A White Paper from the Experts in Business-Critical Continuity™

Economizer Fundamentals: Smart Approaches to Energy-Efficient Free-Cooling for Data Centers

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Executive Summary

The strategic business importance of today's data center requires a more complex and thoughtful approach to environmental control planning than ever before. Intelligent control to maintain the data center environment within acceptable ranges for temperature and humidity is essential for efficient data center operation, integral to protecting the significant financial investment in computer and network technology, and key to preventing downtime that can cost millions and drive away customers.

As energy costs rise and the need to address climate change grows, energy efficiency is becoming a top criterion when choosing a data center environmental control solution. According to a 2008 Digital Realty Trust survey of senior data center decision-makers, power usage of data centers (average kW use per rack) jumped 12 percent from 2007 to 2008. Looking back further, the Uptime Institute reports data center energy use doubled between 2000 and 2006 and predicts it will double again by 2012.

Economizers—with their promise of "free-cooling"—are attracting much attention for their ability to reduce energy usage. Economizers also lessen wear and tear on precision cooling equipment and lower operating costs. However, when considering the use of an economizer system, care must be taken to avoid introducing new problems that result in achieving the goal of reducing energy consumption at the expense of data center availability.

This paper provides guidance for selecting an economizer solution that can deliver energy savings without compromising the reliability of precision cooling equipment or contributing to electronic equipment failure. Questions that will be addressed include:

- What percentage of the year will the economizer provide full or partial free-cooling?
- How can environmental control problems inherent specifically in air economizers be overcome?
- What energy savings can be expected for different types of economizers?

Introduction

Interest in using economizer systems to improve energy efficiency has been gaining since publication of the 2006 International Energy Conservation Code® (IECC) requiring cooling systems in commercial buildings to have economizers, depending on climate zone and cooling system capacity. Generally, the IECC mandates use of an economizer except in climate zones that are extremely hot and humid or extremely cold. In these areas, the energy cost savings would not be enough to offset the initial cost to install economizers.

ASHRAE Standard 90.1 stipulates incorporating economizers into the cooling system design in new commercial buildings, depending on design weather conditions and system cooling capacity. (Data centers have been exempt from this standard to date.) Also driving interest in economizers among data center professionals is that utility rebates may be available for installing them.

If your data center is located where weather conditions are favorable for using an economizer system, doing so can be an extremely effective strategy for reducing energy consumption. However, when selecting an economizer system, care should be taken to weigh the benefits of different types of economizers against their associated costs and risks.

What Are Economizer Systems and How Do They Improve Energy Efficiency?

Economizer systems use outside air, when it is cold enough, to help meet cooling requirements and provide "free-cooling" cycles for computer rooms and data centers. Using outside air when conditions are favorable reduces or eliminates compressor operation in Computer Room Air Conditioning (CRAC) units. This enables economizer systems to lower energy usage of a precision cooling system from 30 to 50 percent, depending on the average temperature and humidity conditions of the installation site. In certain geographical locations, economizers can satisfy a large portion of the annual cooling requirements for data centers. Two types of economizers are commonly available for data centers: fluid economizers and air economizers.

<u>Fluid Economizers</u>

A fluid-side economizer system (often called water-side) works in conjunction with a heat rejection loop consisting of an evaporative cooling tower or drycooler to satisfy cooling requirements. A fluid economizer system is typically incorporated into a chilled water or glycol-based cooling system. For economizer operation on DX (compressor) systems, the fluid used in the cooling system passes through an additional coil to cool the room air, eliminating the need for compressor operation. Or, fluid cooled by the outdoor air replaces the mechanical cooling of the chiller, and provides chilled water to the Computer Room Air Handler (CRAH) units.

<u>Air Economizers</u>

An air-side economizer system serves as a control mechanism to regulate the use of outside air for cooling in a room or building. It utilizes a system of sensors, ducts and dampers to allow entry of the appropriate volume of outside air to satisfy cooling demands. The sensors measure the outside and inside air conditions. If outside conditions are suitable for the use of outside air for cooling, the economizer adjusts the dampers to introduce the outside air, making it the primary source of cooling for the space. This reduces or eliminates the need for the air conditioning system's compressor(s), which results in a significant energy savings for cooling the space. Air-side economizers also require exhaust air dampers to prevent the facility from becoming over-pressurized when large amounts of outside air are introduced.

Evaluating Economizer Systems for Use in Data Centers

When making the choice to improve data center energy efficiency with an economizer system, it is important to consider how it will impact sensitive electronic equipment as well as the effective hours of operation, based on the weather profile of the specific geography.

Data Center Environmental Considerations
Unlike the seasonal and intermittent heating and cooling requirements of office buildings and similar facilities, the controlled environment of a data center requires continuous, year-round cooling. This makes it an ideal candidate for economizer systems during the fall, winter and spring months.

Maintaining consistent, acceptable temperature levels can be achieved using both air and fluid economizers. ASHRAE generally recommends a temperature range of 68 to 77 degrees F for class 1 and 2 data centers. However, it has provided guidelines for expanding the upper limit to no higher than 80.6 degrees F to increase the number of hours economizers can be used without compromising availability. It is important to note, however, that increasing the inlet temperatures to the server can offset efficiency gains brought by the economizer system, because sever fan power increases as those temperatures rise. For example, at an inlet temperature of 73 degrees F, the fan power is approximately 11 watts. At 80.6 degrees F, the fan power nearly doubles to 20 watts.[1]

Ignoring the impact of humidity can result in serious short- and long-term problems, including damage to equipment and to the facility's infrastructure. In most cases, the optimal relative humidity (RH) range for a data center environment is 45-50 percent. ASHRAE recommends a data center dew point between 41.9 and 59 degrees F. Introducing outside air via an air-side economizer system in the cold winter months is fine from a temperature standpoint, but unless the air is further treated, it can lower RH to unacceptable levels, causing electrostatic discharge that interferes with normal equipment operation.
A humidifier can be used to compensate for this, but its operation offsets some of the energy savings provided by the economizer.

In contrast, fluid-side economizer systems use the cold outside air to cool the water/glycol loop, which in turn provides fluid cold enough for the cooling coils in the air conditioning system. This keeps the outside air out of the space and eliminates the need to condition that air.

Economizer Effective Hours for Fluid Economizer Solutions
On chilled water (CW) systems two types of fluid economizers are commonly employed: 1) an air-cooled chiller with a drycooler providing cold water, when available; and, 2) a water-cooled chiller with a cooling tower providing cold water during cold temperatures. How these solutions operate determines their effectiveness in achieving the goal of free-cooling.

Figure 1 shows an air-cooled chiller with a drycooler provided for free-cooling operation. Assuming an entering chilled water temperature to the chiller of 60 degrees F, the drycooler can begin to provide economizer cooling when the outdoor dry bulb is below 45 degrees F. In this case the drycooler fan sheds load from the chiller and allows it to run partially loaded.

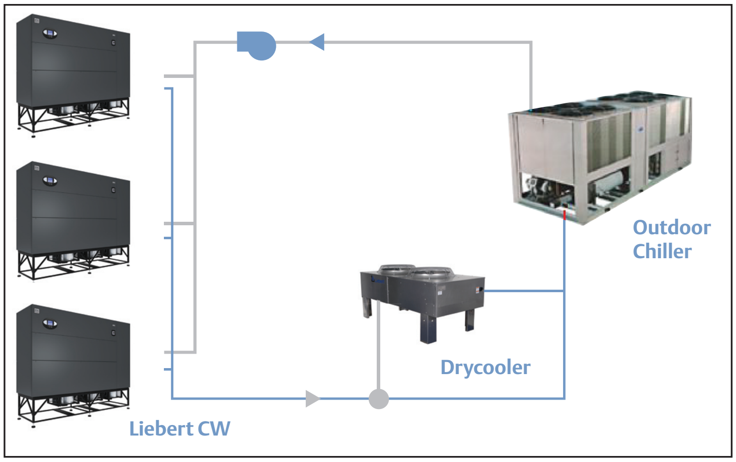

Figure 1. CRAH units with outdoor chiller with drycooler for free-cooling.

Assuming a leaving chilled water temperature from the chiller of 50 degrees F, full-economizer cooling can be achieved when the outdoor temperature is less than 35 degrees F. In this case, the drycooler fans provide the energy to make cold fluid, taking the entire load away from the chiller.

The energy penalty of the drycooler fans—and the added pressure drop—is much less than the chiller operating energy, so reduced energy consumption is achieved in many cold climates. An added benefit of an economizer operating as part of a closed loop is that water is not consumed during heat rejection, as is the case on open cooling towers.

The second fluid-economizer solution is a water-cooled chiller that uses a cooling tower to reject the heat picked up by CRAH units, in addition to the chiller compressors. It is customary for a cooling tower to produce water at a temperature of 85 degrees F when the outdoor wet-bulb temperature is 78 degrees F. This temperature difference is known as a 7-degree approach.

Assuming the leaving chilled water temperature from the chiller is 60 degrees F, the cooling tower can begin to reduce the chiller operation when the outdoor wet-bulb temperature is below 50 degrees F. This 10-degree difference is obtained from the 7-degree tower approach plus a 3-degree loss in a plate heat exchanger. Assuming water at a temperature of 50 degrees F is needed, full economizer cooling occurs when the ambient wet-bulb temperature is less than 40 degrees F, assuming a constant 7-degree approach.

In reality, the cooling tower approach widens as the outdoor wet bulb drops. The approach can widen to as much as 15 degrees at lower wet-bulb temperatures. However, most cooling towers are designed for excess capacity, and because refrigerant heat rejection is reduced or eliminated during free-cooling, the load on the cooling tower is reduced, resulting in excess available capacity of the cooling tower.

Available economizer hours for an open cooling tower system can be determined by plotting weather data of annual hours versus outdoor wet-bulb temperature. Figure 2 shows the available economizer hours for Chicago, Illinois. In this case, the entering water temperature leaving the chiller is assumed to be 45 degrees F, so full economization can be achieved when the ambient wet-bulb temperature is below 35 degrees F. In Chicago, these conditions occur 27 percent of the year. Partial economizer operation occurs between 35 and 43 degrees F wet-bulb temperature—16 percent of the year in this case. If the water temperature leaving the chiller is increased to 55 degrees F, economizer hours can be increased dramatically. As shown in Figure 3, in Chicago full economization occurs 43 percent of the year. Partial economizer operation occurs 21 percent of the year.

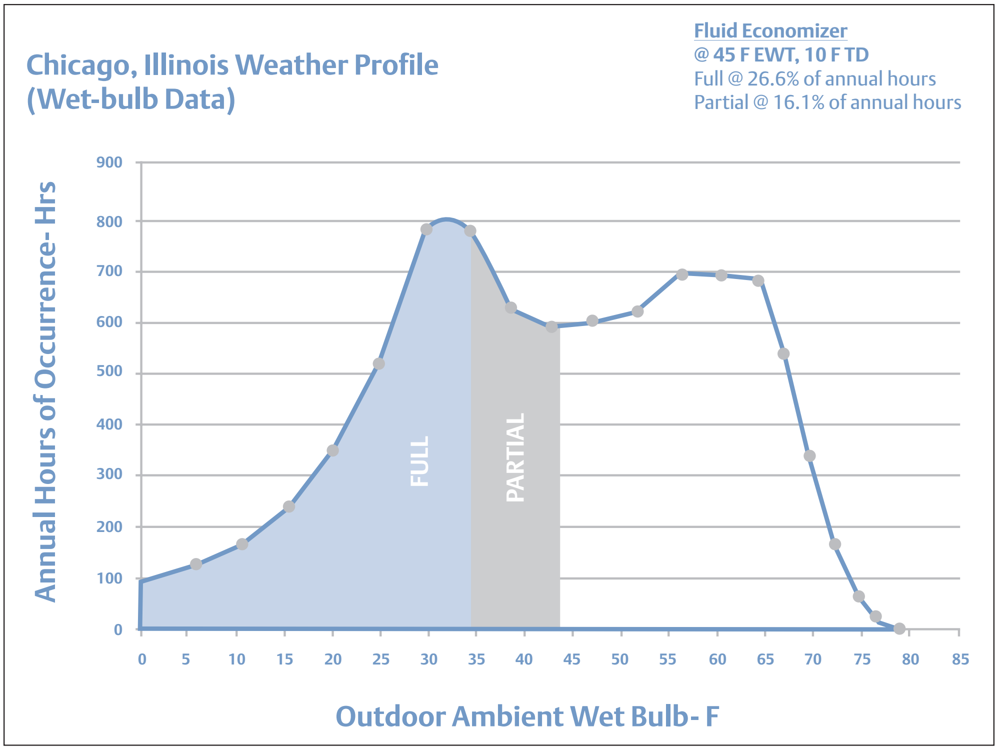

Figure 2. Using a fluid economizer on the chiller plant achieves full economization 27 percent of the year in Chicago when the leaving water temperature is 45 degrees F.

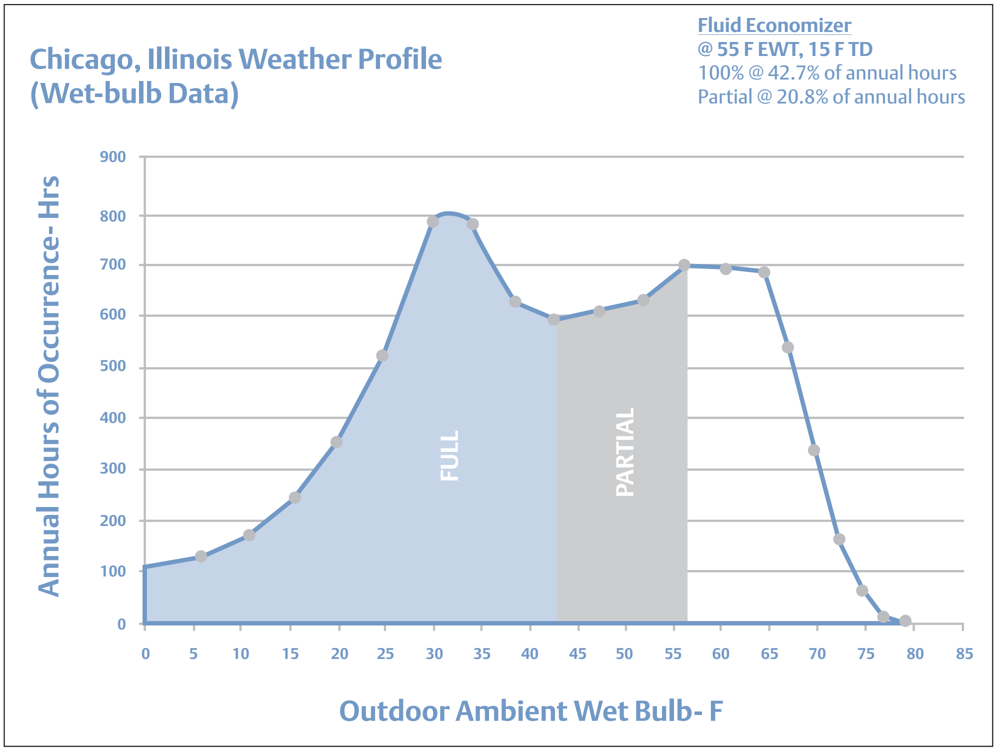

Figure 3. Using a fluid economizer on the chiller plant achieves full economization 43 percent of the year in Chicago when the leaving water temperature is 55 degrees F.

Fluid economizers can also be used in warmer, more humid areas of the United States. Figure 4 shows that, in Atlanta, Ga., with a leaving water temperature of 45 degrees F, full economizer operation is possible 11 percent of the year, with partial operation available 14 percent of the year. When the leaving water temperature is increased to 55 degrees F, full economization is available 25 percent of the year, with partial economizer operation achieved another quarter of the year, as shown in Figure 5.

In addition to higher energy savings achieved by increasing economizer effective hours, raising the entering water temperature to the chiller can increase the chiller efficiency. For some chiller selections this can be up to a 28 percent energy efficiency gain. With a higher entering water temperature, pump energy also is saved because of lower flow requirements.

Fluid Economizer Energy Savings

Using a fluid economizer in Chicago, it is possible to achieve almost 50 percent in energy savings. In Atlanta, a savings of up to 43 percent is possible.

While these savings are substantial, before adding any type of economizer system, consider simply following energy efficiency best practices where possible. These practices include increasing water temperature 10 degrees F, increasing temperature rise 5 degrees F, increasing return air temperature from 75 to 82 degrees F, and using variable speed fans. Taking these measures will save up to 38 percent on energy in both Chicago and Atlanta.

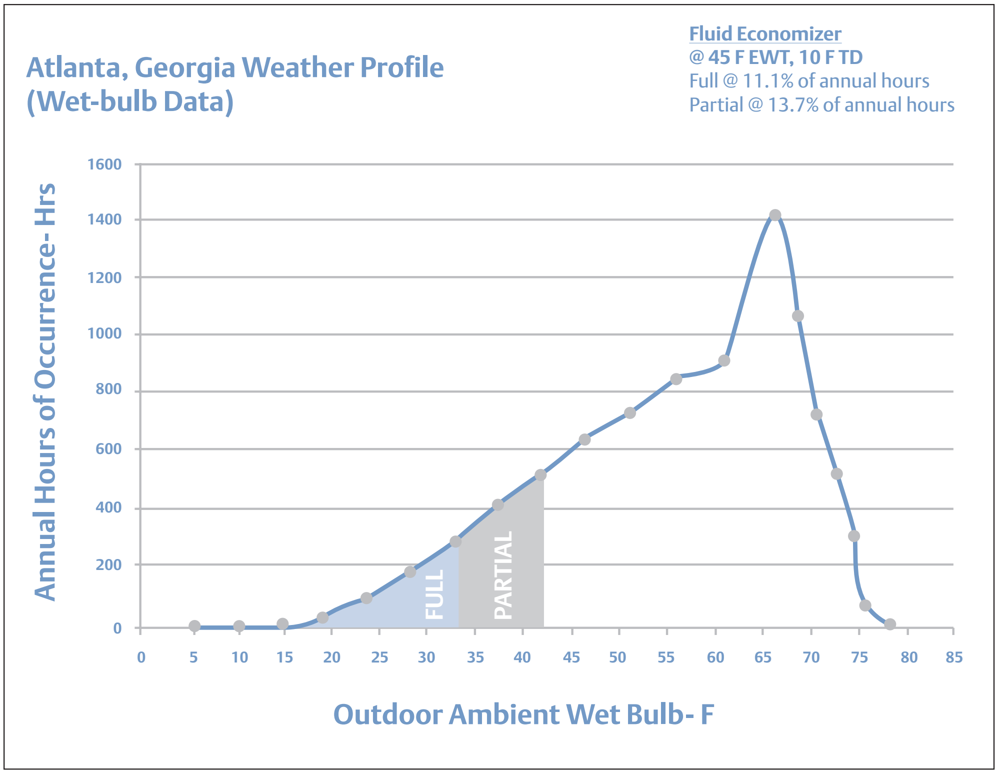

Figure 4. Using a fluid economizer on the chiller plant achieves full economization 11 percent of the year in Atlanta when the leaving water temperature is 45 degrees F.

<u>Economizer Effective Hours for Air Economizers</u>

Air economizers bring in outside air when conditions are right for bringing the air directly into the data center. ASHRAE guidelines limit the data center dew point to be between 41.9 degrees F and 59 degrees F. To avoid the energy required to dehumidify or humidify outside air to meet the data center's stringent environmental requirements, outside air should only be brought into the data center when the outdoor air is within these limits. In addition, the outdoor dry-bulb temperature must be less than the return air temperature to the Computer Room Air Conditioning (CRAC) unit.

A weather plot of outdoor dry-bulb temperature and dew point (or corresponding humidity ratio), illustrates the hours available for economization. In the city of Chicago, assuming 82 degrees F return-air temperature, four weather bins are available in which economization can occur, as shown in Figure 6. This amounts to approximately 30 percent of the annual hours.

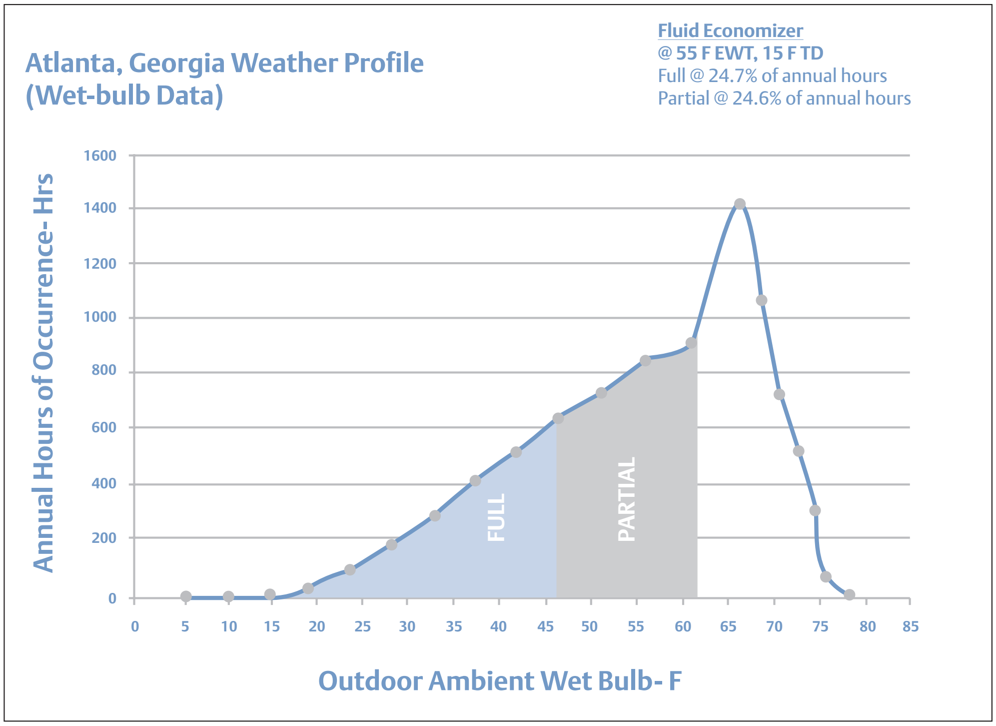

Figure 5. Using a fluid economizer on the chiller plant achieves full economization 25 percent of the year in Atlanta when the leaving water temperature is 55 degrees F.

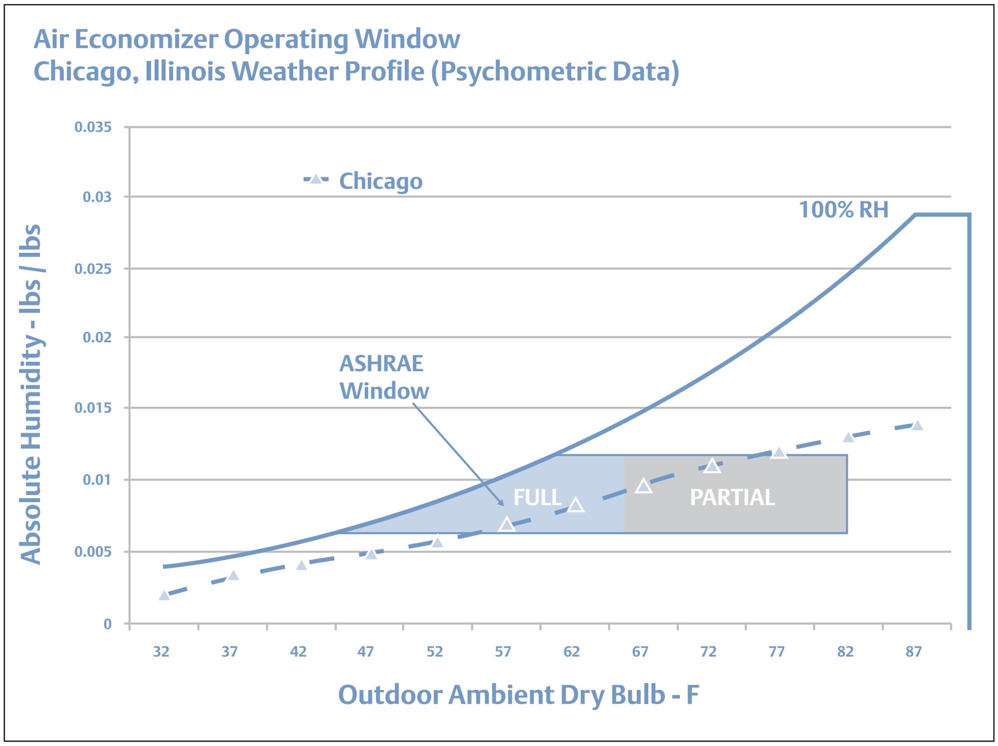

Figure 6. Using an air economizer in Chicago, economization can occur approximately 30 percent of annual hours.

In Atlanta, weather data (Figure 7) show that air economizer hours also are available without humidifying approximately 30 percent of annual hours.

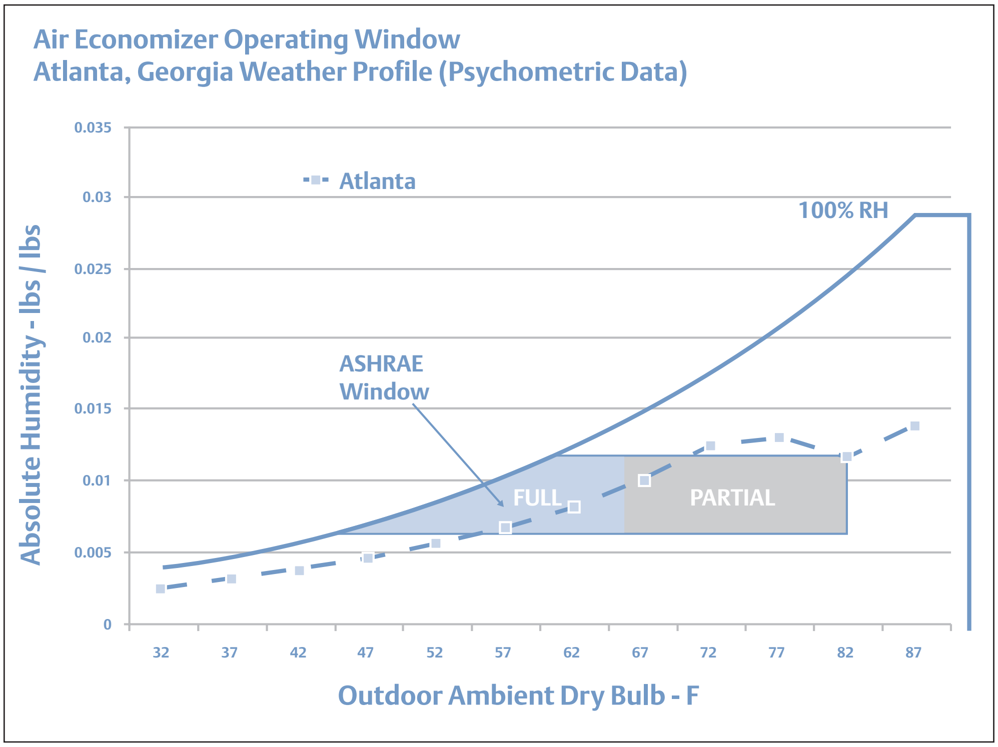

Figure 7. In Atlanta, economization can occur approximately 30 percent of annual hours.

Air Economizer Energy Savings

Using an air economizer in Chicago, it is possible to achieve almost 60 percent in energy savings. In Atlanta, a savings of up to 50 percent is possible. Keep in mind however, that the cost of any humidification or dehumidification required when using air economizers will lower the actual savings.

Comparing Annual Operation in Chicago, Atlanta and Phoenix

For further comparison, the tables below show hours of operation for fluid and air economizers in Chicago, Atlanta, and Phoenix, based on meeting ASHRAE's environmental guidelines.

Fluid Economizer Annual Operation %		
Wet-bulb Temperature	<48° F	48° F to 63° F
Chicago	42.7%	28.8%
Atlanta	24.7%	37.6%
Phoenix	15.3%	52.4%
Economizer Operation	Full	Partial

Air Economizer Annual Operation %			
Dry-bulb Temperature	<82° F		
Dew-point Temperature	<41.9° F	41.9° F to 59° F	>59° F
Chicago	49.4%	30.0%	14.0%
Atlanta	32.7%	29.6%	24.0%
Phoenix	58.8%	0.0%	0.0%
	Humidification Required	No Humidification Required	De-humidification Required

Safely Admitting Outdoor Air in Air Economizer Systems

To apply an air economizer to a CRAC unit, a plenum with two dampers can be installed on top of the CRAC unit. Return air from the room enters through one damper, and if conditions permit, outside air is allowed into the data center through a different damper. An exhaust system must be employed to relieve the pressure from bringing in outside air.

Outside air can be ducted directly to the plenum, with provision made by the installer to prevent rain, dust or other foreign material from entering the data center from the outside. In some cases, it may be more practical to introduce outside air into a perimeter gallery or ceiling plenum, rather than directly ducting to the outside to help prevent contamination from the outside air.

Bringing outside air into the data center risks admitting gaseous contaminants, dust and pollen, which can damage sensitive electronics. Filtration systems can be added, but these do not always remove gaseous contaminants and their cost may minimize the gains from free-cooling. Air economizers also are subject to higher filter replacement and maintenance requirements because of the problems associated with bringing in air from the outside.

When calculating the potential energy savings of an air economizer, the added fan energy must be included, because of added static pressure for filtration and ductwork, exhaust fans, and intake air fans.

The control system must also account for special conditions. For example, if outdoor air is restricted, economizer mode must be disabled on a DX unit to prevent coil freezing. If there is risk of outdoor air contamination, the control should receive a signal to close the outdoor air damper. If CRAC units are installed with humidification or dehumidification systems, these operation modes should be disabled whenever outside air is being introduced into the CRAC unit.

The precision cooling solution chosen by Bay Area Internet Solutions (BAIS) for its "green" co-location facility in Santa Clara, Calif., demonstrates the care that can be taken to help ensure outside air does not contaminate the data center when using an air economizer. The company implemented a precision cooling solution comprised of cold-aisle containment paired with an air economizer in its new 45,000-square-foot raised-floor Tier IV data center. With customers demanding 100 percent uptime and service level agreements mandating 100 percent uptime for cooling, implementing a cooling solution that might compromise availability was not an option for BAIS.

The data center floor is surrounded by a sealed air plenum corridor that functions as an HVAC duct between the facility's economizers and the data center's CRAC units. A fan wall comprised of more than 200 fans along the building's exterior takes in 200,000 CFM of cool air from the outside, which is filtered as it enters the corridor. Air from the corridor is used to supplement the air taken in by the CRAC units along the data center's perimeter walls, allowing chillers to throttle to achieve maximum efficiency.

After the air is filtered a second time by the CRAC units, cool air is delivered under the data center's 30-inch raised floor and directly into the cold aisles. After passing into the cold-aisle containment system and through the server racks, hot air is exhausted outside the containment system back to the CRAC units. To maintain "clean room" air quality standards, BAIS supplemented its redundant filtration system with an integrated building management system capable of shutting down the economizer if it detects tolerances out of the norm, such as smoke.

It should be mentioned that the BAIS data center is located in an area of the country with a high percentage of annual effective hours for air economizer operation. In fact, BAIS estimates the economizer will operate 85 percent of the year.

For more information, read the *Bay Area Internet Solutions* case study at www.liebert.com and view the video case study, available on the ETV Multimedia Portal, at www.liebert.com.

Liebert Economizer Solutions

Liebert economizer solutions maximize energy savings while providing the accuracy and reliability demanded by sensitive data center equipment and operations. Each economizer solution provides the intelligent control of Liebert iCOM™ to determine when conditions are present to operate in one of three modes: normal operation (full compressor/pump operation), full free-cooling, or partial free-cooling. In addition, the Liebert iCOM is ideally suited for controlling air economizer operation to help ensure reliability of air economizer systems–whether they are Liebert technologies or those supplied by other manufacturers.

Liebert GLYCOOL™ System

The Liebert GLYCOOL system is a fluid-based economizer that is a variation on the cooling tower approach previously discussed; however, the Liebert GLYCOOL system uses a Liebert drycooler instead of a commercial cooling tower. This system is applied to DX cooling units (those with compressors).

At ambient temperatures above approximately 65 degrees F, the unit functions as a normal glycol-cooled dual-compressor system, with the compressors providing the cooling. As the outdoor temperature drops, the temperature of the fluid in the heat rejection loop also drops. Once it is cold enough outside to supply some cooling, the control opens the modulating valve on the econ-o-coil circuit. The econ-o-coil then provides some free-cooling, while the compressors provide the rest of the cooling to satisfy the load. Once the fluid temperature is cold enough, the econ-o-coil has enough capacity to eliminate the need for the compressors, so they shut off.

Typically, a closed-circuit drycooler lowers the glycol temperature to the required 45 degrees F needed to get full capacity from the econ-o-coil. Closed circuit evaporative coolers can also be used to take advantage of low wet-bulb temperatures in very dry climates. By controlling the fluid temperature off of the ambient wet-bulb temperature, significant free-cooling can be obtained in cities such as Phoenix.

The GLYCOOL fluid economizer system enables free-cooling that significantly lowers power consumption at outdoor temperatures below 35 degrees F, and relatively lower power consumption as temperatures approach 65 degrees F. GLYCOOL cooling is available for the Liebert DS™, Liebert Challenger™ 3000, and Liebert Challenger ITR.

Chiller Plant Economization

As described on page 4, the chilled water loop that feeds multiple chilled-water based CRAH units uses cold outdoor temperatures to cool the chilled water loop, effectively reducing pump operation. The Liebert chiller plant solution is available for Liebert CW™, Liebert Challenger 3000, Liebert Challenger ITR, and Liebert XD™.

Liebert Air Economizer

The Liebert Air Economizer System reduces cooling costs by taking advantage of cool outdoor air to condition indoor spaces, reducing or eliminating compressor operation in Liebert DS units, and eliminating pump operation in chilled water units. The Liebert Air Economizer System can be field-supplied with high-efficiency filtration and a sensor network that can detect clogged filters. The sensor system also communicates with existing business management systems.

The Liebert Air Economizer System comprises a plenum with an air mixing box; dual enthalpy controls with Liebert iCOM control (temperature/humidity sensors for outdoor air, return air, and supply air). The Liebert iCOM control brings optimal performance even to third-party economizers through the use of a 0-10VDC signal. The Liebert Air Economizer System is available for Liebert DS and Liebert CW precision cooling systems (see Figure 8), and must be applied to each CRAC unit.

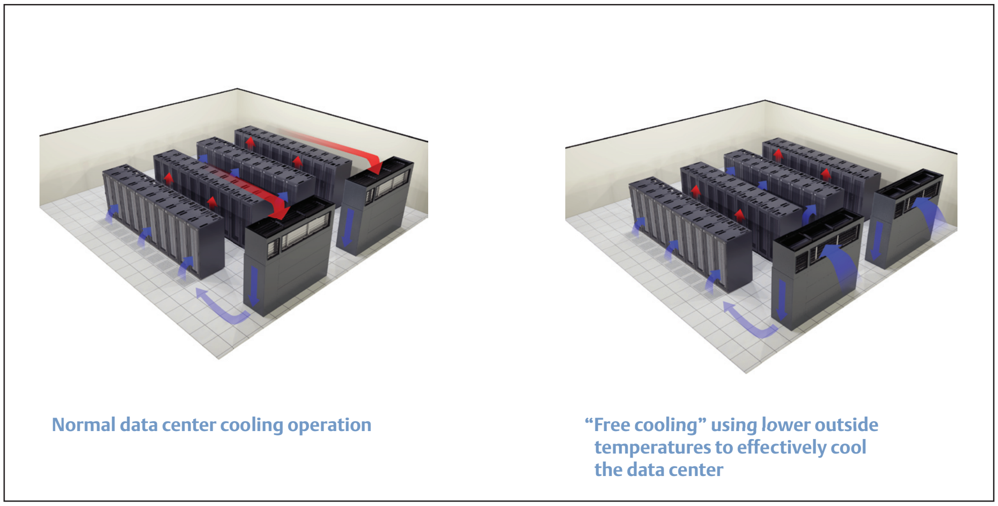

Figure 8. Liebert Air Economizer System installed on a Liebert CW chilled water based precision cooling system in downflow configuration, using lower outside temperatures to minimize cooling compressor and pump use.

Comparing the Benefits and Costs of Fluid Economizers and Air Economizers

The table on page 14 summarizes the environmental requirements, advantages and limitations, and energy savings for fluid and air economizer systems.

For further guidance in choosing an economizer system, the Green Grid provides an online Free-Cooling Estimated Savings calculator (http://cooling.thegreengrid.org/calc_index.html) to help determine potential economizer energy savings based on the parameters of your data center.

Fluid Economizers	Air Economizers
Requirements	**Requirements**
Drycooler application Outdoor dry bulb ~ 15°F below the return air temperature for partial operation; 100% at 35°F dry bulb	Outdoor air enthalpy below the indoor return air enthalpy (generally, dry-bulb less than 80°F)
Cooling tower application Outdoor wet bulb 8°F below the return air wet-bulb temperature for partial operation; 100% at 40°F wet bulb	Outdoor dew point above 42°F and below 60°F
Advantages	**Advantages**
Can be used in any climate where outdoor wet-bulb temperature is less than chiller entering water temperature	Best used in moderate climates to prevent the need to re-humidify or de-humidify
Service requirements and complexities greatly reduced	Low initial capital cost
Disadvantages	**Disadvantages**
Series indirect piping and control more complex	Ductwork required to get air to the space
Initial capital costs are higher	Humidity control can be a costly challenge
	Dust and pollen sensors are required to minimize filter maintenance
	Hard to implement in high-density applications
	Mildew minimization actions required
Annual Energy Savings	**Annual Energy Savings**
The Liebert GLYCOOL economizer system delivers an average annual energy savings of 20–50%	A Liebert Air Economizer System delivers an average annual energy savings of 30–60%
A chiller plant, partnered with Liebert precision cooling technologies, delivers an average annual energy savings of 40–60%	

Conclusion

Economizers—with their promise of "free-cooling"- are attracting attention for their ability to reduce energy usage. If your data center is located where weather conditions are favorable for using an economizer system, doing so can be an extremely effective way to reduce energy consumption. However, when selecting an economizer system, care should be taken to weigh the benefits of different types of economizers against their associated costs and risks, so that availability is not compromised to achieve energy efficiency. In doing so, it is important to keep in mind that proper environmental control is essential for efficient data center operation, integral to protecting the significant financial investment in computer and network technology, and key to preventing costly and potentially reputation-damaging downtime.

As the data center morphs into a strategic business hub, it becomes increasingly critical to ensure it operates efficiently and cost-effectively without jeopardizing performance. Taking a smart approach to energy-efficient free-cooling for data centers can be an important part of your overall strategy to achieve these goals.

References

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2008. 2008 ASHRAE Environmental Guidelines for Datacom Equipment, Expanding the Recommended Environmental Envelope.

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