Evaluation of Water consumption and savings achieved in Datacenters through Air side Economization

By

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ABSTRACT

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MECHANICAL ENGINEERING

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Recent researches and a few facility owners have focused on eliminating the chiller plant altogether by implementing ‘Evaporative Cooling’, as an alternative or augmentation to compressor-based air conditioning since the energy consumption is dominated by the compressor work (around 41%) in the chiller plant. Because evaporative cooling systems consume water, when evaluating the energy savings potential of these systems, it is imperative to consider not just their impacts on electricity use, but also their impacts on water consumption as well since Joe Kava, Google’s head of data center operations, was quoted as saying that water is the “big elephant in the room” for data center companies.
The objective of this study was to calculate the savings achieved in water consumption when these evaporative cooling systems were completely or partially marginalized when the facility is strictly working in the Economizer mode also known as ‘free cooling’ considering other modes of cooling required only for a part of the time when outside temperature, humidity and pollutant level were unfavorable causing improper functioning and reliability issues. The analysis was done on ASHRAE climatic zones with the help of TMY-3 weather data.

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CHAPTER 1

INTRODUCTION

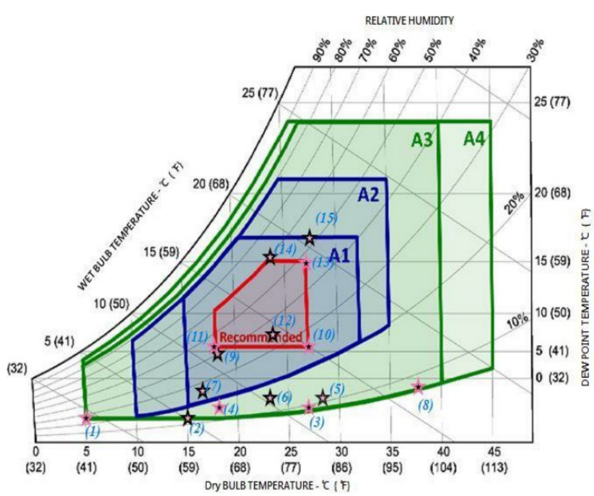
A data center (sometimes spelled *datacenter*) is a centralized repository, either physical or virtual, for the storage, management, and dissemination of data and information organized around a particular body of knowledge or pertaining to a particular business [8]. Data center architectures and requirements can differ significantly depending on the function of use. However its primary functions is housing the electronic hardware used for data processing, storage, and transmission. Their importance has become entrenched in the functioning of society and in particular for the daily operations of all sectors of the economy. US energy consumption is categorized by sector as buildings, industry, and transportation. The buildings sector is the largest consumer of the three. This sector represented approximately 41% of consumption (7% globally) in 2010 [6]. The building sector can be further split into residential and commercial based on primary end-use and datacenters which belong to the latter sector, consumes a huge amount of energy in comparison to the other. Over the past decade, energy use associated with data centers has nearly quadrupled and is currently estimated at nearly 100 billion kWh annually.

Figure 1: Open Compute project

1.1 Cooling requirements

Just imagine, at every 60 seconds, 204 million e-mails are exchanged, 5 million searches are made on Google and around 1.8 million likes are generated in Facebook among much other similar kind of activities. Around 2.5 billion people are using the internet, a number that has grown 566% since the year 2000 and 70% out of them use Internet daily. All our online activities is delivered by datacenters, and the more e-mail we send, watch online videos, use social media and conduct business online, the more demand on datacenters will grow. As we know that Data centers are purpose-built facilities housing IT equipment which needs to be running at all times drawing continuous power. This power gets converted into heat energy as we know from first law of thermodynamics which needs to be removed at all times to keep the servers operating and prevent the datacenters from failing. Therefore cooling becomes important in the proper functioning of these datacenters.

1.2 ASHRAE thermal guidelines and climatic zones

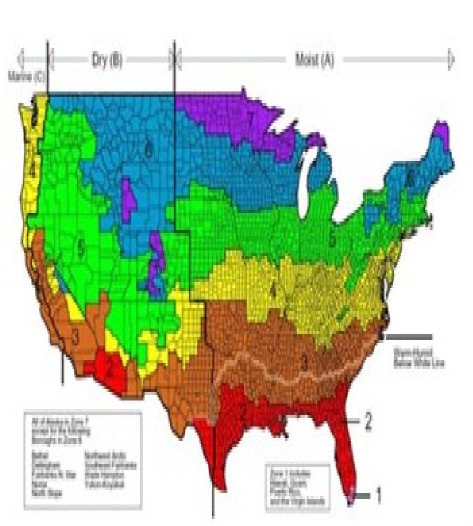


Classes (a)	Equipment Environmental Specifications							
	Product Operations (b)(c)					Product Power Off (c) (d)		
	Dry-Bulb Temperature (˚C) (e) (g)	Humidity Range, non-Condensing (h) (i)	Maximum Dew Point (˚C)	Maximum Elevation (m)	Maximum Rate of Change(˚C/hr) (f)	Dry-Bulb Temperature (˚C)	Relative Humidity (%)	Maximum Dew Point (˚C)
Recommended (Applies to all A classes; individual data centers can choose to expand this range based upon the analysis described in this document)								
A1 to A4	18 to 27	5.5ºC DP to 60% RH and 15ºC DP						
Allowable								
A1	15 to 32	20% to 80% RH	17	3050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20% to 80% RH	21	3050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12˚C DP & 8% RH to 85% RH	24	3050	5/20	5 to 45	8 to 85	27
A4	5 to 45	-12˚C DP & 8% RH to 90% RH	24	3050	5/20	5 to 45	8 to 90	27
B	5 to 35	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29
C	5 to 40	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29

Figure 2: ASHRAE A4 Envelope

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) formed Technical Committee 9.9 Mission Critical Facilities, Technology Spaces and Electronic Equipment (TC 9.9) published its first recommended Thermal Guidelines for Data Processing Environments in 2004 defining inlet supply air envelope inside Datacenters. Since then the committee has made many changes and expanded the envelopes adding a fourth allowable class in the 2011 update, as shown in Figure 2. The Allowable limits has been expanded to push the thermal limits for increased efficiency and to expand the working hours of using economizers by some operators.

The ASHRAE geographic climate zones are classified on the basis of their climatic conditions basically the Dry bulb temperature and the relative humidity round the year. Based on the climatic conditions the cooling systems are decided which could serve the purpose of employing best energy saving methods.



	IECC Climate Zone
Miami	1A
Houston	2A
Phoenix	2B
Atlanta	3A
Los Angeles	3B
Las Vegas	3B
San Francisco	3C
Baltimore	4A
Albuquerque	4B
Seattle	4C
Chicago	5A
Boulder	5B
Minneapolis	6A
Helena	6B
Duluth	7
Fairbanks	8

International Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	9000 < CDD50°F	5000 < CDD10ºC
2A and 2B	Hot-Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000	3500 < CDD10ºC ≤ 5000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300	2500 < CDD10ºC < 3500
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 2000
4A and 4B	Mixed-Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 3000
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400	2000 < HDD18ºC ≤ 3000
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200	3000 < HDD18ºC ≤ 4000
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000	4000 < HDD18ºC ≤ 5000
7	Very Cold	9000 < HDD65°F ≤ 12600	5000 < HDD18ºC ≤ 7000
8	Subarctic	12600 < HDD65°F	7000 < HDD18ºC

Figure 3: ASHRAE Climatic Zones

1.3 Reliability concerns

In order for a data center to function properly, the environment must be tightly controlled to ensure maximum reliability of the electronic hardware components. Any method of controlling the environment has a cost, either in capital or in resources, and therefore becomes an issue for the sustainability of a building or complex [1]. Chief environmental specialist at Microsoft Mr. Rob Bernard reported in a strategy brief that although ASHRAE standards are conservative numbers, often more restrictive than the operating conditions are warranted by server manufacturers. "Elevating operating temperatures enables the broader use of free air cooling instead of extensive air conditioning"[10].

1.4 Metric

Two metrics have been developed to characterize this energy use in data centers: Power Use Effectiveness (PUE) and Data Center Infrastructure Efficiency (DCiE). Power usage effectiveness (PUE) has become the industry-preferred metric for measuring infrastructure energy efficiency for data centers. Datacenter operators rely on this dimensionless parameter to compare the energy efficiency of their facility. The PUE metric is an end-user tool that helps boost energy efficiency in datacenter operations.

Power Usage Effectiveness: This metric defined by the Green Grid measure the effectiveness of a data center. It is a ratio of Total power required by the facility to the IT compute power [4].

$$\text{PUE} = \frac{\text{Total Facility Power}}{\text{Compute Power}} = \frac{\text{Compute Power+Cooli} \quad \text{Power+Mis} \ \text{.Power}}{\text{Compute Power}}$$

Ideal PUE = 1.0. A PUE of 1.15 would mean that 15% of the excess energy is utilized in purpose other than computing. This requires the numerator to be as small as possible.

One of the parameter that can be checked is the “COOLING POWER” as it forms a big part of Total power consumption. DCiE is the inverse of PUE.

One real problem is PUE does not account for the climate within the cities the data centers are built. In particular, it does not account for different normal temperatures outside the data center.

CHAPTER 2

COOLING SYSTEMS

There are various methods currently employed in data centers to cool their servers. Ranging from Liquid Cooling, where water is circulated through micro channels in server to collect and reject heat from the cold plate to immersion cooling practices where servers are immersed in a Di-electric medium, which is circulated through a heat exchanger to reject heat. Although water is used majorly because of its high enthalpy of vaporization however air cooling is widely popular because it is readily available free of cost and offers greater flexibility in operation [4].

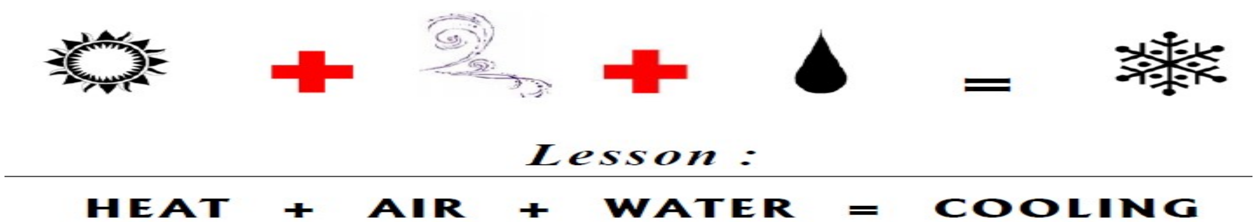


Figure 4: Cooling Process

These are some other various methods of transferring data center heat to its ultimate heat sink. Here is a partial list:

1. CRAH units with water-cooled chillers and cooling towers
2. CRAH units with air-cooled chillers
3. CRAC units with cooling towers or fluid coolers
4. Airside economization
5. Airside economization with direct evaporative cooling (DEC)
6. Indirect evaporative cooling (IDEC)

These methods either employ chiller for their operation or are chiller less.

2.1 Chiller based

Chiller systems which employ compressors for their energy exchange to the surrounding eat on a larger chunk of the total energy supplied to the facilities estimated at around 41% of the total energy supplied to the cooling system. Merely shifting from chiller based to chiller less cooling system can help save a lot of energy. Increasing the Inlet temperature can be an option but the reliability of the equipments faces a challenge on doing so.

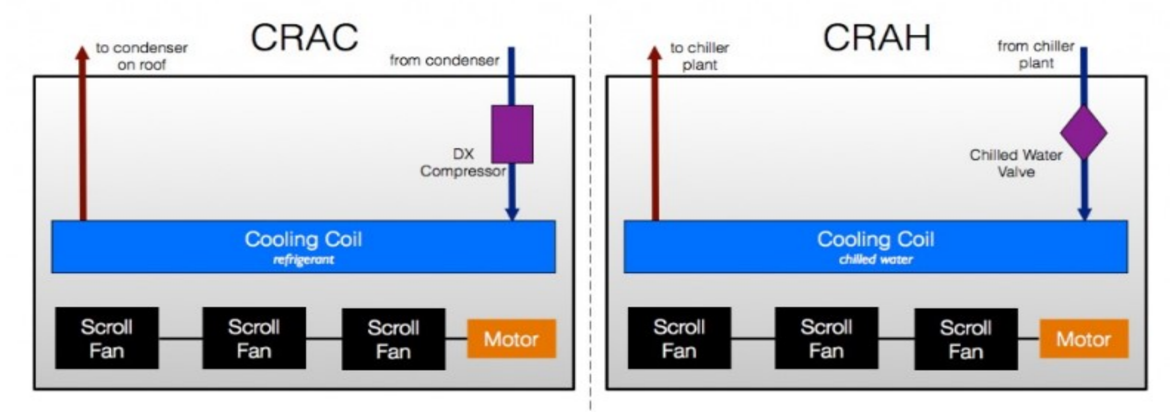


Figure 5: Working of a Chiller plant

2.2 Basic Psychrometry

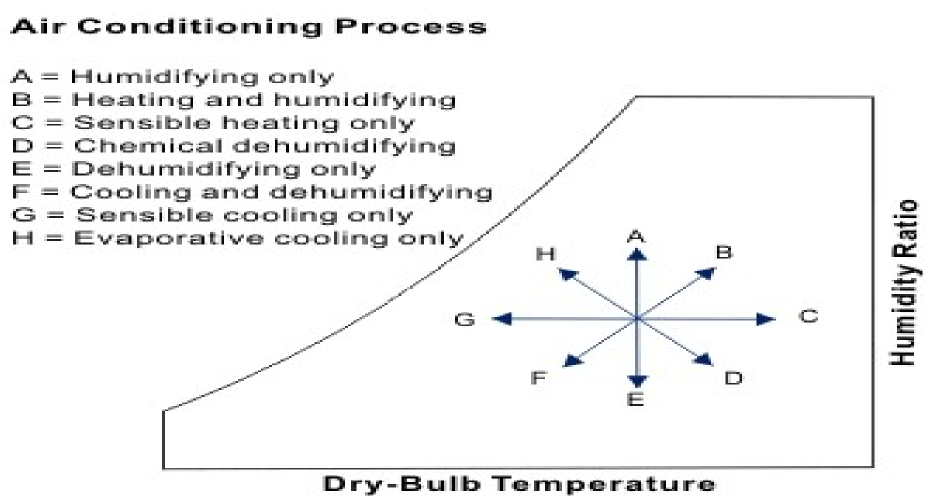


Figure 6: Psychrometric Processes

1. **Dry-bulb Temperature**: It is the temperature measured on thermometer exposed to air in a place sheltered from direct solar radiation. As the DB temperature increases, the capacity of moisture the airspace will hold also increases. It is an indicator of heat content of the air and is shown along the bottom axis of Psychrometric chart.
2. **Wet Bulb Temperature**: The Wet Bulb temperature is the temperature measured by using a thermometer whose glass bulb is covered by a wet wick/cloth. It is shown as slanted lines on Psychrometric chart. Wet-bulb temperature is actually the function of ambient air temperature and relative humidity. This type of temperature measures the amount of water vapor that the atmosphere is capable of holding at certain weather conditions. Lower levels of wet-bulb temperature indicate that the air could carry higher amounts of water vapor compared to higher levels of wet-bulb temperature.
3. **Relative Humidity**: It is the ratio of vapor pressure of moisture in the sample to the saturation pressure at the dry bulb temperature of the sample. It is shown as curved lines on Psychrometric chart.
4. **Dew Point Temperature**: It is defined as the saturation temperature of the moisture present in the sample of air. It is also that temperature at which vapor changes to liquid. It is shown on the vertical axis and increases as we go from bottom to top.
5. **Specific Humidity** (**Humidity Ratio)**: The humidity ratio is very useful in evaporative cooling because it provides the measure of the amount of moisture absorbed by the air stream and is useful in determining the spray water requirements. It is defined as the portion of mass of vapor per unit mass of dry air. It is represented on the vertical axis.
6. **Sensible Heat*:*** The heat used to change the temperature of the air. Sensible heat will always cause a change in the temperature of the substance.
7. **Latent heat*:*** Latent heat is the heat energy involved in the phase change of water. The heat will only change the structure or phase of the material without change to temperature.

2.3 Evaporative cooling

An evaporative cooler is basically a large fan that draws warm air through water-moistened pads. As the water in the pads evaporates, the air is chilled and pushed out to the room. Evaporative coolers are rated by the volume of warm/cool air that can be exchanged in one minute (CFM). The temperature can be controlled by adjusting the airflow of the cooler. They work best in dry climates; the lower the relative humidity, the easier it is for moisture to evaporate from the pads. Companies, including Google and Facebook are also using evaporative cooling along with higher server temperatures, reported to be nearer 120 degrees, in major data centers, such as Microsoft's Redmond Ridge 1. Most designs take advantage of the fact that water has one of the highest known enthalpy of vaporization (latent heat of vaporization) values of any common substance.

2.3.1 Types

There are 2 forms of evaporative cooling

Direct: When water evaporates into the air to be cooled, simultaneously humidifying it, it is called direct evaporative cooling and the thermal process is the adiabatic saturation. The principle underlying direct evaporative cooling is the conversion of sensible to latent heat. Non-saturated air is cooled by exposure to free and colder water, both thermally isolated from other influences. Some of the air’ sensible heat is transferred to the water and becomes latent heat by evaporating some of the water.

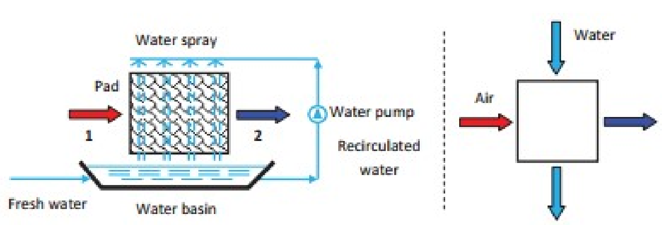


Fig. 1. Working principle scheme and simplified flow scheme of the DEC

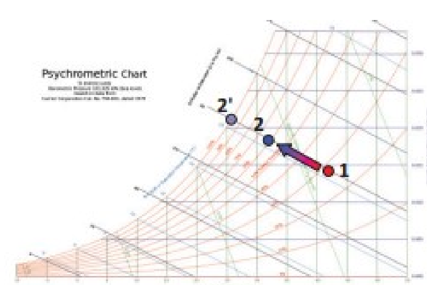


Fig. 2. The working process of the DEC

Figure 7: Direct Evaporative cooling Process

Indirect: When the air to be cooled is kept separated from the evaporation process, and therefore is not humidified while it is cooled, it is called indirect evaporative cooling. It utilizes a heat exchanger to separate the supply air from the water used for evaporation and uses a secondary air stream to reject heat from the evaporation process.

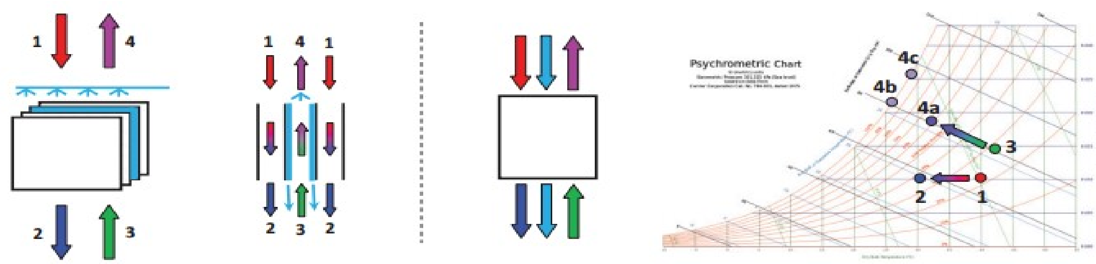


Fig. 3. Working principle scheme and simplified flow scheme of the **IEC** equipment

Fig. 4. The working process of the **IEC** in the psychrometric chart

Figure 8: Indirect Evaporative Cooling Process

2.3.2 Advantage and Disadvantage of Evaporative cooling

Unlike an air conditioner (AC), an evaporative cooler doesn't use refrigerants, which can be hazardous to the environment. Installations costs are significantly lower often half that of more conventional HVAC alternatives, electricity usage is significantly lower and the units themselves are simpler to maintain and operate. Unlike HVAC units that use vapor compression or absorption refrigeration and consumer large amounts of electrical energy in the process, EC uses water evaporation as the coolant. The water pump in EC systems uses little power and overall cost of operation is estimated to be about 25 percent of HVAC units, which leads some to refer to EC as "free cooling."

For optimum benefits, EC needs a reliable water source and a warm climate (averaging around 75 degrees Fahrenheit) with naturally low humidity. And, it helps if servers are capable of operating at high temperatures, an advantage new servers today afford.

One significant risk of EC is that the process itself does not afford dehumidification, as conventional HVAC systems do. If high humidity occurs inside the data center, it could cause condensation, leading to corrosion and other issues with electronic equipment. As the dew point rises, less cooling is available,(coz as DPT rises RH also rises which means less water evaporation or less cooling) which is why EC is more attractive in areas with low humidity and high temperatures.

Main Advantage and disadvantage of Direct and Indirect Evaporative cooling

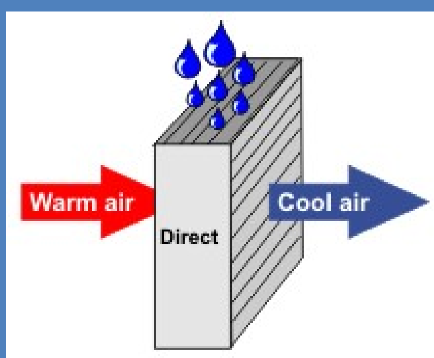
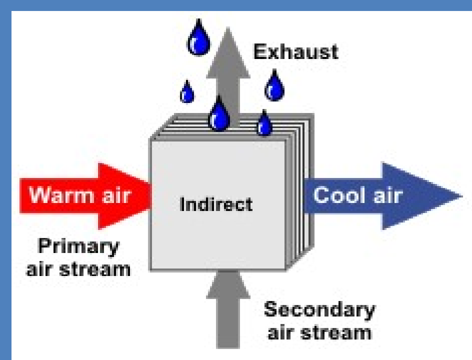
DEC	**IDEC**
	
ADVANTAGE	
1. Very simple construction of the equipment.	2. Primary air is cooled without modifying its moisture content.
DISADVANTAGE	
1. Increase in the air moisture content which may be undesirable for certain applications.	2. Cooling process of the primary air is limited by the WB temperature of the secondary air at the inlet

Table 1 : Advantages and Disadvantages of DEC and IDEC

Although currently the most used system is the mechanical vapor compression system, however, in many cases, evaporative cooling can be an economical alternative in place of conventional system, under several conditions, or as a pre-cooler in the conventional systems.

2.3.3 How much cooling can we get?

The three most important climate considerations are dry-bulb temperature, wet-bulb temperature, and wet-bulb depression during the summer design day. It is important to determine if the wet-bulb depression can provide sufficient cooling during the summer design day. By subtracting the wet-bulb depression from the outside dry-bulb temperature, one can estimate the approximate air temperature leaving the evaporative cooler. It is important to consider that the ability for the exterior dry-bulb temperature to reach the wet-bulb temperature depends on the saturation efficiency *i.e.* how efficiently the pads are wet partly or completely. A general recommendation for applying direct evaporative cooling is to implement it in places where the wet-bulb temperature of the outdoor air does not exceed 22 °C (71.6 °F).

The formula to determine Leaving Dry Bulb (LDB) is: LDB = EDB – (SE x (EDB – EWB))
Where:
LDB = Leaving Air Dry Bulb temperature
EDB = Entering Air Dry Bulb temperature
EWB = Entering Air Wet Bulb temperature
SE = Saturation Effectiveness

For example: Calculate the leaving air dry bulb temperature for a 20,000 CFM unit with 100° entering dry bulb and 80° entering wet bulb temperatures

Solution for Direct:
LDB = 100° - (0.87 x (100° - 80°)) = 82.6°
Note - For Direct Evaporative Cooling units the Wet Bulb temperature will not change.

Solution for Indirect:

LDB = 100° - (0.75 x (100° - 80°)) = 85°

Note - For Direct Evaporative Cooling units the Wet Bulb temperature will change. It is interesting to note that the leaving temperature only depends on the saturation efficiency of the cooling pads.

Saturation Effectiveness: This is a ratio of the actual air temperature drop across the media compared to the Wet Bulb Depression. The key to effective evaporative cooling is ensuring that each of the cooling pads are completely saturated at all times during operation. Since the effectiveness depends on the air velocity, hence direct evaporative has higher saturation efficiency for a given thickness.

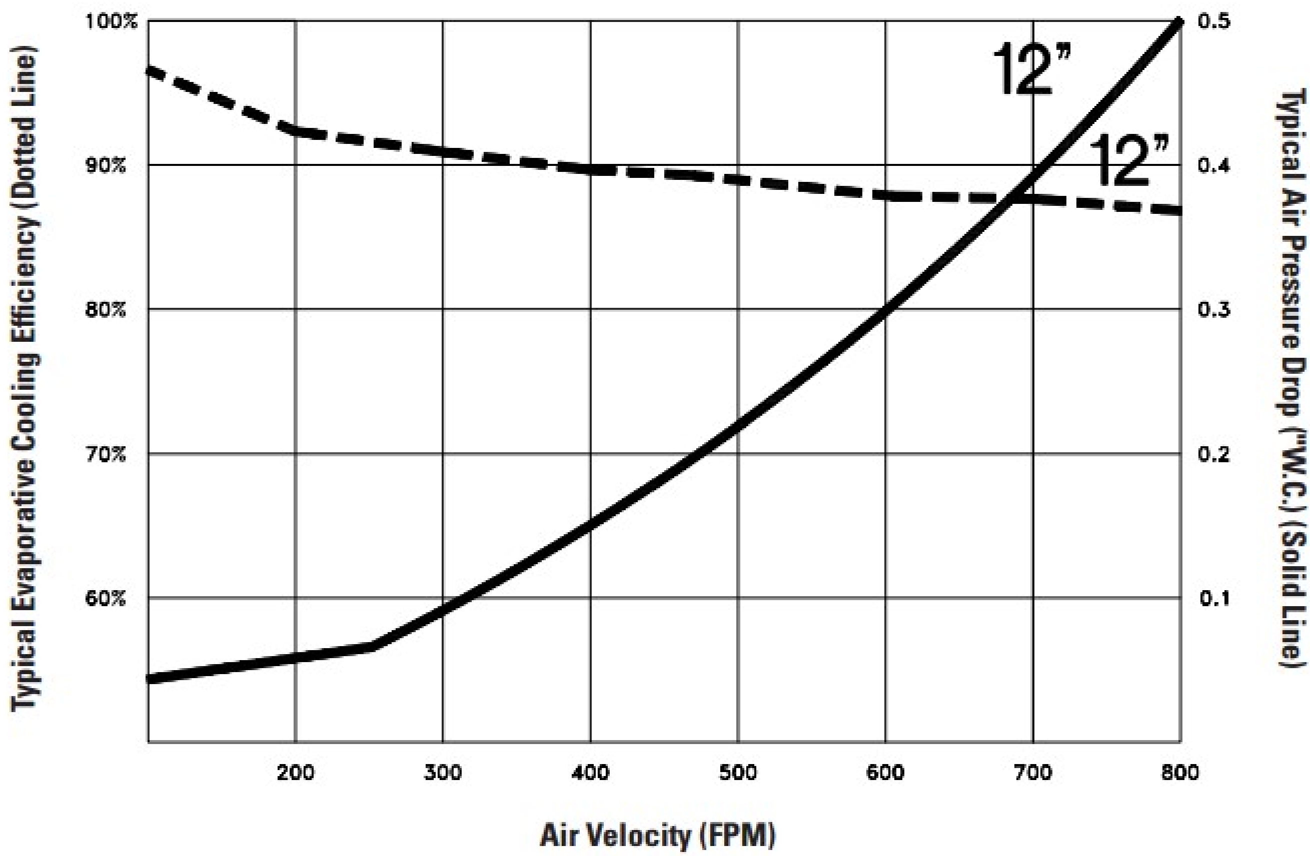


Figure 9: Variation of Saturation Effectiveness

2.4 Methods to increase Energy Efficiency

The potential for evaporative cooling depends on the difference in wet bulb and dry bulb temperatures of the air. Evaporative cooling is most effective in climates where average relative humidity is less than 30%. Anything that increases the rate of evaporation of a system will make evaporative cooling more effective. Some other methods include but are not limited to can be:

1. Lowering ambient humidity
2. Decreasing atmospheric pressure
3. Increasing ambient temperature (though this one is obviously counterproductive)
4. Increasing surface area of evaporation
5. Choosing different evaporative media
6. Adding air movement/wind

Green Grid says 'You can't control or manage what you don't measure'. For a long time a lot of people have realized that we don't need to operate our data centers at 65°F. The unbiased voice of ASHRAE is now confirming this fact. The only question remaining is what is the acceptable length of time to operate in the allowable range? In my opinion we'll have to wait for the next set of guidelines for that answer. But for now, we can start making some changes to the way we currently operate our data centers and not totally freak out if we find an 85°F hot spot. Maybe instead of asking ourselves how cold our data center should be, we should be asking just how warm it can be within allowable parameters. Energy star classifies 3 major category of improvement for datacenter efficiency. They are[10]:

1. **IT Opportunities**

Methods like better server utilization, decommissioning of Unused Servers, consolidation of Lightly Utilized Servers, better Management of Data Storage and by purchasing more Energy-Efficient Servers, UPSs, and PDUs, we can increase the IT efficiency of the system.

2. **Airflow Management Strategies**

By employing Hot Aisle/Cold Aisle Layout and enclosing or containing one Aisle has definitely proved in energy conservation. Variable Speed Fan Drives too have contributed their share. The fan law, or affinity law, states that the power used by an electric motor to rotate a pump or fan is proportional to the cube of its rotational speed. A good rule of thumb is that you can save 50% energy by reducing fan speeds by 20%. This is why it is so attractive to add variable speed capabilities to existing fans.

3. **HVAC Adjustments**

Increasing the server Inlet Temperature and Humidity Adjustments have been helpful but to a smaller extent. However utilizing Air-Side and water-side Economizer are gaining their importance gradually.

2.4.1 Prineville Data Center

Facebook's Prineville, Ore., data center is using water misting evaporative cooling at its LEED Gold data center. Reportedly, the data center did encounter a buildup of condensation that was fixed by modifying the center control system that adjusts for rapid temperature swings. Facebook has drawn its own groundwater since 2011, according to the Oregon Department of Water Resources. In 2014, the company used a combined 10.5 million gallons of water — 1.3 million gallons from the city and 9.2 million gallons from its wells.

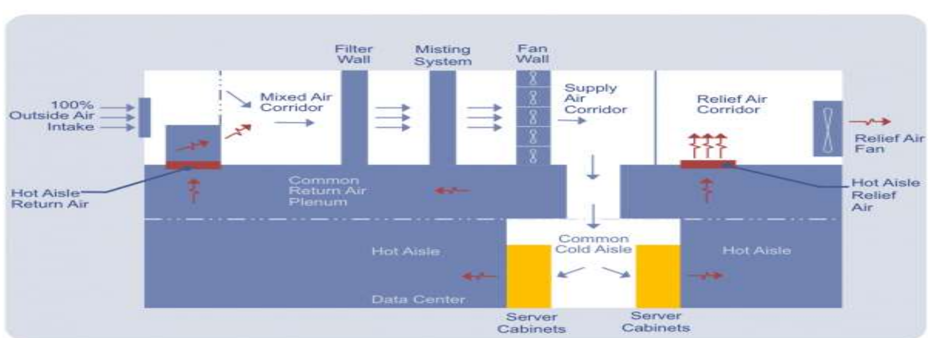


Figure 10: Facebook Prineville Datacenter operation

CHAPTER 3

Water Energy Nexus

These few quotes emphasize the overlooked importance of water use in Datacenters.

"Water is the new carbon" – The Independent

"Water is the new oil" – A Futurist

Water is the "big elephant in the room" – Joe Kava

Water is an excellent coolant because it is plentiful, non-toxic, and evaporates easily in most climates. Six gallons (22.7 L) of water evaporating has the same cooling effect as a typical (3.5 ton-hour) home central air-conditioner. But Over the past decade, energy use associated with data centers has nearly quadrupled and is currently estimated at nearly 100 billion kWh annually. In 2012, the Department of Energy (DOE) identified the Water-Energy Nexus as a key area of research and development that will be critical to the future of power production and national security [5]. It has been projected that the power costs for data center equipment over its useful life will exceed the cost of the original capital investment. By 2020, the carbon footprint of data centers is expected to exceed that of the airline industry. Less than half the power used by a typical data center powers its IT equipment. The balance of the energy used in these facilities is attributed to cooling, uninterruptable power supply (UPS) system losses, power distribution, and lighting.

3.1 Water consumption in datacenters

The demand for data center solutions with lower total cost of ownership and lower complexity of management is driving the creation of next generation datacenters. A 1MW data center operating with water-cooled chillers and cooling towers can consume 18,000 gallons per day to dissipate heat generated by IT equipment.

3.1.1 Metric

The Green Grid defines the new metrics as:

WUE – A site-based metric that is an assessment of the water used on-site for operation of the data center. This includes water used for humidification and water evaporated on-site for energy production or cooling of the data center and its support systems. ƒ

WUE $_{source}$ – A source-based metric that includes water used on-site and water used off-site in the production of the energy used on-site. Typically this adds the water used at the power-generation source to the water used on-site

Thermoelectric power plants account for 45 percent of total water withdrawals in the US, including freshwater sources like lakes and rivers, and saline sources, such as oceans and estuaries, hence to find the correct value of water consumed we cannot ignore the water consumed by power generation plants.

$$WUE = \frac{\text{Annual Site Water Usage}}{\text{IT Equipment Energy}}$$

$$WUE_{source} = \frac{\text{Annual Source Energy Water Usage} + \text{Annual Site Water Usage}}{\text{IT Equipment Energy}}$$

3.1.2 Reporting and Issues

There is significant apathy about water conservation across the data center industry as a whole. Uptime Institute survey data shows that less than one third of data center operators track water usage or use the Green Grid's Water Usage Effectiveness metric. And according to Uptime Institute's 2015 Data Center Industry Survey, in a question asking data center operators about the most important metrics, water usage ranked near the bottom of priorities. The only thing data center managers said they care about less than water is carbon dioxide emissions. On June 24, 2015, The Wall Street Journal published an article focusing on data center water usage, “Data Centers and Hidden Water Use.” With the industry still dealing with environmental scrutiny over carbon emissions and water scarcity poised to be the next major resource to be publicly examined. IT organizations need to have a better understanding of how data centers consume water, the design choices that can limit water use, and the IT industry’s ability to address this issue.

3.2 Water scarcity concerns

In recent years, the coupled nature of energy production and water consumption has become a focal point for legislation and national research priorities [3]. As drought conditions continue to spread across the country and energy demand continues to rise, water availability and access rights are coming to the forefront of societal concerns.

Although water covers approximately 70 percent of the Earth's surface, but less than 1 percent of that is available for human use. Across the globe, water consumption has tripled in the last 50 years. Around **700 million** people in 43 countries suffer today from water scarcity. By 2025, **1.8 billion** people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions. In addition, water scarcity in some arid and semi-arid places will displace between 24 million and 700 million people. **Sub-Saharan Africa** has the largest number of water-stressed countries of any region [9].

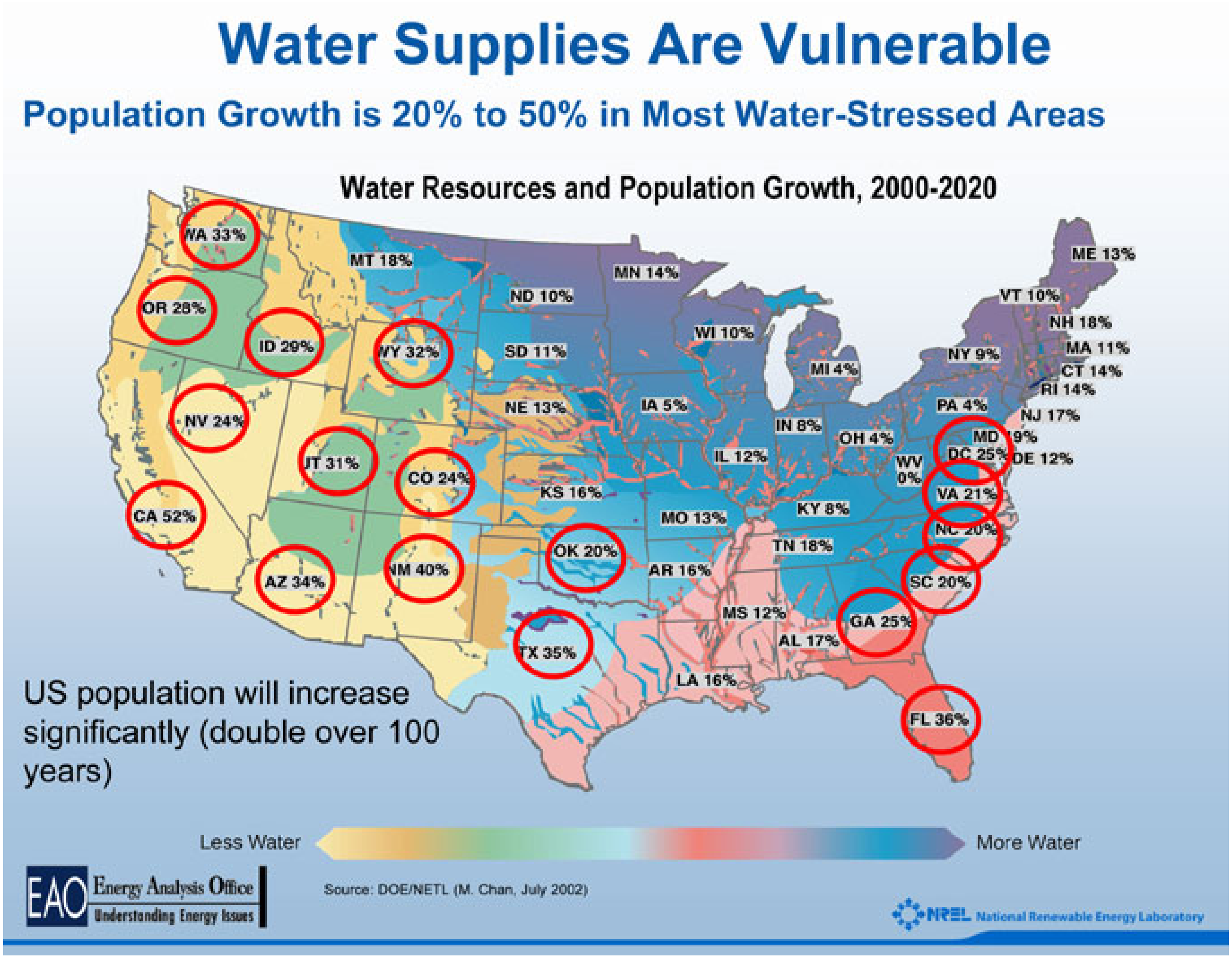


Figure 11: Water stressed area in US

3.2.1 Stress Indicators

Hydrologists typically assess scarcity by looking at the population-water equation. An area is experiencing water stress when annual water supplies drop below 1,700 m3 per person. When annual water supplies drop below 1,000 m3 per person, the population faces water scarcity, and below 500 cubic meters "absolute scarcity".

3.3 Water saving potential

There are many ways for data centers, big and small, to reduce their water use, from raising the temperature and reducing humidity inside the centers to sitting them in areas with optimum climate to using recycled water for cooling. All choices to reduce water use will impact energy use and carbon emissions, and vice-versa, in sometimes positive or negative ways. But remember that as more and more Americans rely on the internet to send emails, watch movies and pay bills – or in the NSA's case, keep an eye on all those digital transactions – we place even more strain on energy and water resources. It's just one more example of how the nexus of water and energy systems plays a direct role in our lives. Google has implemented three different approaches in its data centers: treating water from a nearby industrial canal, retreating water from a municipal wastewater facility, and retaining rainwater collected on its property. Google installed evaporative cooling for its large Douglas County, Ga., computing center in 2007. Initially, the center used potable water from the local utility. However, earlier this year, Google revealed its system would use 100 percent recycled water to cool the facility. Water filtration systems might be necessary to avoid contaminants in the airstream. And finally, drought is an ever-present threat that can quickly increase the cost of free cooling, should water supplies be limited. This is a real concern in the very same dry climates where free cooling is most effective. Large operators have also introduced efforts to increase efficiency through "penthouse" facility designs that include large free cooling plenums, cleaning and reusing grey water, cooling entire facilities with seawater, or even going so far as to overhaul treatment plants. Grey water is considered environmentally friendly because it reduces demands for fresh water and doesn’t consume the energy required to purify it at waste water treatment sites. Some companies use a blow down reclamation system to recycle water from their cooling tower. Investing in new cooling towers can save conserve water and money, Namek said. “Invest in a water treatment and filtration system to take solids out of the blow down. You can use a managed magnetic pulse inside the cooling tower to dissolve solids and filter them out”.

CHAPTER 4

ECONOMIZERS

An “economizer” is **NOT** an object; it IS a **mode** of operation. The use of an economizer mode is completely dependent on the geographic location of the data center. The seasonal conditions of the site will dictate if using an economizer mode is even practical

4.1 Modes and types

Economizer technologies include commercial direct air rooftop units, direct air plus evaporative systems, indirect evaporative cooling systems, water-side economizers, and direct air plus dry cooler systems. Select direct air systems also use evaporative cooling, but all of them combine of them combine direct air and multi-stage direct expansion (DX) or chilled water. Outside air units suitable for mission critical spaces require the capability of 100% air recirculation during certain air quality events (e.g., high pollution events and forest or brush fires) that will temporarily negate the efficiency gains of the units.

There are fundamentally two ways to increase economizer mode hours:

1) Move the data center to a colder climate, and

2) Increase the server inlet design temperature.

The first choice is obviously unrealistic for existing data centers. The second choice is realistic and is currently being implemented in new and existing data centers.

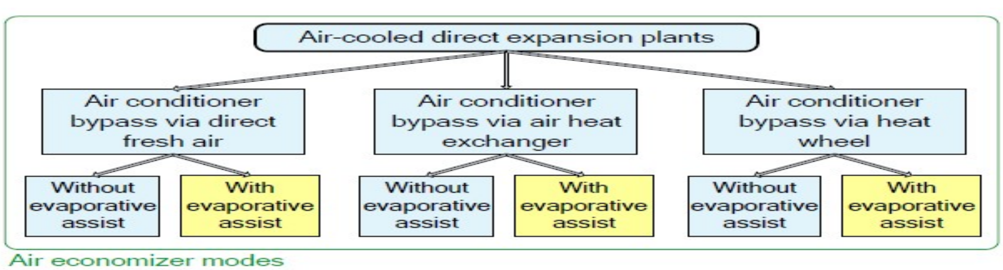


Figure 12: Air Economizer modes

They are basically of two types:

1. **Air side**
    - Direct
    - Indirect

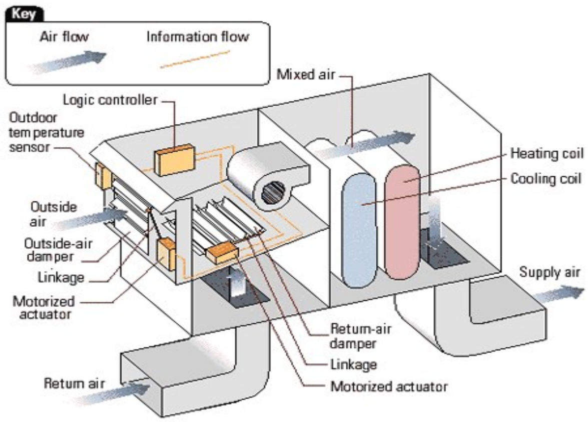


Figure 13: Air side Economizer

2. **Water side**

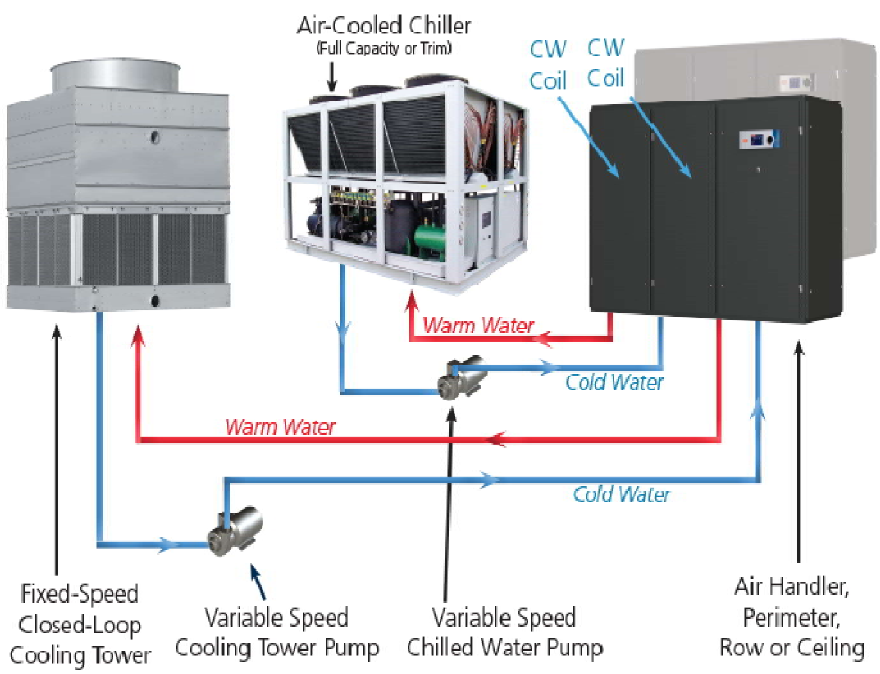


Figure 14: Water side Economizer

Figure 15: Capital cost comparison between direct and indirect air economizer systems for San Francisco, California, USA

4.2 Advantages and Limitations

There is reluctance from many data center owners to use this common cooling technique, however, due to fear of introducing pollutants and potential loss of humidity control. Concerns about equipment failure from airborne pollutants lead to specifying as little outside air as permissible for human occupants. The average particle concentrations were measured at each of the eight data center locations and the study results are summarized below [7]:

Measurements show low particle concentrations at all data centers without economizers, regardless of outdoor particle concentrations. The particle concentration in the data centers, however, quickly dropped back to pre-economizer levels when the vents closed. Since economizers only allow outside air part of the time, the annual average concentrations still met the ASHRAE standards. However, concentration were still above the levels measured in data centers that do not use economizers. Current filtration in data centers is minimal (ASHRAE 40%) since most air is typically recycled. When using economizers, modest improvements in filtration (ASHRAE 85%) can reduce particle concentrations to nearly match the level found in data centers that do not use economizers.

Results show that, while slightly less steady, humidity in data centers with economizers can also be controlled within the ASHRAE recommended levels. However, this control of humidity reduces energy savings by limiting the hours the economizer vents are open.

The potential energy savings from economizer use has been measured in one data center. When economizers were active, mechanical cooling power dropped by approximately 30%. Annual savings at this center is estimated within the range of 60-80 MWh/year, representing approximately a 5% savings off the mechanical energy load of the data center. Incoming temperatures and humidity at this data center were conservative relative to the ASHRAE acceptable temperature and humidity ranges. Greater savings may be available if higher temperature humidity levels in the data center area were permitted.

4.3 Survey by Green Grid

The Green Grid (TGG) sought to gain a clearer picture of the attitudes toward, and use of economizers within data centers. To do so, it launched an online survey in January 2011. TGG's goal was to better understand what compels economizer use in data centers, the implementation and operational challenges associated with economizers, their effects on data centers' overall operating costs, decision makers' reasons for not using them, and so on. According to the survey results, respondents adopted economizers chiefly to increase efficiency and save money; those considering economizer use gave the same two reasons for that consideration. Since implementation, respondents have saved an average 20% on energy costs and 7% on maintenance costs. With regard to economizer-related difficulties, the results seem to indicate that the greater challenge lies in learning about and implementing economizers rather than operating them. Certain obstacles to economizer adoption—such as climate unsuitability—cannot easily be addressed, but it may be possible to address others. In fact, reluctance to adopt economizers may be overcome if data center decision makers were to learn more about economizers' dependability, return on investment, and ease of operation from satisfied industry peers [11].

CHAPTER 5

RESULT AND CONCLUSIONS

To analyze the water saving by using only outside air Economizer (favorable conditions) compared to when the facility is assisted with Evaporative cooling mode for climatic conditions of California has been discussed. Since the outside temperature and humidity conditions are favorable for most part of the year and the water scarcity concerns are huge, so the choice of study for California stands valid. The water concerns are such that the waiters are advised not to serve complimentary water unless requested.

5.1 Evaluation

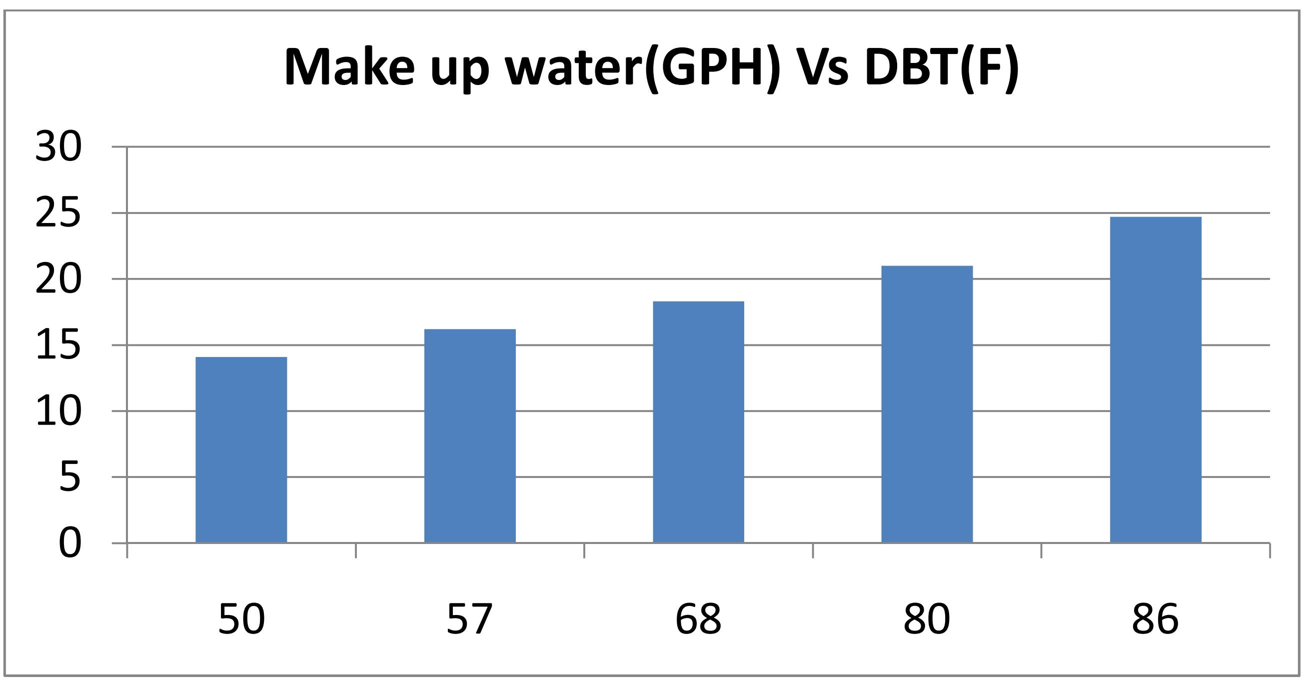
Assumptions: Since the variation in climatic conditions is considerable, the evaluation has been done considering a fixed condition on the facility.

1. Calculation of available hours based on a 68°F DB/50°F dew-point supply air.
2. The server fans are considered to be 100% efficient to utilize the measured data
3. Evaporative media effectiveness = 90%
4. The facility has a total IT capacity of ~25 kW
5. Drift loss = 0.008 %
6. Blow down cycles = 4
7. CFM = 6800

CFM	TDB	WBT	Effectiveness %	Gal/Hr Evaporated	Gal/Hr Bleed	Make-up total
6800	86	61	0.9	19.1	5.6	24.7
6800	80	61	0.9	15.4	5.6	21
6800	68	50	0.9	12.7	5.6	18.3
6800	57	50	0.9	10.6	5.6	16.2
6800	50	44	0.9	8.5	5.6	14.1

Table 2: Water consumption Calculation

5.3 Result



Graph 1: Result

Weather data for California

Dry bulb Temperature	Hours	Fraction at full	Fraction at Partial
<65F	7775	7680.3	174.84
<60F	6136	6061.05	137.98
<55F	3366	3324.88	75.69
<50F	1076	1062.85	24.19
<45F	346	341.77	7.78
<40F	56	55.89	1.25
<35F	0	0	0

Table 3: Total economizing hour calculation

ASHRAE, The National Renewal 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. This data is usually called “bin data” since the weather data is binned into temperature intervals. Using the weather data of a given location, the number of economizer mode hours can be calculated.

Available Hours of Full Economizer = 8653

Available Hours of Partial Economizer = 197

Total hours in a year = 8760

5.4

5.5 Conclusion and Future work

As the water consumption increases with increase in DBT and the outside DBT remains low for most part of the year in CA, It would be wise to run the facility in Economizer mode for most part of the year. If one focuses purely on reducing water use, technologies such as air-cooled chillers and heat wheels are easy choices that use no water in the cooling process. But if taking a more holistic view, you may pay a premium in the form of increased energy use with these systems. Cost of retrofitting the existing buildings for OSA should also be considered. Similar calculations can be done for water side Economizer if the Total cost of retrofitting is not justified and then results can be compared. Off-site cost of water consumption can be calculated for a particular facility to calculate WUE of the facility for a better analysis.

5.6 Intel Case study

Data center management is an interesting and evolving science. Several years ago, Intel IT conducted a Proof of Concept test by placing a data center in the Arizona desert. Around 900 heavily utilized production servers in a high-density data center utilizing 100% air exchange at up to 90 degrees F, with no humidity control and minimal air filtration estimated 67% power savings using economizer 91% of the time—an estimated annual savings of approximately USD 2.87 million in a 10-MW data center . Rather than turning the data center into a meat locker like is usually the case. It found no harm, no foul. Data centers can stand heat. They couldn't handle the dust, however [12].

Appendix

List of Equations used:

$\dot{m}_{evap} = \dot{m}_{air}\ (\omega_{a,e} - \omega_{a,i})$

LDB = EDB – (SE x (EDB – EWB))

GPH (E) = (0.9 X CFM X (EDBT - LDBT))/10,000

WBD = DBT - WBT

$$Make-up\ \ Volume = Evaporation\ \ Volume + Blowdown\ \ Volume$$

$$Cycles = \frac{Volume\ \ of\ \ Make-up\ \ Water}{Volume\ of\ \ Blowdown}$$

$$Cycles = \frac{Chloride\ Concentration\ in\ Blowdown}{Chloride\ Concentration\ in\ Make-up}$$

$$Blowdown\ \ Volume = \frac{Evaporation\ \ Volume}{(Cycles-1)}$$

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BIOGRAPHICAL INFORMATION

Ravi Mishra received his bachelor degree (B.E) in Mechanical Engineering from the RGTU Bhopal, India in 2008. After working for 4 years in Automotive and Education sector, he decided to pursue his higher studies in Mechanical Engineering. Hence after he began his M.S. (Master of Science) Program in Mechanical Engineering at The University of Texas at Arlington, Arlington, Texas in August 2014 and earned his Degree in December 2016. Ravi’s research is focused on HVAC design and facility cooling solutions. He is an environmentalist and yearns on finding solutions for a sustainable environment.