SynJet: Low-Power “Green” Cooling

Nuventix, Inc.
4301 Westbank Dr. Building A150
Phone: 512-382-8100 Fax: 512-382-8101
Email: info@nuventix.com
www.nuventix.com

Introduction

The realities of finite petroleum resources and growing global energy needs along with the confidence that we are indeed experiencing global warming caused by burning fossil fuels have awakened governments and the media to “green” concerns. Both organizations and individuals have started to pay attention to the increasing cost of energy in the past few years and to the expectation that those costs will continue to rise.

Much as we as a society might like to reduce our energy needs to cope with these facts, that is not likely. The cost of transportation captures much attention today, but the cost of speedy communication, which is ever more crucial to the world economy, is not insignificant. One plausible estimate in 2007 puts the energy consumption of the Internet in the U.S. at 9.4% of total electricity use and global consumption at 5.3%.[1] Lighting is another area where electricity use is already huge, 20% of all power consumption in the U.S., and it is certain to increase globally as developing nations become more urban.[2]

Greater electricity use has such consequences as these:

- Increased emissions from generating more electricity
- Greater strain on the existing power grid to meet demand
- Higher energy costs for businesses
- Higher IT capital costs, for expansion and construction of data centers
- Higher energy costs for consumers

In this paper we will examine the conservation effect of using low-power cooling in the computer and lighting industries.

Data Centers and Energy Use

Today data centers are critical infrastructures to businesses, governments, medical and educational organizations– indeed, to virtually every modern social institution. Our economic growth, scientific advances, quality of life, and national security depend on using and managing computing power.

Despite huge improvements in the performance of servers (today's web server is roughly 50 times faster than last decade's model[3]), the total number of servers is growing, driven by the Internet, electronic records storage, and the needs of global commerce. Therefore, data centers are consuming more power each year. Other advances in computing, particularly blade servers and high-speed switching, have caused power consumption in data centers to rise even more rapidly since 2005.

A recent presentation on IT ecological sustainability laid out the need for a "library of flexible, miniature, scalable, hybrid active-passive cooling approaches that can apply across the entire range of future products." [4] SynJets combined with heat sinks are an ideal solution of this type.

Data Center Power Consumption and Costs

The U.S. Environmental Protection Agency estimated that U.S. data centers consumed 61 billion kilowatt-hours (kWh) of electricity in 2006, about 1.5% of total U.S. electricity consumption, and projected that by 2011 energy consumption by data centers will nearly double (Table 1).[5]

Table 1. Annual Electricity Use of Data Centers

	2000 (billion kWh)	**2005** (billion kWh)	**2006** (billion kWh)	**2011 Projection** (billion kWh)
US*	22	45	61	~110
Global**	55	112.5	152.5	~275

* EPA estimates
**2005 documented; other years estimated based on a factor of 2.5 times U.S. consumption[6]

Increasing energy use is not the only reason energy costs are rising for data centers. The cost of power is also increasing. The average price of electricity to commercial users in the U.S. rose from 8.13 cents per kWh in 2003 to 9.43 cents per kWh in 2007. In fact, the cost of electricity across the globe is now more volatile than it has been for several decades, due in part to deregulation and severe weather. This volatility is likely to continue for the foreseeable future and costs will increase, especially in areas of the world where infrastructure investments are needed.[7]

Data Center Cooling Costs

Anyone with a computer at home knows how quickly and how hot a single computer can get. Electronic equipment in the confined space of rack after rack in a data center generates a huge amount of heat and can malfunction if not adequately cooled. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) recommends that data centers remain within a temperature range of 68 to 77°F (20-25°C).

To keep servers operational, cooling a server consumes 1 to 2 watts for every watt that powers it, depending on cooling efficiency. One study found that, on average, 63% of total electricity usage went to cooling.[8] Clearly, realizing low-power cooling in the data center can translate to big savings in energy costs.

Neil Rasmussen, chief technical officer for American Power Conversion Corp., calculates that a 1-megawatt data center will spend $17 million for electricity over 10 years.[9] A 2005 survey of IT professionals revealed that although 70% of organizations say cooling is the most important power consumption issue, only 30% are actively investigating energy issues as a way to lower costs.[10]

Economic sustainability depends on managing the available energy well by designing products that use less energy during operation and minimize energy use during manufacture and reclamation.

Here are some facts:

- By 2008, the annual cost of power and cooling are expected to match the cost of the IT infrastructure itself.[11]
- The cost of cooling is as much or more than the cost of powering a data center.
- Introducing low-power cooling in a data center can save costs and reduce greenhouse gas emissions, or allow more IT equipment in the same space, or a combination of these.

Reducing Energy Use in Data Centers

Reducing energy use while data needs expand is a challenge. The EPA is urging organizations to focus on the entire infrastructure of the data center to get the most energy efficiency possible. However, some technologies can only be implemented in new "smart" data centers, which are very expensive to build, or by radical upgrading. Many organizations cannot expect to completely upgrade their data centers for 5 to 10 years, a typical data center lifetime.

Adopting more energy-efficient servers is one of the few choices that an organization with limited IT funds, staffing, or space can make in the short term to conserve power. Along with processors that deliver more power at the same or even lower heat load, more efficient low-power cooling at the component level can have a significant impact on cooling costs, as the following case study shows.

Nuventix Server Case Study

Nuventix engineers retrofitted a 3U rack-mounted server, the 800W Newisys 4300, with a synthetic jet module and tested it for heat dissipation.[12] The results showed that the jet increased the induced flow by 10-25% and improved heat dissipation by 8-22%, depending on fan speed. As you can see in Figure 1, the actual performance closely correlates to the predicted performance.

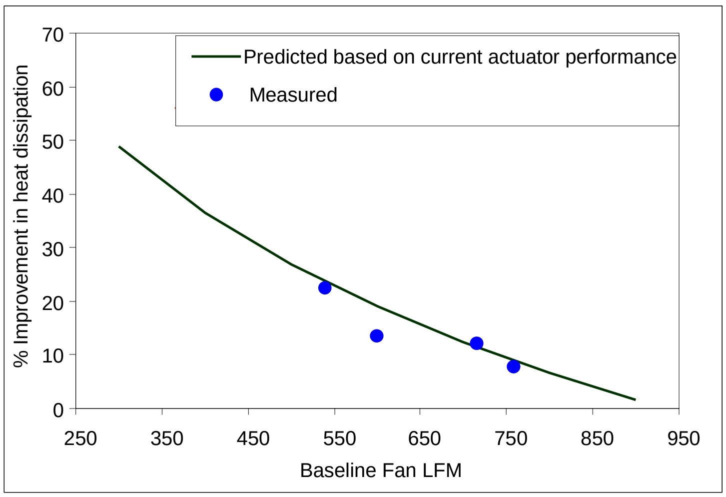

Figure 1: Improvement in thermal performance

In this test, using synthetic jets resulted in reducing the fan speed from 9000 rpm to 6500 rpm. The power consumption of the fans dropped from 108 watts to 62 watts per hour, a 46-watt savings. An added advantage is that the noise level decreased from 75 dBA to 65 dBA, essentially dropping from the level of lawn mower to that of an air conditioner. Not a “green” concern per se, but a related environmental issue.

These findings can be exploited in several ways to affect costs and power efficiency in real-world applications.

Scenario 1: Cost Savings + Better Reliability

Augmenting a fan with a SynJet in a 3U server saves energy costs, and the cooling system reliability improves because the fan is running 2500 rpm slower than its rating of 9000 rpm.

Imagine a data center housing 100 racks of 13 servers each, with a savings of 46 watts per hour per server:

$$46 \ \ Wh \times 1300 \ \ servers = 59{,}800 \ \ Wh = 59.8 \ \ kWh$$

Assume the data center operates 24/7:

$$365 \ \ days \times 24 \ \ hours = 8{,}760 \ \ hours$$

The savings per year is:

$$8{,}760 \ \ hours \times 59.8 \ \ kWh = 523{,}848 \ \ kWh$$

Assume the amount of power the data center’s cooling system uses roughly equals the amount of power to run the fans, so we can double this power savings:

$$523{,}848 \ \ kWh \times 2 = 1{,}047{,}696 \ \ kWh$$

Commercial prices of electricity in 2006 ranged from less than 6¢ per kilowatt-hour in parts of the Midwest to highs of 21.5¢ in California, with an average of about 9.5¢ (Figure 2).[13] Globally, the range is about the same.[14]

$$1{,}047{,}696 \ \ kWh \times \$0.215 = \$225{,}555$$

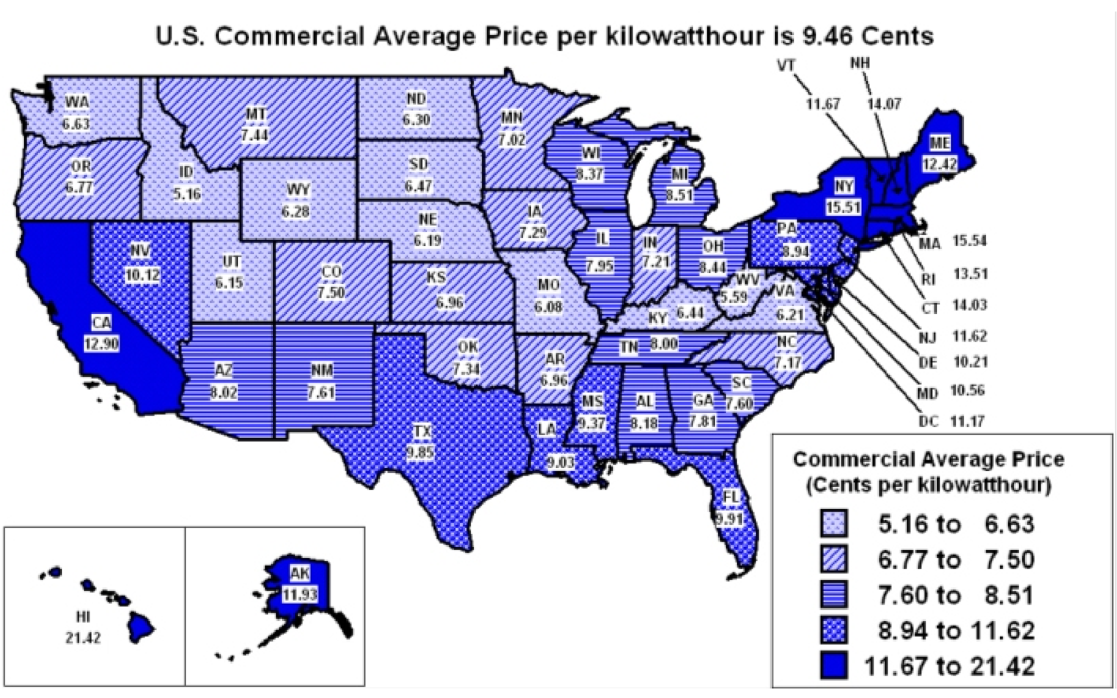

Figure 2. Commercial prices of electricity in the U.S. by state, 2006

Without any other change in configuration of the components or room layout, augmenting fans with SynJets can save up to \$225,555 per year in electricity costs in a 1300-server data center while increasing system lifetime and decreasing acoustics.

Scenario 2: Cost Savings with Higher Server Room Temperature

Augmenting the fans with SynJets also reduced the thermal resistance of the server in the test by 24%. A different option for implementing savings by using SynJets is to allow the ambient room temperature to rise.

The thermal resistance before using SynJets was 0.347°C/watt. After adding SynJets, the thermal resistance was 0.264°C/watt.

$$\frac{0.347°C/W - 0.264°C/W}{0.347°C/W} = 0.239 = 24\%$$

The power of the processor in the server was 95 watts. The lowered thermal resistance allows for a temperature rise in the server room of almost 8°C at the same power:

$$95\ W \times (0.347°C/W - 0.264°C/W) = 7.88°C$$

Without any other change in configuration of the components or data center, augmenting fans with SynJets allows the ambient temperature in the server room to be kept 8°C higher, reducing electricity costs.

Savings Projections

Data centers in the U.S. consumed 61 billion kWh of electricity in 2006. With this one simple change, how much energy could be saved? We will look at some projections using the two scenarios above along with data from the U.S. Environmental Protection Agency (EPA).[15]

Savings using Data from Scenario 1

The EPA estimates that in 2006 there were 10,985 million servers in use in the U.S. Assume each server augmented with a SynJet saves 46 watts per hour, as shown in Scenario 1:

$$46\ W \times 8{,}760\ hr = 402{,}960\ Wh = 403\ kWh$$

$$403\ kWh \times 10{,}985{,}000\ servers = 4{,}426{,}955{,}000\ kWh$$

The total power use of all servers is estimated to be 24.5 billion kWh per year.

$$\frac{4.4\ billion\ kWh}{24.5\ billion\ kWh} = 0.1796 = 18\%$$

EPA estimates the number of midrange servers at 367,000.

$$403\ kWh \times 367{,}000\ midrange\ servers = 147{,}901{,}000\ kWh = 0.15\ billion\ kWh$$

The total power use of midrange servers is estimated to be 2.2 billion kWh per year.

$$\frac{0.15\ billion\ kWh}{2.2\ billion\ kWh} = 0.068 = 6.8\%$$

$$6.8\% \times 24.5\ billion\ kWh = 1.64\ billion\ kWh$$

Augmenting every server in the U.S. with a SynJet could cut servers' electricity consumption by 18%. Augmenting every midrange server in the U.S. with a SynJet could cut costs by 6.8%

Savings using Data from Scenario 2

According the EPA, a server room uses 16% of the total energy of a data center.

$$16\% \times 61.4\, billion\, kWh = 11.7\, billion\, kWh$$

About 63% of power use goes to cooling:

$$63\% \times 11.7\, billion\, kWh = 7.4\, billion\, kWh$$

Every 1.7°C rise in temperature can save 15% in air conditioning costs. Adding a SynJet can allow the ambient temperature in a server room to rise by about 8°C due to the improvement in thermal resistance:

$$\frac{8°C}{1.7°C} = 4.7$$

$$P = 7.4 \times e^{(-0.1625 x 4.7)} = 3.4\, billion\ kWh$$

$$\frac{(7.4 - 3.4)\, billion\ kWh}{7.4\, billion\ kWh} = 0.541 = 54\%$$

At an average price of 10¢ per kWh, the savings is substantial:

$$3.4\, billion\, kWh \times \$0.10 = \$340\, million$$

Adding a SynJet to each server in the U.S. could reduce electricity used to cool servers in data centers by 54% at a savings of $340 million dollars. This reduction in energy would equate to 34% of the total energy use of the server room and 6.5 % of the overall energy use for a data center based on the energy estimates from the previous page.

Lighting and Energy Use

The EPA estimates that the total electricity use in the U.S. in 2006 was 3,820 billion kWh. [16]According to the National Nanotechnology Initiative, lighting accounts for about 20% of this number, or 764 billion kWh. The efficiency of incandescent and fluorescent lamps is so low that only 5% to 25% of the energy they consume is converted to light. Cutting the amount of electricity needed for lighting in half would save roughly the equivalent of the annual energy production of 50 nuclear reactors. [17]

Reducing Lighting Costs

So far, efforts to reduce energy consumption of lighting have focused on replacing incandescent lamps with fluorescent lamps, which are much more efficient (Table 1). However, fluorescent lighting has a number of disadvantages:

- Association with health problems
- Buzzing noise
- Flickering
- Color of light
- Lack of dimming capability

- Reduced efficiency at high and low temperatures
- Mercury content

LED lighting has the potential to replace both incandescent and fluorescent lighting as brighter lamps are developed. The luminous efficacy (perceived brightness per watt) of LED lighting currently surpasses incandescent but is far from approaching that of fluorescent. However, LED prototypes have achieved 80 to 150 lumens per watt, approximately doubling the efficacy of fluorescent bulbs.[18, 19]

Table 1. Comparison of the efficacies of light sources

Light Source	**Luminous Efficacy[20] (lumens/watt)**	**Life (hours)**
Incandescent, including halogen	10-20	1,000-2,000[21]
Fluorescent	75-90	10,000[22]
High-Intensity Discharge (HID)	100-120	500-20,000[23]
LED, available as of 2007	20-54[24]	50,000-100,000
LED, predicted to be available by 2012	150	50,000-100,000

Another advantage of LED lamps is that they last much longer than any other light source, thus they need not be replaced as often, which both lowers maintenance costs in commercial uses and reduces landfill waste. LEDs meet the other concerns about fluorescent lighting as well: no UV radiation, no flickering, and no mercury content to pollute landfills. LED lights are dimmable and can be designed to look more like natural light than fluorescents.

To date, LED lamps are still too expensive to compete aggressively with other forms of lighting for residential applications, but as prices decrease they may well become the preferred lamp in homes everywhere. For commercial and industrial applications, the time payback periods makes LEDs a very attractive solution.

Lighting Examples

Synthetic jets consume very little power; therefore, they are ideal match for LEDs in terms of “green” concerns. An ANSI standard size LED MR-16 lamp dissipates 5 to 6 W through natural convection. With a SynJet cooler that is currently available, an LED MR-16 lamp can dissipate 15 to 20 W, increasing the lumen output 3 to 4 times while using only 750 mW of power for cooling.

In a LED PAR 38 lamp, natural convection might dissipate 15 to 20 W under ideal conditions and less in applications such as recessed lighting. With a SynJet cooler, an LED PAR 38 lamp can dissipate 35 to 50 W, increasing the lumen output 2 to 2.5 times while only consuming 2 W of power for cooling.

Example 1: Higher Efficiency of MR16 LED Lamp

Assume that a retail space uses 10 banks of three 50-watt MR16 halogen lamps each, for accent spotlighting. Each lamp uses 50 watts, so the total wattage consumed is 1500 W. Passively cooled LED MR-16s are not currently capable of producing enough lumens to replace 50-watt halogen lamps. However, active cooling using a SynJet makes this market possible today. If the 50W halogen lamps are replaced with actively cooled LED MR-16s that produce 900 lumens (brightness equal to a 50W halogen bulb[25]), at today's top achievable output of 40 lumens per watt, an LED MR-16 would use 25 watts.

$$\frac{900 \ \ lumens}{40 \ \ lumens/W} = 22.5 \ \ W$$

Add 750 mW for the SynJet module, and the total energy use is 23.25 W per lamp and just under 700 W for the store, or 54% less electricity than halogens use.

$$22.5W \quad lamp + 0.75W \quad SynJet = 23.25 \ \ W$$

$$23.25 \ \ W \times 30 \ \ lamps = 697.5 \ \ W$$

$$\frac{(1500 - 697.5)\,W}{1500\,W} = 0.535 = 54\%$$

At today's efficacy, replacing 50W MR16 halogen lamps with SynJet-cooled LED lamps could cut electricity use by more than half.

Example 2: Higher Efficiency of PAR 38 LED Lamp

Assume that a hotel uses 500 PAR 38 incandescent lamps for general lighting. Each lamp produces 1800 lumens and consumes 120 W[26], so the total wattage consumed is 60 kW. The passively cooled LED PAR 38 lamps that are currently available consume about 8-12 W but use a large array of LEDs and only produce 200 lumens. This lumen output is not enough to replace existing 120W PAR 38 lamps. However, with active cooling using a SynJet, an LED PAR 38 can operate at much higher power and produce enough lumens to compete with 120W incandescent lamps. At today's top achievable output of 40 lumens per watt, an LED PAR 38 would use 45 watts.

$$\frac{1800 \ \ lumens}{40 \ \ lumens/W} = 45 \ \ W$$

Add 2 W for the SynJet module, and the total energy use is 47 W per lamp and just under 23.5 kW for the hotel, or 61% less electricity than incandescent lamps use.

$$45W \ lamp + 2W \ SynJet = 47\,W$$

$$47\,W \times 500\,lamps = 23.5\,kW$$

$$\frac{(60 - 23.5)\ kW}{60\ kW} = 0.608 = 61\%$$

At today's efficacy, active cooling using SynJets makes efficient LED PAR 38 lamps possible that could replace incandescent lamps and reduce electricity use by almost two-thirds.

Conclusion

Improving energy efficiency has many benefits for businesses and for the nation:

- Lower energy costs and better economic competitiveness
- Better reliability of the energy grid

- Reduced fuel use, which reduces emissions of greenhouse gases and pollutants

The simple upgrade of cooling with SynJets can add up to significant cost savings in data centers, by requiring less power to run each fan plus less power to cool a server room. Organizations can easily replace their servers or upgrade them with better internal cooling either as a short-term strategy before upgrading a data center or as part of a long-term plan to maximize power efficiency.

Switching out incandescent and halogen lamps with SynJet-cooled LED lamps can greatly reduce electricity costs. The future of lighting will be even more ecologically sound when fluorescent lamps, with their mercury hazard, are replaced with long-life, efficient LED lamps.

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