

# Keep it Cool! Inside the World's Most Efficient Data Center

*Warm water is part of the system that keeps supercomputers in business and the sidewalks snow free in renewable energy research*

By Alan S. Brown

WARMING SIDEWALKS to melt snow seems an extravagant waste of energy. Yet that is just what the National Renewable Energy Laboratory, the nation's top alternate energy lab, does on the plaza fronting the new wing at its Golden, CO, headquarters. More surprisingly, those ice-free sidewalks actually showcase the incredible efficiency of NREL's new high performance computing center.

The center houses Peregrine, a supercomputer made of thousands of interconnected servers and capable of 1.2 quadrillion floating-point operations per second. Peregrine is used for large and complex simulations as NREL researchers look for ways to integrate renewable energy systems into the electrical grid.

Behind its tall glass walls, the computing center is a radical departure from previous data centers. It crams a lot of computing power into a very small space. Peregrine takes up less than one-third of the center's 10,000 square-foot area, much smaller than comparable supercomputers. The room has none of the large floor vents that conventional data centers use to direct cold air at servers. Nor are there any chillers, the giant air conditioners used to cool com-

puter room air. Instead, warm water circulates through the servers, drawing away heat that NREL uses to warm the rest of the new 182,500 square-foot facility—and keep the entrance free of snow and ice.

"We designed it from chips to bricks to be the world's most efficient data center," its director, Steve Hammond, said.

Data center energy use is usually ranked by power utilization efficiency, or PUE. It equals the amount of energy used by a data center divided by the energy needed to run just the computers. A perfectly efficient data center that used all its energy for servers would have a PUE of 1.0. The Uptime Institute, a professional organization for data center operators, found the average PUE of members' largest (and presumably best run) data center was 1.8-1.9, while other estimates have pegged the rational average at 2.5.

## More Energy

Hammond designed his data center to reach 1.06. In other words, it will use only 6% more energy than it takes to run its computers to run the center's infrastructure. Yet that does not fully capture the center's true efficiency, since PUE does not count the credit the data center should receive for

warming offices and sidewalks.

Switching from energy to money puts things in perspective. Hammond expects to save \$800,000 annually when compared to a more typical data center with a 1.8 PUE. He also expects NREL to save another \$200,000 on its heating bill. And, by eliminating expensive chillers and other cooling infrastructure, the new center costs less to build than conventional installations.

NREL's new high performance



The NREL complex at Golden, CO. Photo: Dennis Schroeder/NREL



Cooling fans at the Facebook data center at Lulea in northern Sweden. Photo: Facebook

To understand how things got so out of hand, forget about high performance computing centers like NREL's and consider commercial data centers. Since the birth of the Internet, they have had to run to stand still, and they are still trying to catch up with demand. First, they expanded so everybody could get online. They added more capacity to stream music, sporting events, games, and high-definition movies. More recently, they bulked up to serve smartphone and tablet apps.

To survive, data centers had to be fast. Websites that couldn't handle a sudden surge in traffic or that spent too long queuing up a movie or game lost viewers and revenue. They also needed to be reliable, since outages meant lost revenue. Last year, for example, Amazon sold \$2,361 worth of goods every second. If its computers were only 99% reliable, it would lose roughly \$745 million annually. Raise that to 99.9% and the loss drops to \$75 million. At 99.99%, it falls to \$7.5 million.

The same economics apply to all Internet companies, which is why data center managers spend nearly all their time paying attention to uptime. "They want their facilities running 99.995% of the time. That's where they get their bonus at the end of the year," said **Dennis P. Symanski**, *Massachusetts Epsilon '74*, a senior project manager at the Electric Power Research Institute (EPRI), a power utility think tank.

To keep up with demand and prevent failure, data centers added rack after rack of increasingly powerful servers to meet day-to-day requirements and also peak demand. "They never unplug an old server; they use it as a backup," Symanski said. They also run the same applications on many different servers, so if one goes down, the others are ready to step in. Even so, front line servers spend most of their time waiting for the next search request or customer order. Yet, the data center world does not see this duplication as waste, but as reliability.

Such duplication comes at a cost, especially in terms of power consumption. Data centers must power all their servers, and also the infrastructure that keeps it running. That

includes everything from air conditioning and fans to power transformers and constantly charging backup batteries.

In the past, energy was always a distant second to uptime. But as the Internet giants revealed how they combined reliability with economy, other companies began to ask why they could not do the same. According to the Uptime survey, 57% of data center managers say energy savings is very important, and another 39% say it is somewhat important.

Discussions about wasted energy always begin with cooling. Servers, like any electrical device, emit heat. Cram thousands of them into a room and temperatures rise while servers begin to fail. Preventing that consumes most of the non-IT electricity used in data centers.

This starts with multimillion dollar chillers, the giant air conditioners that circulate cold air through the building. Chillers are one of the few mechanical systems in the data center. They run 24/7 and are prone to breakdown.

#### Pedal to the Metal

They are also energy sinks. The most efficient way to run chillers is pedal to the metal, yet most data centers rarely run them above 50% of capacity. Why? Because reliability always comes first. Running two chillers at half capacity ensures that if one fails, the other can ramp up to 100% and take its place, explained Steven Carlini, senior director of global data center solutions for Schneider Electric.

The chillers push cold air through floor vents, where it comes out in aisles flanked by front-facing racks of servers. Fans pull the cold air through the racks, where it cools the servers and exits as hot air in the rear.

In a poorly organized data center, not all the racks in an aisle face in the same direction, so some might blow hot air directly into the cooling stream. Some racks may run hotter than others and create hot spots that never cool properly. Even when aisles are properly aligned, they release hot exhaust into the building, raising its temperature and forcing chillers to work harder to cool the room.

There are many simple ways to solve these problems. Managers can reshuffle servers between racks to prevent hot spots and align racks so they form hot and cold aisles. Most data centers either contain cold air in aisles or pipe hot exhaust out of the data center so it cannot mix with room air. Data centers are also growing warmer. Anyone who walked into a data center 10 or 15 years ago quickly noticed the chill. Technicians often wore sweaters or fleecies to stay warm. Since then, temperatures have been inching upwards. While 43% of data centers still run at temperatures below



computing center is certainly on track to be one of the world's most efficient data centers. But it has competition, especially from such Internet giants as Amazon, eBay, Facebook, and Google.

Until recently, most of these companies closely guarded their data center designs and operational procedures. After all, for Internet companies, data center operations are as much a competitive advantage as a new process or procedure in a manufacturing plant.

Their silence made them an easy target for criticism, especially because data centers consume so much electricity. Consider, for example, Facebook. Every day, its users upload 350 million photos, send more than 10 billion messages, and click "like" 5 billion times. That takes a lot of computing power. Its Prineville, OR, data center, one of several, covers nearly six football fields. Together, Facebook's server farms draw enough electricity to power a city of 155,000 people. Google, the world's largest data farm operator, could power a city of 750,000, more than the populations of Boston, Seattle, or Denver.

Data centers are also increasing electricity use at a dizzying rate. Facebook's consumption rose 33% in 2012, and Google's jumped 47% between 2010 and 2012. Stanford University's Jonathan Koorney estimates that servers now use 1.7-2.2% of all electricity in the United States. Globally, the world's data centers use roughly as much electricity as New Zealand or Singapore.

#### Inefficient Infrastructure

Greenpeace and other environmental groups complained that they were incredibly wasteful. That argument gained some traction. So did Congressional hearings on data center waste. Then, in the fall of 2012, *The New York Times* published a series of articles that claimed only 6% to 12% of data center electricity went into actual computing. The rest was wasted on woefully inefficient infrastructure and wasteful backup computers that did no real work.

At that point, the industry began to respond. While some data centers were indeed grossly inefficient, others used outstanding engineering to drive electrical consumption—and costs—way, way down. Facebook's most efficient data centers have FUEs of 1.09, while Google's best checked in at 1.06 (and that was two years ago).

In fact, as measured by PUE, the best commercial data centers used 5 to 15 times less power to run their infrastructure than the 1.8-1.9 average identified by the Uptime Institute. That is an enormous gap. How did it happen? And how can NREL drive its PUE down so low but still heat its sidewalks?



ABOVE: Steve Hammond, director of the computational science center at the NREL, stands in front of computer racks in the high performance computing data center. BELOW: Pipes circulate water beneath the high performance computing data center. Photos: Dennis Schroeder/NREL.



70°F, some 48% now operate in the 71°F to 75°F zone. Some of them get a lot hotter than that.

This is due to the giant strides taken by chip and equipment makers. According to Jay Kyathsandra, Intel's manager of data center efficiency solutions, most facilities could run the latest Intel chips at 77°F to 81°F simply by doing things they should be doing anyway, like aligning hot and cold aisles, containing hot or cold air, and eliminating hot spots.

They could go even higher, to 86°F to 95°F, by using economizers. This is the data center equivalent of opening the windows. The key, Kyathsandra said, is to locate somewhere relatively cool and move large amounts of outside air through the facility. This is exactly what Facebook does at Prineville. It is located in Oregon's cool high desert, where fans drive outside air through the facility. When temperatures rise too high—about 6% of the time—Prineville diverts warm air through water-drenched media, which cools the air the way misters cool crowds standing in line in amusement parks. According to Facebook, Prineville has a PUE of 1.09.

Facebook, Google, Amazon and many others have also tackled the problem of duplicate servers with a technique called virtualization.

In the past, when servers were less powerful, applications such as catalog databases and streaming video, each needed to run on its own server, Symanski explained. Today, servers can easily host several applications at a time. Sophisticated software divides each of these physical servers into "virtual" servers that act as if they are operating independently of one another.

As demand for servers ebbs and flows, these virtual servers expand and contract. "These apps can spread across multiple servers. In fact, Google's crawler, which indexes the contents of web pages, is running on thousands of servers at once," Symanski said. The same type of software can also adjust the size of hard drives to create virtual storage systems on the fly. Because data centers can adjust their computing resources so rapidly to meet demand, they can finally unplug slow and under-utilized servers without sacrificing reliability.

When Hammond began planning NREL's data center in 2006, he did not have to worry about virtualization. Supercomputing time

is a scarce commodity, and researchers generally book time weeks and even months in advance. Supercomputers always run near capacity.

But he did have to tackle cooling. Supercomputers use the most powerful servers and they tend to generate lots of heat. Hammond quickly realized that he could not achieve new levels of efficiency with air cooling.

#### A New Type of Data Center

"From a data center perspective, it's not very efficient," he explained. "It's like putting your beverage on your kitchen table and then turning up the air conditioner to get your drink cold."

Instead, NREL decided to cool its servers with water. In terms of physics, this makes sense. Compared with air, water has greater heat capacity, thermal conductivity, and density. It removes heat 1,000 times better than air. "It is the difference between sitting in front of an air conditioner or jumping in a pool. But from an energy efficiency standpoint, that's where you have to go," Hammond said. He also noted that a juice glass of water has as much cooling capacity as a room full of air.

While the physics made sense, electrical engineers recoil at the idea of running water through hot electronics. It is right up there with crossing the beams in *Ghostbusters*. They may acknowledge water's superior cooling power, but its potential for leaks, short circuits, and corrosion threatens operating reliability.

It took NREL and partners Intel and Hewlett Packard a couple of years to develop and test a safe and reliable liquid cooling technology. HP plans to unveil this new generation



Peregrine runs complex simulations. Here, senior scientist Kenny Gruchalla examines the velocity field from a wind turbine simulation using a 3D model. Photo: Dennis Schroeder/NREL





Inside the hot aisle containment racks in the high performance computing data center at NREL's Energy Systems Integration Facility. Photo: Dennis Schroeder/NREL

of water-cooled servers this year, but has not yet discussed the technology in any depth.

Water cooling has been used to cool supercomputers going back to Cray's vector processors 30 years ago. More recently, IBM used it in several supercomputers, including Blue Gene/Q. What makes NREL's system different is that it uses warm rather than chilled water, it deliberately packs its racks with servers to heat them up, and it fully integrates the hot water into the building design.

#### Warm Water Cooling

Why warm water? First, as Intel's Kyathsandra noted, today's processors can withstand much higher operating temperatures. Warm water is all NREL needs to keep them running at full speed. Second, to truly drive down energy costs, NREL had to eliminate mechanical chillers, which are used to cool water as well as air.

Instead of chillers, NREL uses a series of heat exchangers and segregated cooling loops. This starts with an evaporative cooler, which chills water the same way perspiration lowers the temperature of our bodies on a hot day. As some water in the system evaporates, the process removes heat and lowers the temperature of the rest of the liquid. (On cold days, running the water through the roof-mounted heat exchanger is enough to reach the desired temperature.)

NREL uses tap water for the evaporative loop, since it releases water into the atmosphere. Its other cooling loops are closed because the water contains rust inhibitors and antibiological agents to prevent the formation of scale and biofilms that can clog cooling systems.

Water from the evaporation system chills the water in a series of 50-gallon containers distributed throughout the facility. This water is cooled to 75°F, filtered, and then sent to the computer.

Since Hammond wants to reuse the computer water to heat his building, he needs to get it hot. To do this, he jams lots of servers into his racks. A typical data center rack holds servers drawing 20kW. NREL's racks draw 80kW. That is hot enough to rapidly heat the cooling water to 95°F or higher.

The hot water heats a 3,000 gallon closed loop system that keeps the rest of the facility warm. It uses beam heaters, which resemble old fashioned steam radiators. Hot water circulates through the heater, which acts as a heat exchanger to warm the air in the rooms.

According to Hammond, the system provides all the heat needed for the new wing. "We use the heat exchanger all year round," Hammond said. "We're always bringing in air from

the outside because we suck air out through the lab. Even in the summer, we have cold nights, and we pre-heat the air so we don't bring in cold air," he explained.

The result is not just a data center that sets new PUE milestones, but one that is fully integrated with its environment. Equally important, it is highly stable and reliable.

"It provides a thermally stable environment that improves system stability. Instead of throttling back clock server speeds due to overheating, we can operate at the highest possible speeds," Hammond said.

It is a marvel of innovation, a self-contained system that not only provides all the uptime its users demand but one that slashes operating costs to the barest minimum.

Yet, it is just one of many innovative designs that have begun to attract attention. Facebook's Norwegian data center, for example, is located inside a naturally cool cave and takes advantage of glacial waters for cooling. Google's Belgian data center, which uses fresh air and water for cooling, lets temperatures rise as high as 95°F.

Yet, so many other data centers have been left behind. Even among large companies, 22% of Uptime respondents do not use hot/cold aisle containment. That rises to 38% among small companies. They have a long way to go in terms of raising operating temperatures or using outside air.

That is likely to change. NREL and the Internet leaders show that data centers can run more efficiently and save money. They are setting a standard, and increasingly, data center managers are noticing.

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