Chiller-less Facilities: They May Be Closer Than You Think

A Dell Technical White Paper

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Contents

Figures

Introduction

Modern data centers are typically run at much lower temperatures than necessary. The financial and environmental costs of tightly controlling the environment to a cold temperature are starting to be questioned by both the business community and governmental regulatory bodies. Two of these regulatory bodies include ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) and the Institute for Energy of the Joint Research Centre of the European Commission.

ASHRAE has recently updated its standard on building efficiencies[1] to include mandates for data centers on economizers, which allows facilities in some environments to take advantage of cool external temperatures, bypassing compressor-based cooling for portions of the year. This can eliminate the need for compressor-based cooling altogether. In addition to ASHRAE's updated standard, The Institute for Energy, a European guidance body, has issued a challenge to IT manufacturers to increase their allowable environmental limits, setting a goal of enabling chiller-less facility designs.[2] This not only decreases the operational costs associated with chilling the air, but it also eliminates a capital-intensive item: the chiller.

Currently, the strongest interest in chiller-less facilities is among European telecom companies and some US-based cloud companies. However, the topic of chiller-less operation is expected to enter mainstream awareness relatively soon. There are many locales which can consider chiller-less operation using today's IT equipment, but it is very likely the equipment would need to occasionally operate near its allowable extremes. Additionally, there are several examples of facilities that exceed these extremes, but only slightly.

To consider employing chiller-less facility designs, your IT equipment needs a slightly larger environmental operating window. The current generation of Dell™ PowerEdge™ servers (such as the R610, R710, and T610) was tested with this larger environmental operating window in mind. Recent validation testing has shown Dell systems to be capable of short-term, excursion-based operation up to 45°C (113°F) with comparable increases in humidity, without thermal shutdown, and with limited performance impact. This 10°C (18°F) extension to our current limits was easily achievable due to the nature of Dell thermal design. The improved operational flexibility makes chiller-less design and increased use of economizers much closer than previously considered.

Economizers

Economizers take two forms: water economizers and air economizers. A water economizer replaces or subsidizes the chilling process with either an evaporative cooling tower or a dry external heat exchanger. Rather than flowing through the chiller to be cooled, cooling water is routed outside to one of these external forms of heat rejection. With a water economizer, the data center remains an essentially closed environment, bringing in only a small amount of fresh air to maintain personnel safety. An air economizer is a system of external dampers and facility fans that can allow fresh air to enter and leave the facility. It is basically an automatic way to open and close the windows.

When considering the narrow historical environmental window of operation for using fresh-air cooling in data centers, one could conclude that the more capital-intensive water economizer offers more

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[1] ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings
[2] "European Union Code of Conduct for Data Centres," http://re.jrc.ec.europa.eu/energyefficiency/html/standby_initiative_data_centers.htm

hours of free cooling. Humidity extremes force the air-economized facility to turn off the economizer and revert to compressor-based cooling, due to the introduction of large volumes of outside air. If a larger environmental range is allowed, an air economizer not only offers lower initial costs, but it also can offer more hours of free cooling.

With an air economizer, the temperature entering the IT equipment is only a few degrees above the external air temperature. With a water economizer, inlet temperatures can be much higher than the external temperature due to multiple water/air heat exchangers.

One other concern with air economizers is contamination. With proper filtering, this should not be a concern in the US and much of Europe. Lawrence Berkeley National Laboratory conducted a study on contamination levels in economized data centers and found that most locations in the United States would support air economizers without additional filtration.[3] ASHRAE has also published guidelines on contamination levels.[4]

Maximizing the Value of Economizers

Many data centers still operate very conservatively, even with economized operation. It is not unusual for a data center to distribute 13˚C (55˚F) air year-round, economizing when outside temperatures are colder and chilling when they are not. Many more free cooling hours could be available if these facilities would simply increase their operating window to include higher temperatures.

In a previous white paper, Dell suggested that compressor-based facilities should be run with inlet temperatures in the range of 25-26˚C (upper 70s in Fahrenheit).[5] This study was conducted using hardware that was three years old. Subsequent server improvements suggest the most efficient operating point may be above 27˚C (81˚F), and Dell recommends operating economized facilities at even higher temperatures. Many US locations have significant hours (40%-50%) within the range of 13˚C-27˚C (55˚F-81˚F), and making a shift toward 27˚C (81˚F) operation could more than double the amount of hours available for free cooling.

Chiller-less Facility Designs

Facilities with chiller-less designs are possible using today's IT equipment, but the standard allowable temperature maximum of 35˚C (95˚F) limits the locations where they can be used. Nearly three years ago, Dell began the process of ensuring that its servers are capable of withstanding higher temperatures and humidity levels. As a result, Dell's current generation of servers (for example the R610, R710, and T610) and data center systems can meet and exceed the stated requirements recently published by various regulatory bodies.

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[3] "Data Center Economizer Contamination and Humidity Study," Lawrence Berkeley National Laboratory, http://hightech.lbl.gov/documents/data_centers/economizerdemoreport-3-13.pdf

[4] "Gaseous and Particulate Contamination Limits for Data Centers," ASHRAE TC 9.9, 2009, http://attachments.wetpaintserv.us/FSZfOoNXybHUa5pPDg6ztg%3D%3D442325

[5] "Data Center Operating Temperature: What Does Dell Recommend," David Moss, 2009, http://i.dell.com/sites/content/business/solutions/whitepapers/en/Documents/dci-Data-Center-Operating-Temperature-Dell-Recommendation.pdf

With increased focus and discussion of higher temperatures in data centers, and the removal of chillers entirely in some cases (Google[6], Yahoo[7]), Dell took it one step further and validated a number of current platforms for short-term excursions of wider temperature and humidity limits. Dell racked nine servers with 18 Intel® Xeon® processors, three storage units, and three network switches for sustained operation at multiple temperatures, including -5˚C (23˚F) and 45˚C (113˚F). A separate study was conducted to validate that Dell hardware can withstand extreme conditions for several months. Our test results demonstrate that the products can tolerate up to 900 hours of 40˚C (104˚F) operation per year and up to 90 hours at 45˚C (113˚F). Dell plans to expand this portfolio in future generations.

This validation testing included not only Dell servers, but also the related systems such as storage, networking, and power infrastructure. Validation testing has shown that the higher temperature tolerance is not a stretch for current Dell systems. Dell routinely tests 5˚C (9˚F) past the allowable limits on all products, and current products have already been tested to 40˚C (104˚F). With some minor tradeoffs, such as using 95W maximum TDP bin processors and having redundant power supplies, we were able to reach the specified 40˚C (104˚F) and 45˚C (113˚F) excursion temperature requirements needed with no major changes to the systems. This is due to the existing thermal design inherent in Dell systems.

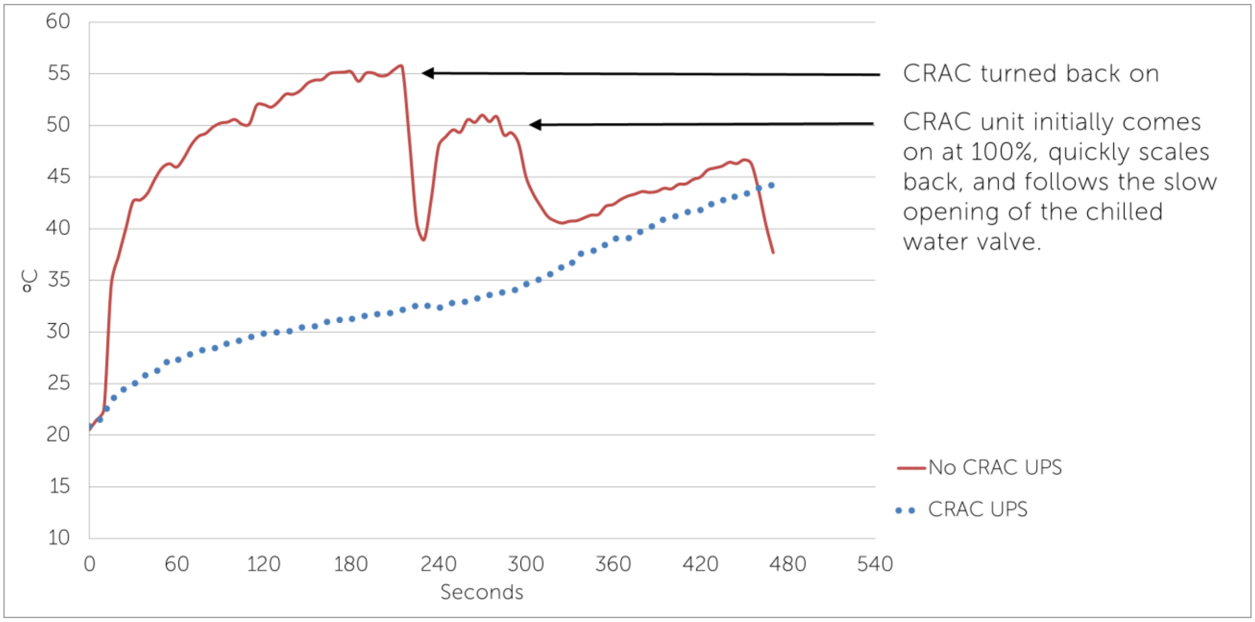
The Dell Advantage During Facility Cooling Failures

The excursion capability of IT equipment can be crucial during facility cooling outages. When not backed by Uninterruptible Power Supplies (UPS), the loss of air distribution causes a stagnant room to heat up very quickly. In recent tests conducted in Dell's data center research lab, a 350 watt/square-foot room load produced temperatures exceeding the current 35˚C (95˚F) maximum specification very quickly.

Some vendors are quick to void warranties when this happens. There also is a risk that equipment may go into automatic shut-down mode when pushed above its allowable temperature range. The ability of Dell systems to excurse to higher temperatures allows facilities more time to react and move into redundant operation—failing over to a generator and restarting the chiller. Figure 1 shows the benefit to having UPS-backed air handlers.

[6] "Google's Chiller-Less Data Center," Data Center Knowledge, 2009, http://www.datacenterknowledge.com/archives/2009/07/15/googles-chiller-less-data-center/
[7] "Inside the Yahoo Computing Coop," Data Center Knowledge, 2010, http://www.datacenterknowledge.com/archives/2010/09/20/inside-the-yahoo-computing-coop/

Figure 1. Temperature Rise After Facility Cooling Failure



Excursion Capability

Testing the excursion capability of IT equipment can reveal just how capable the equipment is. There is a common misconception that the IT equipment should never operate outside of the ASHRAE TC9.9 recommended window, which is currently limited to 27°C (81°F). This recommendation is often treated as an absolute, with many data centers operating well below 27°C (81°F). This is sometimes assumed to be the standard vendor-warranty window. Dell does not share these assumptions. The fact that the equipment can reliably tolerate temperatures to 45°C (113°F) underscores the fact that operation at a more efficient inlet temperature (27°C, 81°F) is well below what the equipment can tolerate.

Dell recommends separation as a best practice, like using blanking panels and containment. Blanking panels become more critical with higher temperature operation. Containment external to the rack is also considered an enabler of higher temperature operation, since it creates the consistency of inlet temperatures needed to raise the facility temperature.

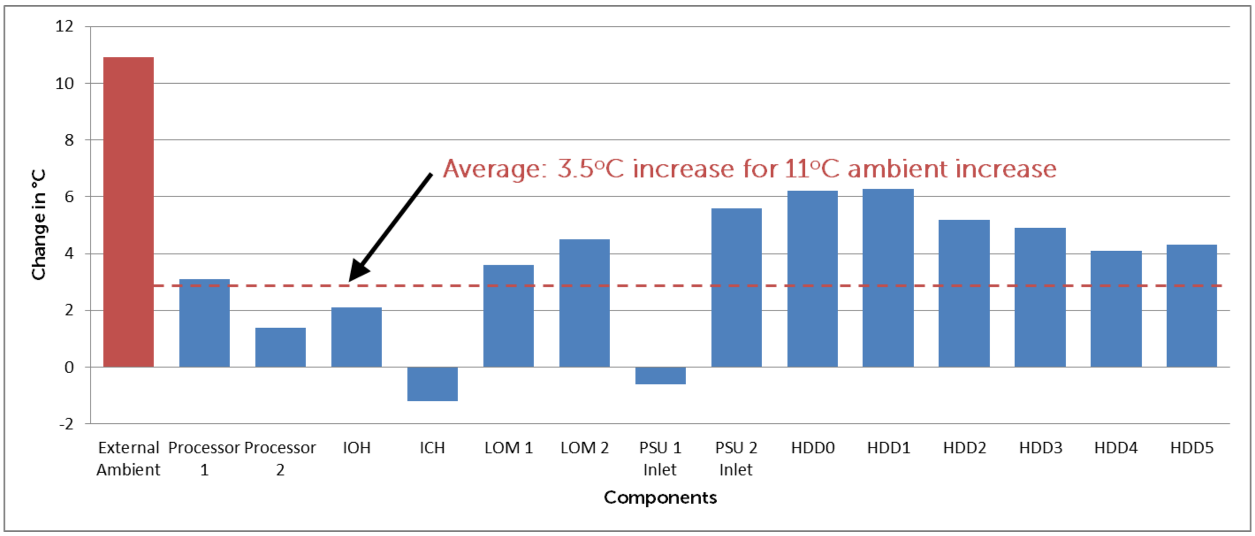
IT Reliability

Reliability is a common concern when running IT gear at higher temperatures. For nearly three years, Dell has been carrying out a comprehensive research and development program to investigate the impact of fresh air cooling, along with wider temperature and humidity ranges, on data center hardware failure rates. The Dell fresh air cooling research program has explored extreme operating conditions that span the majority of worldwide climates, including hot and humid as well as cold and dry conditions. The research comprised a wide range of sizes and types of Dell data center equipment, and the test duration was more than two and a half years.

During testing, the hardware was closely monitored by collecting more than 10,000 parameters at a one-minute sampling interval. All systems were fully operational and heavily loaded for the duration of the testing. The Dell fresh air cooling research was designed to simulate over seven years of fresh air cooling in a worst-case southern European climate. The research has given us the insight we needed to design IT hardware to operate reliably under fresh air cooling conditions.

The primary factor determining system failure rate is component temperature. Nearly all of the known component failure mechanisms are activated by temperature. For a server, the component temperature is determined by several factors, including the cooling fan speed control algorithm, the power management features of the system, and the inlet air temperature (for fresh air cooling, this is a function of the local climate). Data from the PowerEdge R710 server, seen in Figure 2, shows that for an 11°C (20°F) inlet air temperature increase, the corresponding rise in the temperature of a typical component was only about 3.5°C (6°F), and many components, including all memory chips, actually had lower surface temperatures at 35°C (95°F) than at 24°C (75°F). When sensing a rise in the inlet air temperature, the fans inside the server compensate by spinning up and moving more air. The additional air movement improves convective heat transfer which keeps component temperatures lower relative to the air temperature moving past them. If temperature determines the failure rate and the increase in component temperature is small, then the increase in server failure rate will also be small.

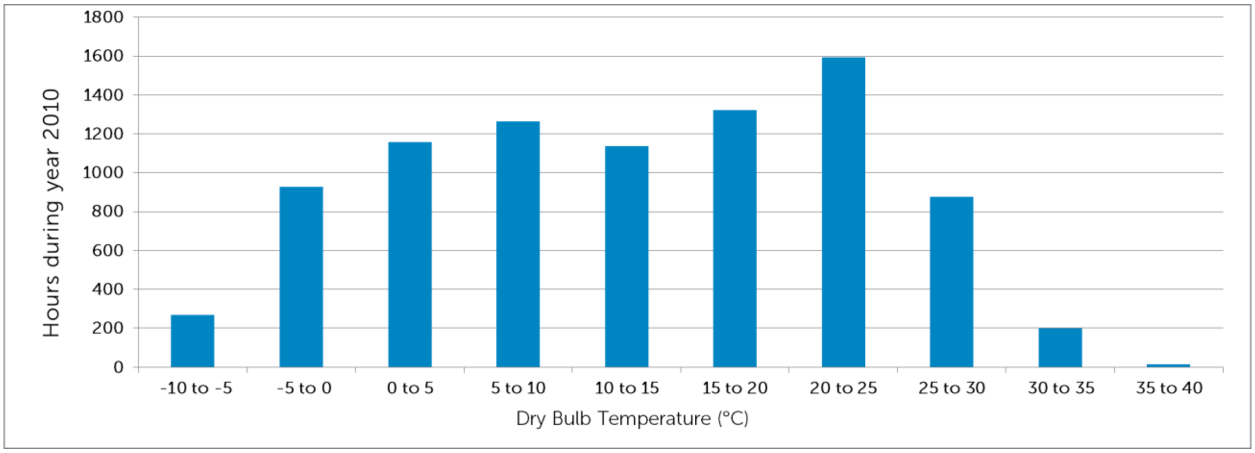
Figure 2. Component Temperature Increase Relative to Ambient (24°C-35°C)



As part of our fresh air cooling research, Dell conducted climate studies on a wide range of US, European, and Asian cities to predict the hardware failure rate of fresh-air cooled data center equipment in various world-wide locales. While it is well known that hardware failure rate increases with temperature, our analysis shows that for most climates, the time spent at elevated temperatures is fairly short, and this time is balanced by long periods spent at cool or cold temperatures where the equipment failure rate is low. Thus, the net impact of chiller-less fresh-air cooling on hardware failure is negligible. Fresh-air cooling is not about running a data center at high temperatures continuously (7 days a week, 24 hours a day, 365 days a year). Rather, it is about the ability of data center equipment to tolerate a small number of short-term elevated temperature excursions.

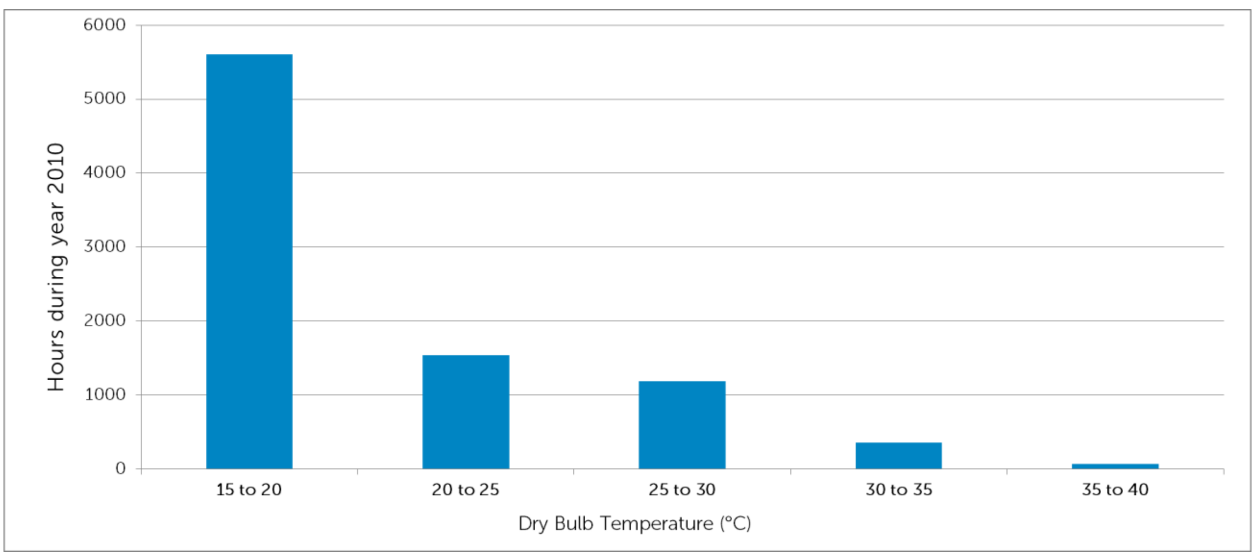
As an example, consider the climate of New York City, as represented by the histogram of outdoor temperatures in Figure 3.

Figure 3. Outdoor Temperatures: New York City, 2010



Fresh-air data centers typically have an air mixing capability that takes hot exhaust air from the equipment and mixes it with incoming cold air, maintaining a minimum data center temperature near 20°C (68°F) even in the winter. If the outdoor temperature histogram for New York is adjusted, considering the mixing of hot air to maintain a constant minimum temperature and a 1.5°C (3°F) temperature rise to account for the energy transferred to the air by the fans in the form of heat, the histogram in Figure 4 represents the inlet temperature of the IT equipment.

Figure 4. Inlet Temperatures of Chiller-less Data Center: New York City, 2010



With hot air mixing to maintain a minimum data center temperature, over 90% of the operating hours per year are within the ASHRAE recommended range of 18°C–27°C (64°F–81°F), 4.6% of the hours are in the range of 30°C-35°C (86°F-95°F), and fewer than 1% of the hours are in the range of 35°C-40°C (95°F-104°F). Dell IT equipment is capable of operating reliably in this type of chiller-less fresh air environment with temperature excursions, wider humidity ranges, and additional thermal cycling. Dell IT equipment with fresh air capability can enable significant data center cost savings, allowing for more hours of economization. In some climates, the capital cost of having to build a chiller plant as part of the data center facility can be avoided altogether.

Summary

Whether you are thinking chiller-less or just looking for reassurance about increasing your operating temperature (or for handling temperature anomalies), you can expand your options with Dell. By increasing your temperature set point, you can improve the efficiency of your compressor-based or economized facility. For economized facilities, you can also extend the number of hours in economized operation. Using Dell servers, storage units, or network switches that can tolerate temperature spikes up to 45°C (113°F), you can reduce the risk of facility cooling failures as well.