volume of air drawn in by equipment as the temperature rises.

To ensure data center equipment reliability, it is vital to monitor temperature and humidity throughout the airflow. In addition to discrete probes, most systems and components now have temperature probes that can be accessed through a DCIM tool. These multiple additional probes can be used to map the actual temperatures of the systems and components throughout the data center. The Green Grid advises active thermal mapping, combined with occasional thermography activities.

PUBLISHED ENVIRONMENTAL RANGES

Any extension to a data center's operational range should be based on the published ranges for all of the equipment in the data center. Those ranges may be difficult to ascertain in data centers with equipment that is more than three to four years old. Historically, a device's environmental range was not considered important, due to the assumption that equipment would remain in a closely controlled environment. This may mean that the effect of extended ranges was never considered or tested for some equipment, beyond the closely controlled range. In addition, documentation may have been poorly maintained and the data may simply no longer be available. Environmental data for more recent systems should normally be available as a result of the increased importance placed on the energy savings associated with expanded environmental operation. Equipment that does not conform to more current guidelines should be segregated to ensure that, where needed, tight control can still be maintained.

VIII. Conclusion

Data centers can realize operational cost savings with minimal effect on IT equipment reliability and availability. Where applicable, the use of economizers and looser environmental control with an extended range of temperature and humidity can reduce the amount of energy required to keep IT equipment within the ranges supported by IT vendors. Data centers can achieve these reductions without substantively affecting IT reliability or service availability by adopting a suitable environmental control regime that mitigates the effects of short-duration operation at higher temperatures.

Adopting an extended environmental operating range within a data center to reduce energy consumption is not straightforward. This paper has highlighted several aspects relating to IT equipment operation as well as data center and data floor design, all of which need to be considered to successfully deploy an extended-range approach. Operating at higher temperatures within the ranges defined by ASHRAE prompts new operational, health and safety, and component-selection considerations associated with the higher exhaust temperatures that will be encountered in hot aisles.

This paper's analysis of the reliability data published by ASHRAE shows that many geographic areas can adopt economizer-based cooling and operate within the supported boundaries of the defined classes. They can do so with minimal effect on overall reliability due to short-term operation at higher temperatures. In addition, the introduction of the recently defined A3 and A4 classes, with higher supported peak operating temperatures, helps many more locations exploit economizer mode cooling to reduce overall energy consumption.

The data and analysis methodology outlined also enable operators to determine the appropriate control regime for any data center location to ensure that it continues to meet the business expectations of IT reliability and service availability. Exploiting an extended operational range may not be appropriate for all classes of equipment or IT services. Alternative cooling approaches may be appropriate or operators can segregate equipment and use zoning to ensure that tight environmental control can still be maintained where necessary. Adopting the best practice of zoning avoids compromising the reliability of critical equipment or services, while allowing the benefits of utilizing a wider operational range to be applied to the majority of the data center.

Further supporting this recommendation, some emerging IT hardware platforms are designed to operate at these higher temperatures with little or no increase in server fan energy consumption. Industry adoption of the wider ASHRAE operating classes is increasing, and supported products are increasingly becoming available. How organizations deploy wider operating ranges may be influenced by procurement lifecycles and equipment selection decisions.

IX. About The Green Grid

The Green Grid Association is a non-profit, open industry consortium of end users, policy makers, technology providers, facility architects, and utility companies collaborating to improve the resource efficiency of information technology and data centers throughout the world. With more than 150 member organizations around the world, The Green Grid seeks to unite global industry efforts, create a common set of metrics, and develop technical resources and educational tools to further its goals. Additional information is available at www.thegreengrid.org.

X. References

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