Choosing Between Direct and Indirect Air Economization for Data Centers

White Paper 215

Revision 0

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Executive summary

The choice of direct or indirect air economization for a data center depends on their benefits, geographic locations, capital costs, operating costs, and availability risks. We examined both approaches in this paper across these five factors. While both approaches can cool a data center with little to no use of mechanical cooling, indirect air economization uses less energy in the majority of locations around the world. The direct approach can have a lower capital expense but presents more availability risks compared to indirect. The added capital expense of mitigating these risks diminishes the appeal for direct air economization. Therefore, in general, indirect air economization is the recommended approach.

Introduction

A cooling plant operating in economizer mode is one of the biggest opportunities to save energy and lower carbon footprint because the energy-intensive, refrigerant-based cooling components like chillers and compressors can be eliminated, shut off, or operated at a reduced capacity. 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[1]. Direct and indirect air economizer modes are two approaches of air-side economizer mode which uses outdoor air to cool the data center when the outdoor conditions are favorable.

This paper focuses on the benefits, associated costs, and risks of direct and indirect air economizer modes. Practical guidance is provided on selecting an approach. There are also several other economizer modes that save energy like water-side economizer mode. White Paper 132, *Economizer Modes of Data Center Cooling Systems* discusses all economizer modes, and compares economizer modes best suited for data centers.

Direct air economization

Direct air economization (often referred to as “fresh air” economizer) uses fans and louvers to draw a certain amount of cold outside fresh air through filters and then ***directly*** into the data center when the outside air conditions are within specified set points, as shown in **Figure 1**. Therefore, no make-up air is needed for this type of economizer mode.

This system uses dampers to control the amount of hot exhaust air that is exhausted to the outdoors and mixed back into the data center supply air to maintain environmental set points. This type of economizer mode can be used with evaporative assist whereby the outside air passes through a wet mesh material before entering the data center. Note that using evaporative assist with this type of economizer mode increases the data center humidity. Mechanical cooling is often used as a backup system in case the outside air conditions are not favorable (i.e. air pollution, high humidity).

Common questions raised when considering direct air economization:

- Which locations are favorable for this kind of economizer mode?
- What’s the capital investment?
- What’s the operating cost?
- Do I need a full mechanical system for backup?
- What’s the impact of increased temperature, elevated humidity, and air pollutants on the reliability of the IT equipment housed in my data center?
- Can my IT equipment withstand external conditions?
- Can my data center be retrofitted with this kind of economizer mode?
- What are the design considerations to install a direct fresh air system?
- What are the main differences compared to indirect air economization?

In this paper we provide answers to these questions, comparisons with indirect air economization, and practical guidance for selection.

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[1] The Green Grid. WP #41 - Survey Results: Data Center Economizer Use. 2011. Available from: http://www.thegreengrid.org.

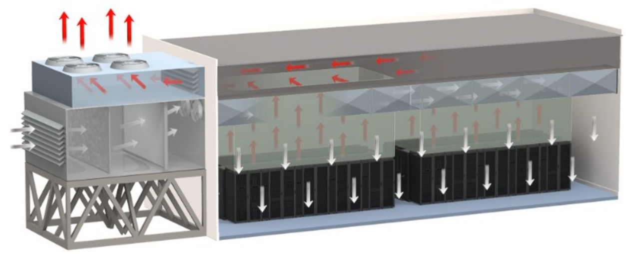


Figure 1

A data center cooled directly with outside fresh air

Indirect air economization

Heat wheel vs. heat pipe technologies

Heat wheel technology uses fans to blow cold outside air through a rotating heat exchanger to cool data center air while heat pipe technology uses fans to blow cold outside air through a series of heat pipes to cool fluid inside, which in turn passively cools the hot data center air.

Both technologies can preserve the humidity conditions of the data center space, and prevent contaminates from polluting the data center air. Evaporative assist can also be used for both technologies to further cool outside air and increase economizer hours.

Indirect air economization uses outside air to ***indirectly*** cool data center air when the outside air conditions are within specified set points. Air to air heat exchanger, heat wheel, and heat pipe are three common technologies which can isolate the impact of outside humidity and prevent outside pollutants from entering the IT space. Of these three, the air to air heat exchanger approach is most commonly used in data centers. In this paper we focus on the air to air heat exchanger approach. The side bar provides a simple description of the heat wheel and heat pipe technologies.

The indirect air economization with air heat exchanger uses fans to blow cold outside air over a series of plates or tubes which in turn cool the hot data center air running through the plates or tubes, completely isolating the data center air from the outside air, as shown in **Figure 2**. This type of economizer mode can also be used with evaporative assist whereby the outside of the plates or tubes are sprayed with water which further lowers the temperature of the outside air and thus the hot data center air. Unlike direct fresh air economizer, the evaporative assist does not increase the humidity within the IT space, but a minimal amount of make-up air is needed. Mechanical cooling is often used as a cooling assist for locations where the outside conditions are not favorable (i.e. high temperature and high humidity).

Common questions raised when considering indirect air economization:

- Which locations are favorable for this kind of economizer mode?
- What's the capital investment?
- What's the operating cost?
- How much cooling capacity do I need to configure mechanical cooling assist?
- What's the energy efficiency penalty due to the air to air heat exchange?
- What are the design considerations to install an indirect air economizer system?
- What are the main differences compared to direct air economization?

In this paper we provide answers to these questions, comparisons with direct air economization, and practical guidance for selection.

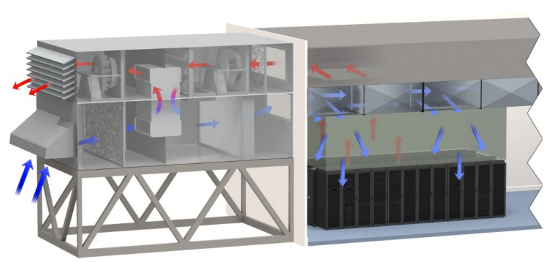


Figure 2

A data center cooled indirectly with outside fresh air through an air to air heat exchanger

Note that any data center that uses direct or indirect air economization will see a dramatic efficiency gain when a hot air containment system is used. It generally makes little sense to invest in an economizer mode without first investing in a con-

tainment system. For more information on hot air containment deployment, see White Paper 182, *The Use of Ceiling-Ducted Air Containment in Data Centers*. For more information on containment deployment for new data centers, see White Paper 135, *Impact of Hot and Cold Aisle Containment on Data Center Temperature and efficiency*. For more information on containment deployment for existing data centers, see White Paper 153, *Implementing Hot and Cold air Containment in existing Data Centers*.

Direct vs. indirect air economization

Both direct and indirect air economizer modes have pros and cons. Their individual benefits should be weighed against their associated costs, risks and other factors like geography, IT environmental setpoints, and so on. An ideal economizer mode takes advantage of a wide range of outside conditions to maximize the number of economizer mode hours, has the lowest operating and capital cost, while presenting the fewest risks to data center availability. This section compares direct and indirect air economizer systems against various attributes commonly identified by data center designers and users, including:

- Capital cost
- Operating cost
- Performance
- Availability risk

Figure 3 assumptions

- Location: San Francisco, USA
- Data center capacity: 1000 kW
- System redundancy: N
- Configuration: prefabricated

Direct fresh air system:

- Devices include louvers, filters, dampers, fan arrays on VFDs, and with or without 100% DX for backup.
- Full unit controls
- Hot aisle containment

Indirect air economizer system:

- Devices include fans, indirect evaporative cooler, pumps, valves, water spray nozzle/drift eliminator, sensors and DX assist.
- Integrated control system
- Hot aisle containment
- 30% DX backup to supplement heat exchanger under extreme outdoor conditions at full load

Capital cost

Capital cost includes materials, installation labor, design costs, and all project fees associated with the entire cooling system in terms of dollars per watt of IT load. **Figure 3** illustrates a capital cost comparison between a direct fresh air system and an indirect air economizer system. Both systems are prefabricated and configured to achieve the required ASHRAE recommended environmental conditions for the IT space assuming San Francisco weather data (see side bar for detailed assumptions). In general, the DX backup for direct fresh air systems is sized for the sensible[2] cooling requirement and we assume this in our analysis.

The capital cost of the indirect air economizer system is slightly higher because the air to air heat exchanger adds cost. However, the indirect air economizer system inherently controls humidity and air pollution risks. Adding 100% DX backup to the direct air system to address these risks pushes its cost above the indirect system. In addition, having 100% DX backup also increases the cost and capacity requirements of upstream power distribution equipment and generators required to support the data center.

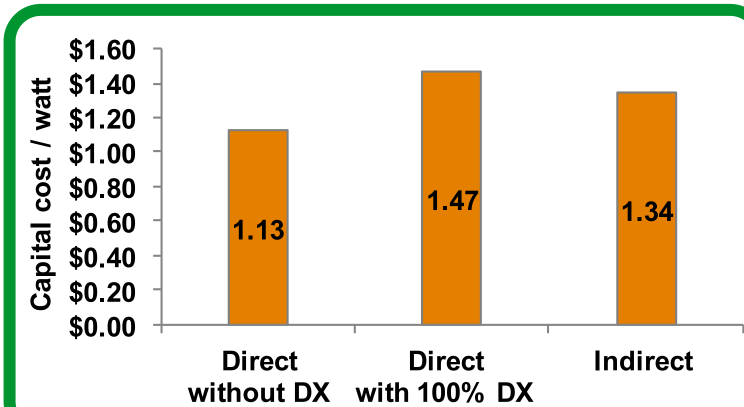


Figure 3

Capital cost comparison between direct and indirect air economizer systems for San Francisco, California, USA

[2] See White Paper 56, *How and Why Mission-critical Cooling Systems Differ from Common Air Conditioners* for explanation.

Operating cost

Operating cost of the entire cooling system includes the following:

- **Energy cost** - Assumes energy consumed by the entire cooling system at 100% load. It includes the power consumption when the system is under full and partial economizer modes.
- **Water cost** - Water is used by evaporative assist components to achieve more economizer hours.
- **Maintenance cost** - The maintenance cost includes the cost of air filter changes, water filter changes, nozzle changes, cleaning of the filters, and cleaning of air to air heat exchangers. The filter change cost of the direct fresh air system depends on the air pollution of the data center locations and filter replacement frequency.

Figure 4 and 5 assumptions

- Data center and cooling system configurations are the same as **Figure 3** assumptions
- Data center load: 100%
- Based on ASHRAE recommended range, the supply air setpoints for both direct and indirect systems:
  - -Fixed supply air temperature: 27°C (80.6°F)
  - -Relative humidity: 30%<RH%<60%
  - -Dew point: 5ºC<DP<15ºC (41°F<DP<59°F)
- Delta T between supply and return air temperature: 14°C (25.2°F)
- Electricity cost: 0.09 $/watt
- Water cost: $0.62/m^3$ ($0.0176/ft^3$)
- Clogged filter resistance: 50% collapsed

Figures 4 and **5** illustrate an annual operating cost comparison between direct and indirect air economizer systems (see side bar for assumptions) for two different locations. **Note that San Francisco was chosen because it is an optimal climate for direct air systems.** Both direct and indirect economizer systems have good cooling performance throughout the year in San Francisco. The direct air system has a lower operating cost in San Francisco due to lower humidity and mild temperatures. However, in climates like St. Louis (more humid/hot), the direct air system requires more frequent 100% DX operation to maintain humidity thresholds in the IT space. The following lists some detailed findings:

- The direct air system can operate on full economizer mode for about 99.8% of the hours in a year in San Francisco, compared to 76.4% hours in St. Louis.
- The indirect air system operating cost is less dependent on geographic location compared to direct air.
- The energy cost of the direct fresh air system can significantly increase when the filters are clogged because the fans consume more power to overcome the resistance. Clogged filters also pose a potential risk for data center availability.
- The indirect air economizer system has slightly less full economizer mode hours in San Francisco due to the heat transfer efficiency loss penalty of its heat exchanger, discussed later in the performance section.
- For the indirect air economizer system, more water is consumed by evaporative assist to achieve more economizer hours in both San Francisco and St. Louis.
- The maintenance cost of the direct fresh air system is higher in both San Francisco and St. Louis due to more frequent filter replacements.

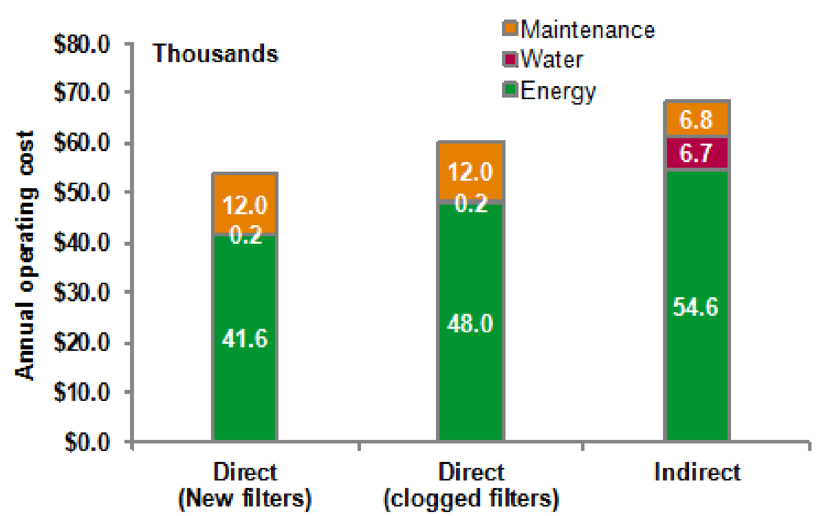


Figure 4

Operating cost comparison between direct and indirect air economizer systems for San Francisco, California, USA

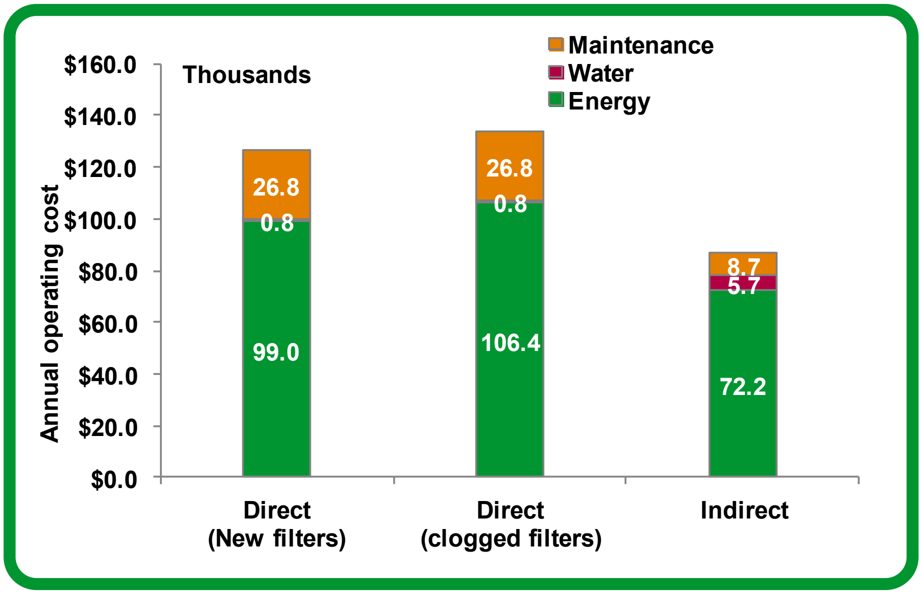


Figure 5

Operating cost comparison between direct and indirect air economizer systems for St. Louis, Missouri, USA

Performance

The performance differences between direct and indirect air economizer systems depend on:

- Heat transfer efficiency of the system
- Data center geographies and IT environmental setpoints

Heat transfer efficiency of the system

In general, lowering the number of heat exchanges increases the number of economizer mode hours and ultimately increases efficiency. The direct fresh air system is often viewed as the "most efficient" economizer-based cooling approach if the outdoor conditions are favorable because the system simply filters the outside air into the IT space. There are no heat exchanges and the fans become the primary mechanism in removing the heat.

If the outdoor conditions are not favorable, the fresh air needs to pass through mixing dampers/chambers, a wet mesh material, and/or DX coils to reach the setpoints before entering into the IT space, which adds heat transfer efficiency losses to the system. In order to reduce the air pollution risks, high MERV[3] rated filters[4] are typically used for direct fresh air systems which adds additional pressure drop to the air delivery system. This means more energy is required to move the same amount of air. As the air filters become clogged, the fan power consumption increases which reduces the energy savings.

The indirect approach has one heat exchange process between the outside and inside air, which adds heat transfer efficiency losses. This kind of economizer mode also requires makeup air which slightly reduces the efficiency of the whole cooling system. However, except for makeup air, there is no direct contact with outside air. Indirect air economizer system does not require air filters for the outdoor air stream nor does it require a wet mesh material. Low MERV rated filters (e.g. MERV8) are typically used for the indoor air stream. The evaporative cooling effect is accomplished by spraying water on the outside of the plates or tubes, which has no negative impact on the humidity level in the IT space, unlike the direct air system.

[3] For information on MERV see http://en.wikipedia.org/wiki/Minimum_efficiency_reporting_value

[4] MERV 13 rating or better with frequent use of pre-filters

Geographies and IT environmental setpoints

Geography plays a big role in the decision between direct and indirect air economization, because temperature, humidity, and air quality of a location determine if it makes sense. This section focuses on the temperature and humidity analysis (air quality is discussed in next section). The choice between direct and indirect air economization depends on geography because:

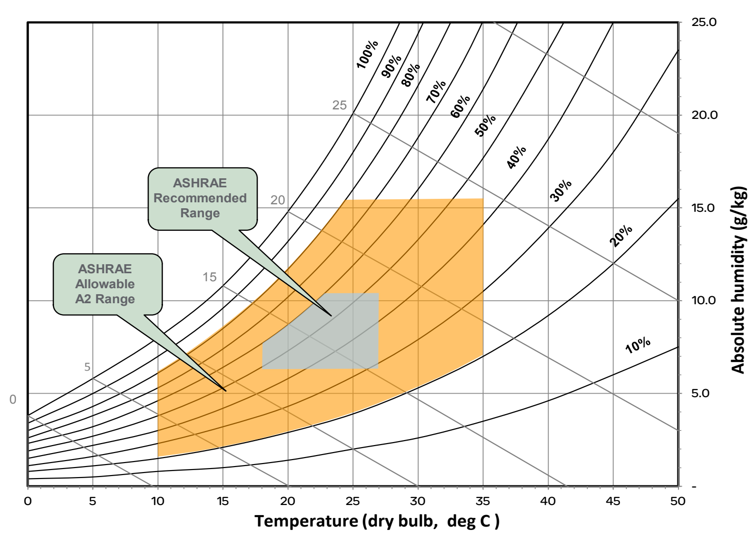
- The temperature and humidity of a data center location determine how many economizer hours can be achieved, which are critical to minimizing energy and water costs.
- The geography also determines the configuration of direct and indirect economizer systems such as how much DX system backup (i.e. 100% DX, de-rated DX or even no DX for backup), which impacts the capital investment of the cooling system.

However, the decision also depends on the IT environmental setpoints which need to be balanced with downtime risks. Most data center operators today are very conservative with what they consider to be "acceptable" temperature and humidity envelopes for their IT space (risk of expanding IT environmental setpoints is discussed in next section). These "acceptable" temperature and humidity envelopes determine the performance of direct and indirect air economizer systems. In order to leverage direct fresh air cooling to reduce energy costs, some IT server vendors are trying to design server models to run at broader temperature and humidity ranges[5]. Note that increasing IT inlet temperature may result in an overall increase in data center energy consumption. For more information see White Paper 221, *The Unexpected Impact of Raising Data Center Temperatures*.

In order to drive cooling system energy savings, ASHRAE also expanded the environmental range in its 2011 Data Center Thermal Guidelines[6]. **Figure 6** shows the latest ASHRAE recommended and allowable A2 range for data processing environments which are typically the environmental specifications of most currently available IT equipment.

Figure 6

ASHRAE recommended vs. allowable A2 operating environments



The horizontal axis is the temperature range and the vertical axis is the humidity range. **The bigger the window of acceptable conditions defined for the IT equipment in a data center, the greater the number of hours the cooling system can operate in economizer mode.**

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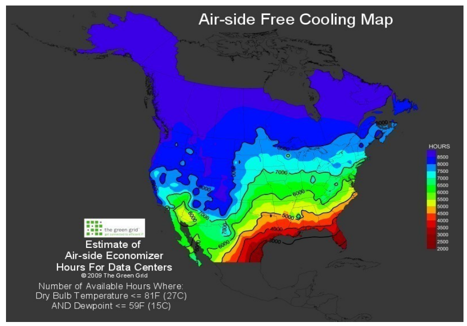
[5] http://en.community.dell.com/techcenter/extras/m/white_papers/20102656.aspx

[6] ASHRAE. 2011, Thermal Guidelines for Data Processing Environments, Developed by ASHRAE Technical Committee 9.9.

Figure 7a and **7b** show the estimated total number of annual hours a data center can operate on direct fresh air economizer mode. This is based on ASHRAE recommended (**Figure 6a**) and allowable A2 (**Figure 6b**) ranges using The Green Grid's free cooling tool[7]. The dark blue regions in **Figure 7a** mean that the direct fresh air system can operate on full economizer mode for 100% of the hours in a year assuming the ASHRAE recommended range is acceptable as the IT environmental setpoints. Therefore, there is no need for mechanical cooling backup in these locations, setting aside the risks of air pollution and other emergencies. If IT equipment can operate within the ASHRAE allowable A2 range, more locations will have increased economizer hours as shown in **Figure 7b**.



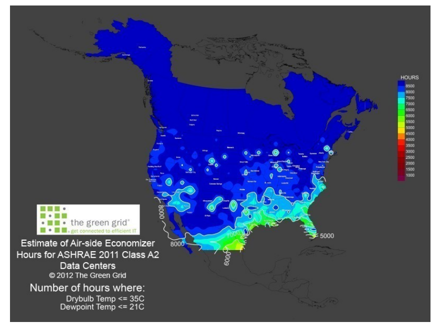


Figure 7a (left)

Direct fresh air economizer mode hours of North America based on ASHRAE recommended range

Figure 7b (right)

Direct fresh air economizer mode hours of North America based on ASHRAE allowable A2

Worst case dew point

- Singapore: 29°C (84.2°F)
- Miami: 28.6°C (83.5°F)
- Beijing: 30°C (86°F)
- Tokyo: 28°C (82.4°F)
- Sydney: 24°C (75.2°F)
- St. Louis: 28.6°C (83.5°F)
- New York City: 27.5°C (81.5°F)
- San Francisco: 19.7°C (67.5°F)
- Moscow: 24°C (75.2°F)
- London: 21°C (69.8°F)
- Seattle: 28.6°C (83.5°F)

DX backup requirement with ASHRAE allowable A2

When the dry bulb is higher than 35°C and the enthalpy is lower than 75.4 kJ/kg at 35°C DB and 21°C DP, evaporative cooling can be used to drop the dry bulb to the 35°C setpoint, while maintaining a dew point at or below the maximum 21°C. When the enthalpy is greater than 75.4 kJ/kg, evaporative cooling can't meet the 35°C DB setpoint without violating the 21°C dew point. DX backup cooling is required in this case.

Cooling load factor (CLF) [8]

This section quantifies the cooling performance of direct and indirect air economizer systems across 11 cities where large data centers are commonly located. The cooling systems are configured to achieve the required IT environmental setpoints (per ASHRAE).

The side bar shows the worst case dew point[9] of these 11 cities. For the ASHRAE recommended range, the maximum allowable supply air dew point is 15°C (59°F). Since all the cities violate the maximum allowable dew point, the direct fresh air system typically requires 100% DX backup. In other words, for those hours in the year when the outdoor humidity levels are high enough to violate the dew point, the outside air is typically not allowed to enter the data center and 100% of the IT load is cooled using only DX backup.

If we broaden the supply air setpoints to the ASHRAE allowable A2, the maximum allowable supply air dew point becomes 21°C (69.8°F). This means that in a city like San Francisco where the dew point is lower than the maximum allowable dew point, there may be a chance to remove the DX backup for the direct fresh air systems. In this case, the enthalpy at a given dry bulb temperature and dew point drives the DX backup requirement (see sidebar for explanation).

ASHRAE, The National Renewable Energy Lab (NREL), and The National Oceanic and Atmospheric Administration (NOAA) are just a few sources that provide weather data to assess the number of economizer mode hours available. Based on this weather data, TradeOff Tool 11, *Cooling Economizer Mode PUE Calculator*, can help calculate the CLF of direct and indirect air economizer systems. It also provides these results for other cooling system economizer modes, and illustrates which architecture(s) have the optimal PUE, energy cost, and carbon emissions for their data center location and IT operating environment. **Figure 8** illustrates the inputs and outputs of this tool.

[7] http://www.thegreengrid.org/Global/Content/Tools/NAmericanFreeCoolingTool

[8] Cooling Load Factor (CLF) is the total energy consumed by the cooling system divided by the IT load energy. CLF is the portion of the PUE dedicated to a data center's cooling system. For more information on CLF, see page 7 of The Green Grid white paper #1.

[9] Weather Data Viewer, version 5.0 © 2013 ASHRAE, Inc.

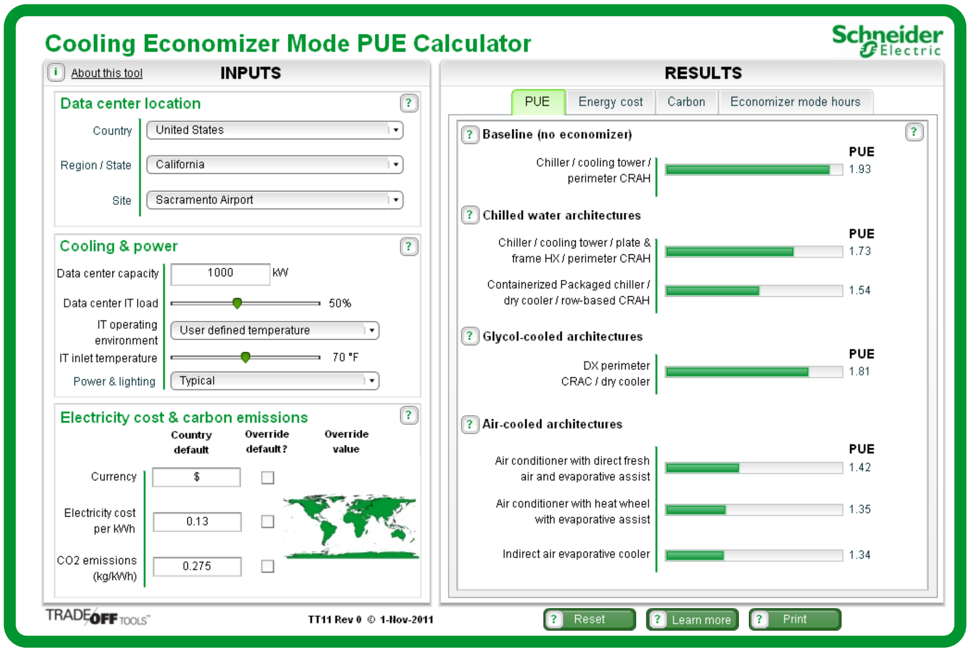


Figure 8

TradeOff Tool Calculator to help assess performance of various cooling approaches

IT environmental setpoints based on ASHRAE allowable A2

- Fixed supply air temperature: 35°C (95°F)
- Relative humidity: 20%<RH%<80%
- Maximum dew point: 21°C (69.8°F)
- Delta T between supply and return air temperature: 14°C (25.2°F)

Figure 9 compares the annual average CLF of the direct and indirect air economizer systems based on **Figure 3, Figure 4**, and sidebar assumptions across 11 cities with ASHRAE recommended range and allowable A2.

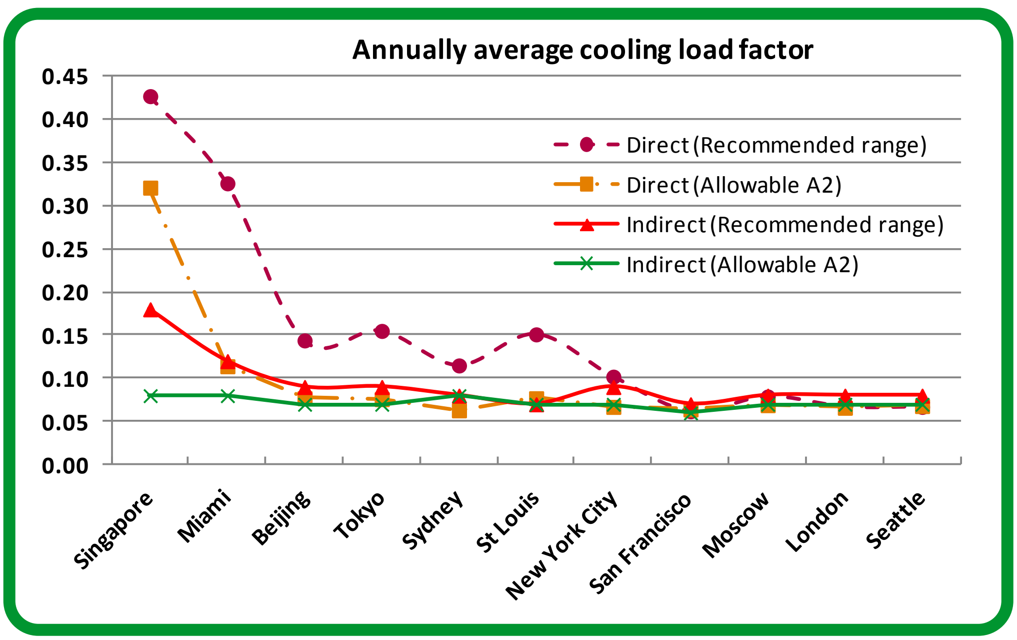


Figure 9

Cooling load factors for direct and indirect air economizer systems throughout the world

Köppen climate classification

- Tropical rain forest – No dry season (i.e. Singapore)
- Tropical monsoonal – Pronounced wet season, short dry season (i.e. Miami)
- Humid continental – Humid with severe, dry winter, hot summer, cold winter (i.e. Beijing)
- Humid subtropical – Mild with no dry season, hot summer, mild winter (i.e. Sydney)
- Mediterranean – Mild with dry, hot summer, mild winter (i.e. Seattle)

For geographies with tropical rain forest climate (see sidebar for explanation) like Singapore, the direct fresh air economizer mode exhibits poor cooling performance when the IT environmental setpoints are set to the recommended range. This is because the cooling system operates entirely under mechanical mode due to the humid outdoor conditions. In another words, the outside fresh air is not allowed to enter the IT space at any time throughout the year. If the allowable A2 setpoints are used, the data center can be cooled with direct fresh air for about 30% of the annual hours. The indirect air economizer system benefits from indirect evaporative cooling and operates under partial economizer mode to save some energy. Therefore, direct fresh air systems don't make sense for humid geographies under ASHRAE recommended setpoints.

For geographies with tropical monsoonal climate like Miami, the cooling system operates under direct fresh air economizer mode for about 27% of annual hours, saving some energy when the IT environmental setpoints are set to the recommended range. With allowable A2, the economizer hours are extended to 86% of the annual time. For indirect air economizer systems in tropical monsoonal climates, more energy can be saved compared to tropical rain forest due to a longer dry season which can enhance the efficiency of evaporative assist.

For geographies with a humid continental climate like Beijing, and a humid subtropical climate like Sydney, both direct and indirect air economizer systems can achieve many economizer hours during winters and transition seasons. The direct fresh air system with the ASHRAE recommended range has less economizer hours than with the ASHRAE allowable A2 range due to outdoor humidity conditions. The indirect air economizer system has similar cooling performance for different ASHRAE ranges.

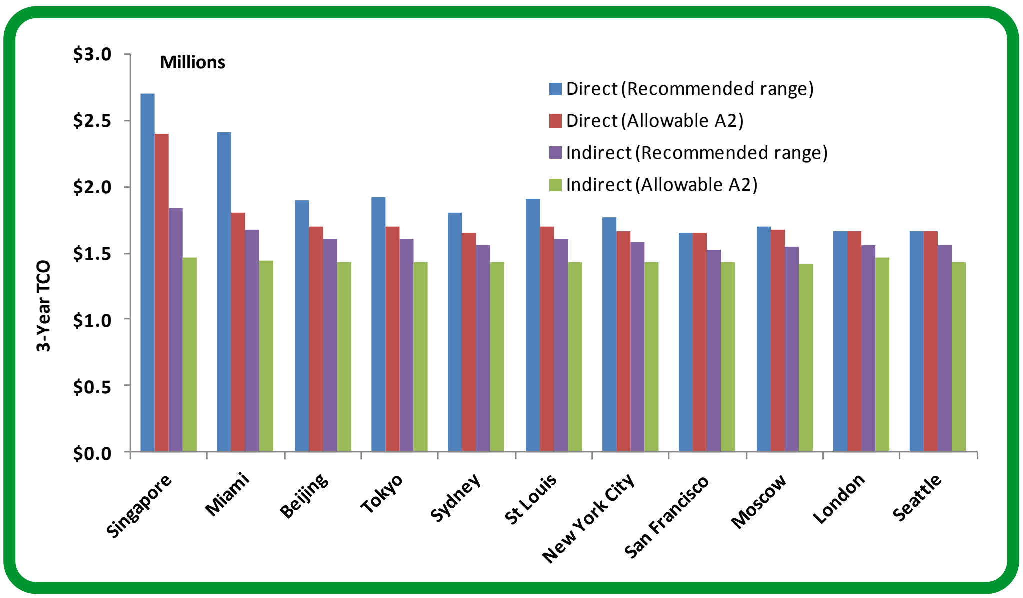
For geographies with a Mediterranean climate like London and Seattle, both direct and indirect air economizer systems perform well because they can operate under full economizer mode most of the year. Because these systems run on DX so few hours, the energy difference between a 100% rated and 50% rated DX systems is tiny compared to the total energy consumption.

3-Year TCO

The financial decisions between direct and indirect air economizer systems should be based on the TCO of each system. **Figure 10** compares the 3-Year TCO between direct and indirect air economizer systems based on **Figure 3**, **Figure 4**, and **Figure 8** assumptions.

Figure 10

3-Year TCO of direct and indirect air economizer systems



For geographies like Singapore and Miami, the direct fresh air system has the highest TCO for the ASHRAE recommended range. The indirect air economizer system with the ASHRAE allowable A2 setpoints has a similar cooling performance all over the world. Across all these locations, the indirect air economizer system has an improved TCO as a result of the de-rated DX backup configuration requirement. The decision between direct and indirect also depends on other attributes like building shell compatibility, footprint constraints, potential air pollution risks, fault tolerance of the data center, and the type of equipment it houses.

Availability risks

The main barrier to using direct fresh air is the concern of air pollution and high humidity risks on server longevity, which is the biggest difference compared to indirect air economizer systems. Other data center availability risks associated with these two economizer modes include expanded IT inlet temperature range, DX backup configuration, loss of evaporative water, impact on the fire suppression system, and human error.

Air pollution

According to research done by Lawrence Berkeley National Laboratory (LBNL)[10], filters on direct fresh air systems can provide very good levels of filtration in the United States. However, in locations such as marine, industrial, or other regions of high pollution (e.g. China, India or other areas of south Asia), the amount of filtration is large and if the filters are not replaced frequently enough, or during the replacement of the filters, particulate and gaseous contamination such as dust, chemicals from spills, smoke / ash, etc. may have a chance to enter the data center.

According to ASHRAE research[11], harmful dust in data centers is generally high in ionic content, such as sulfur and chlorine-bearing salts. Deliquescent relative humidity, the relative humidity at which the dust absorbs enough water to become wet and promote corrosion and/or ion migration, determines the corrosivity of dust. Another form of particulate contamination detrimental to hardware reliability is zinc whiskers, which are the most common electrically conductive particles found in data centers.

Gaseous contamination such as sulfur dioxide and hydrogen sulfide are the most common gases causing corrosion of electronic equipment. The corrosion rate of copper is a strong function of relative humidity. The filtration systems need to satisfy the gaseous contamination within the modified severity level G1 of ISA – 71 (ISA 1985) that meets:

- A copper reactivity rate of less than 300 Å/month
- A silver reactivity rate of less than 200 Å/month

Note that corrosion monitoring systems are required to ensure adherence to these values. **Figure 11a** and **11b** show two common modes of IT equipment failures due to particulate and gaseous contamination. In order to prevent these two common IT equipment failure modes, the following list contains some strategies to control the cleanliness level of data centers:

- Data centers must meet an ISO class 8 clean room standard.
- Data centers must be free of zinc whiskers.
- Monitoring systems should be used to ensure copper and silver reactivity below the standards.
- The deliquescent relative humidity of particulate contamination should be more than 60%.
- The room air should be continuously filtered with MERV 8 filters.
- Fresh air from direct systems and the make-up air for indirect air economizer systems should be filtered with MERV 11 or preferably MERV 13 filters.

[10] LBNL. March, 2011, "Air-Side Economizer Cooling Is Safe for Most California Data Centers".

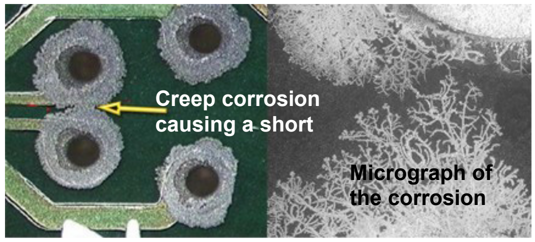
[11] ASHRAE. 2011, "Gaseous and Particulate Guidelines for Data Centers", Developed by ASHRAE Technical Committee 9.9.

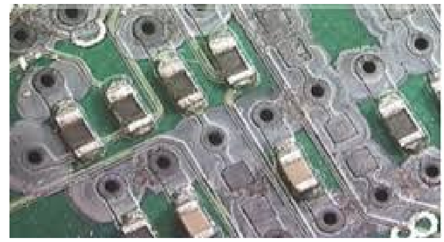
Figure 11a (left)

Copper creep corrosion on printed circuit boards

Figure 11b (right)

Corrosion of a plated through hole





Expanded IT inlet temperature range
Expanding the IT inlet temperature range helps to achieve more economizer hours and may[12] reduce energy consumption of direct and indirect air economizer systems. However, increasing IT inlet temperatures may increase overall data center energy and will also increase IT equipment failure rate[13]. Data center owners should assess this risk against the energy benefit.

DX backup configuration
Increasing DX backup capacity comes with a capital cost penalty. Depending on the outside air conditions of a location and environmental setpoint requirements, the designer may not have a choice but to use 100% DX backup which also buys them added reliability. But in cases where there is a choice, we need to quantify the cost premium of reducing risks. The following shows how capex is affected for direct and indirect air economizer systems while ignoring the capex implications on upstream power distribution equipment and generators required to support the data center.

- Some vendors may use a fixed DX capacity in their direct or indirect economizer systems but some may have options for lower or higher capacity DX compressors depending on specific locations and/or configurations. Varying the size of these DX compressors may add or subtract 7%-13% of the cost of the standard system or 4%-8% of the total capital expense for the economizer project (not including the racks and rack containment).
- Some vendors may also have an option to completely remove the DX system which could save 20%-35% of the cost of the standard system or 15%-23% of the total capital expense for the economizer project (not including the racks and rack containment).

Loss of water

This can occur due to construction projects in the vicinity of a data center, whether through planned or unplanned outages. For both direct and indirect systems, evaporative cooling is used for both increasing capacity and improving efficiency. The risk of losing the water source can be addressed by installing water back-up or sizing the mechanical cooling system to handle 100% of the load.

Impact on fire suppression system
Data centers that depend on clean agent fire suppression systems must seal the data center space in order to maintain the proper concentration of clean agent to effectively suppress a fire. For direct fresh air systems, this requires closing all air dampers and doors which are used to supply fresh air into the data center; for indirect air economizer systems, only the air dampers used for makeup air need to be closed.

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[12] While increasing IT inlet temperatures will reduce the economizer system energy, it may increase the overall data center energy due to increased IT equipment energy (leakage current and IT fans).

[13] ASHRAE. 2011, Thermal Guidelines for Data Processing Environments, Developed by ASHRAE Technical Committee 9.9

Human error

According to Uptime Institute's AIR database, 70% of reported data center outages are directly attributable to human error. Direct and indirect air economizer systems with customized controls increase the complexity of operation and maintenance. This increased complexity is likely to increase human error. Conversely, human error is less likely with standardized, prefabricated control systems with integrated economizer modes that are designed holistically.

Table 1 summarizes the differences between direct and indirect air economization against various attributes.

Table 1

Comparison between direct and indirect air economizer modes

Attribute	Direct air economization	Indirect air economization
Capital cost	Lower capital cost for prefabricated systems. For customized systems, the cost can be higher than indirect air economization.	These systems normally cost more than direct, but are a relatively small premium as a percentage of an entire data center project.
Operating cost	Higher energy cost for geographies with high temperature and humidity. Higher maintenance cost due to filter replacement. The cost will be closer to indirect for geographies with favorable outside conditions.	Lower operating and maintenance cost since the outdoor air is isolated completely by air to air exchanger, which results in longer full and partial economizer mode hours.
Efficiency	No heat transfer needed when the outside conditions are favorable, but fan power will increase as filters become clogged.	Lower efficiency due to one more heat exchange between outdoor and indoor air.
Availability risk	Highly susceptible to outdoor air quality and high MERV rated filters are required. Shutdown required with clean agent suppression in the event of a fire. High risk of human error for customized systems.	Lower downtime risk due to water loss. No risk due to poor air quality or fire suppression. Low risk for human error as a result of pre-engineered.

Choosing between direct and indirect

Direct fresh air systems perform best where the climate is favorable throughout the year. However, systems may require full mechanical backup due to environmental risks. Some direct fresh air systems require more integration with the physical building for the required airflow. Indirect air economizer systems pose less or no environmental risks as a result of separation of inside and outside air streams. However, indirect air economizer systems have a heat transfer efficiency loss penalty due to one more heat exchange.

This section explains when direct or indirect air economizer systems are recommended based on the previous section and other research[14]. For existing facilities with very inefficient cooling solutions, direct fresh air systems are a good solution to retrofit and run as the primary method of cooling, with the existing inefficient systems as backup. The following recommendations apply to green-field data centers:

<u>Direct fresh air systems are recommended under the following conditions:</u>

- Geographies with favorable outdoor conditions throughout the year
- There is no need for full mechanical cooling backup
- Data center operators can overcome the psychological barrier to expand their environment setpoints

[14] "The Use of Fresh Air in the Data Center", a white paper of a round table debate was hosted by Keysource with participants including the Uptime Institute.

- IT equipment can operate under broader temperature and humidity ranges like ASHRAE allowable A2
- Data center owners can afford to shut down the facility due to external factors

Indirect air economizer systems are recommended under the following conditions:

- Facilities with critical applications or transactions with high downtime cost
- Geographies with unfavorable outdoor conditions
- IT equipment cannot operate under broader temperature and humidity ranges like ASHRAE allowable A2

Conclusion

Both direct and indirect air economization can result in significant energy savings when compared to traditional cooling approaches. The decision between direct and indirect air economizer systems depends on their benefits, total cost of ownership, associated risks, and other attributes. When all factors are considered, we believe the optimal choice is indirect air economization.

Capital cost: Direct air system require 100% DX backup in locations where the maximum allowable ASHRAE recommended dew point of 15°C (59°F) is violated. Finding adequate data center site locations with worst case dew point temperatures below this limit becomes impractical. Therefore, the vast majority of data center locations are likely to require 100% DX backup for direct air which is likely to push the capital cost above that of indirect systems and also adds to the cost of upstream power distribution equipment and generators required to support the data center.

Operating cost: Indirect air system operating costs are less dependent on geographic location compared to direct air. Locations where the allowable dew point is violated, requires that the DX system (for direct air) operate in full mechanical mode which increases energy cost. We analyzed 54 cities around world, including those in **Figure 8**, and found that in 43 cities (80%), the indirect air system had a lower cooling load factor than the direct air system.

Availability risks: The availability risks posed by using direct air economizer systems are well known and can be mitigated with additional cost and operational maturity. However, we don't believe this "insurance premium" makes financial sense given the two factors above. If data center operators cannot justify the risks of running direct air economizer systems without these safety nets, the logical decision is to use indirect air economizer systems.

About the authors

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