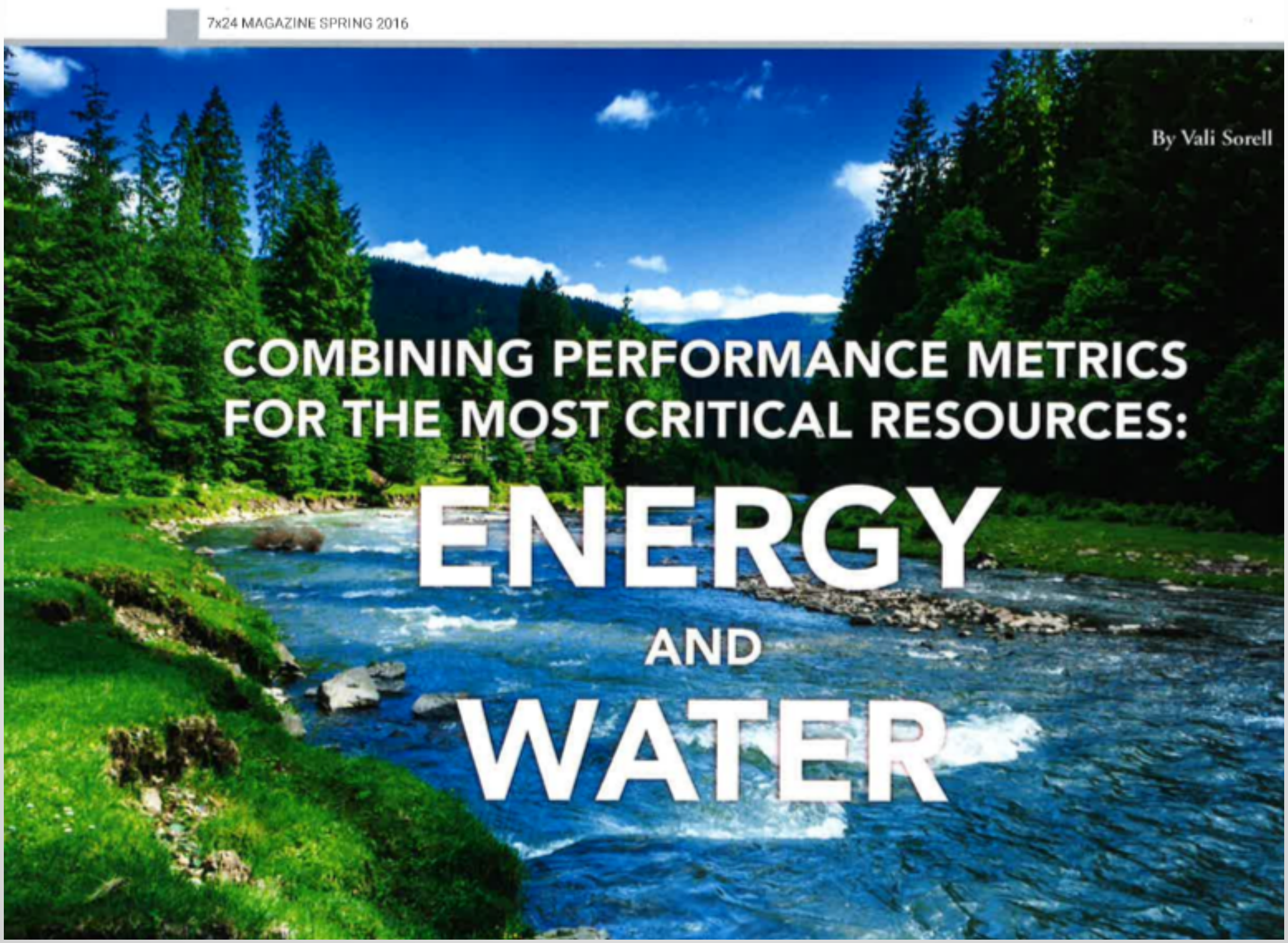

…or "What is the True Value of Water Consumption in Your Data Center?"

7x24 Exchange Rocky Mountain Chapter

September 29, 2017

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Agenda

- Consider the impact of cooling a data center with little or no water consumption
  - Water consumption is a complex issue
    - save water at site, but use more energy to cool
    - "Kick the can down the road"
- Data Centers in Perspective - How much water do data centers use?
- Where is the water consumed
- Energy and water usage of various types of systems
- Qualitative impacts of each type of system
- Case studies: two water-challenged cities
- Conclusions

Water is a scarce resource

- Contrary to popular belief, water is not exactly a renewable resource…
  - It is not under our control
  - We cannot grow it whenever we want it
  - We cannot transport it great distances without significant losses
  - Transporting it can reduce the amount available to other users
- There is a finite amount of fresh water for use to the population
- One of society's biggest challenges is to create an equilibrium between the amount of water used vs. the amount of water replenished by climatic forces
- Not finding this balance creates stress on the environment, agriculture, business, and every day life

Why is water used as the primary heat rejection medium?

- 1 British Thermal Unit (BTU) = the amount of heat that must be added to 1 lb of water to raise it 1 deg F
- SENSIBLE heat transfer
  - Raises the temperature of water
  - 1 lb of water (0.12 gallons) raised 10 deg F ➔ removes **10** BTU of heat
  - 10 deg of temperature change is typical for many circulating water systems
- LATENT heat transfer
  - Evaporates water, does NOT raise the temperature
  - 1 lb of water (0.12 gallons) evaporated into air ➔ removes **970** BTU of heat (Latent Heat of Vaporization)

Why is water used as the primary heat rejection medium? (Cont'd)

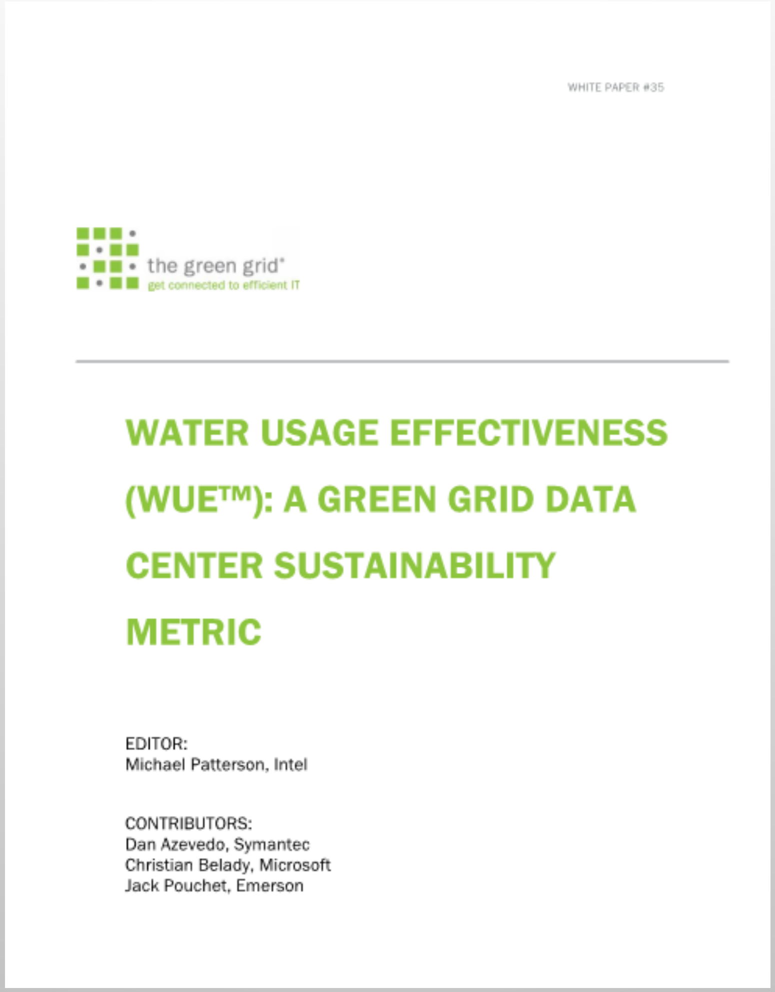
- Withdrawn water:
  - Sensible heating of water (i.e. raising the temperature)
  - Water taken from source; full amount is returned, albeit at higher temperature
  - Once-through system (groundwater, surface water, ocean, etc.)
- Consumed water:
  - Evaporative heating of water (i.e. all the water withdrawn is consumed, evaporated away)
  - Due to higher heat removed by evaporation, much less water is consumed than for withdrawn water case

Why is water used as the primary heat rejection medium? (Cont'd)

- Which is preferred:
  - Consumed water is preferred by the Clean Water Act because of its reduced impact on the environment
    - Less water withdrawn
    - No impact on the temperature of the source body

Water Use Metrics

- The Green Grid has attempted to make industry aware of water usage issues:



WHITE PAPER #35

the green grid®
get connected to efficient IT

WATER USAGE EFFECTIVENESS (WUE™): A GREEN GRID DATA CENTER SUSTAINABILITY METRIC

EDITOR:
Michael Patterson, Intel

CONTRIBUTORS:
Dan Azevedo, Symantec
Christian Belady, Microsoft
Jack Pouchet, Emerson

Water Use Metrics

- The Green Grid has attempted to make industry aware of water usage issues:
  - How many people actually understand the WUE (compared to PUE?)

Analogous to the direct (Scope 1) and indirect (Scope 2) definitions used to describe carbon emissions, TGG 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 (similar to carbon Scope 1).
- **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 (similar to carbon Scope 2).

$$WUE = \frac{\text{Annual Site Water Usage}}{\text{IT Equipment Energy}} \quad (2)$$

$$WUE_{source} = \frac{\text{Annual Source Energy Water Usage} + \text{Annual Site Water Usage}}{\text{IT Equipment Energy}} \quad (3)$$

Water Use Metrics

- To what extent have water use metrics been adopted by the industry?
  - ASHRAE Standard 90.4 - 2016
    - Most common comments from advisory review
      - "Why has a water use metric not been implemented?"
  - Energy modeling software
    - TRACE, eQUEST/DOE 2.2, EnergyPlus, Romonet
      - Poor or non-existent calculation of both site and source water usage
      - Even where water usage is calculated, the calculation of COST is poor to non-existent
  - USGBC's LEED Certification
    - Water usage
      - More points can be given for low-flush toilets in a data center than for eliminating consumptive water usage at the cooling towers!

How much water do we really use?

Description	Water use (gal / day)	Compared to NSA MD Data Center	Source
Average American per capita, incl. outdoor water use	98	--	USGS, 2005, http://goo.gl/v5y2Ad
US Household, including outdoor use	254	0.005%	American Water Works Association, http://goo.gl/Yl4qLs
Golf course in Southeastern U.S.	216,000	4.3%	USGA, http://goo.gl/JTd4NU
Quarter Section (160 acres) alfalfa in CA	650,000	13%	Hanson, B., UC Davis, http://goo.gl/So36Xz
1 mile square of corn	2,500,000	50%	Hanson, B., UC Davis, http://goo.gl/So36Xz
NSA MD Data Center	**5,000,000**	**100%**	DCK, http://goo.gl/v98qbW
Beaufort County, SC (Hilton Head)	6,370,000	127%	USGS, http://goo.gl/I466E
Oil recovery using hydraulic fracking, per well	2 to 10M	0.4 to 2X	Forbes, http://goo.gl/T8KxWZ
City of Boulder, CO (pop. 98,903)	10.2M	2X	Boulder Economic Council, http://goo.gl/OC3Bm3
U.S. lawn irrigation	9B	1800X	US EPA, http://goo.gl/BO13Pb
Total U.S. daily water extraction	410B	82,000X	USGS 2005, http://goo.gl/yVEEZg

Yes, that's right. The NSA Maryland data center will draw one thousandth of one percent (0.001%) of the US water extraction per day, and less water than the golf courses in Beaufort County, SC.

SOURCE: http://www.datacenterdynamics.com/blogs/mark-Monroe/nsa-data-center-use-5m-gallons-day-lot

Which has the greater impact on TOTAL COST OF OWNERSHIP (TCO) – water or electricity?

- Considering energy (kWh) and water (in1000s of gallons) consumption alone does not tell the appropriate story.
- Cost of electricity is usually an order of magnitude GREATER than the cost of water, yet must still consider the impact of water.
- There are other factors to consider
  - Availability of the resource
    - Is there sufficient transmission capacity?
    - Are redundant substations available?
  - Reliability of the resource
    - How stable is the power to the site?
    - How often are there floods?
    - How often are there droughts and water use restrictions?
  - Cost of the resource
    - Non-interruptible vs. interruptible rate
    - Real time pricing
  - Environmental impacts
- These factors must play into the balance of factors. COST OF THESE IS NOT ALWAYS THE MOST IMPORTANT

For most projects, TCO is usually the most important BUSINESS driver

- Does the market adequately account for all other factors?
- Do regulatory issues (local, state, national) eventually work their way into the market forces and costs?
- For the uncertainty related to these issues, it is practically impossible to complete an analysis on a hypothetical case study using quantitative means. ("Your actual mileage may vary depending on …")
  - DO <u>NOT</u> USE TCO to predict actual future consumption
- Each project must be evaluated on a case-by-case basis
  - Include the capital costs, operating costs, maintenance costs, and develop a Total Cost of Ownership which include the "intangibles"
    - Consider the intangibles
      - availability and reliability of power and water
      - environmental impact to the local community
  - REGARDLESS OF THE TCO, ARE ANY OF THE INTANGIBLES "DEAL BREAKERS?"
    - ABSOLUTELY! e.g. If cost of energy is $0.03/kWh and substation trips 6 times a year, is that a good site for a data center?

With respect to MECHANICAL DESIGN, there are different types of water

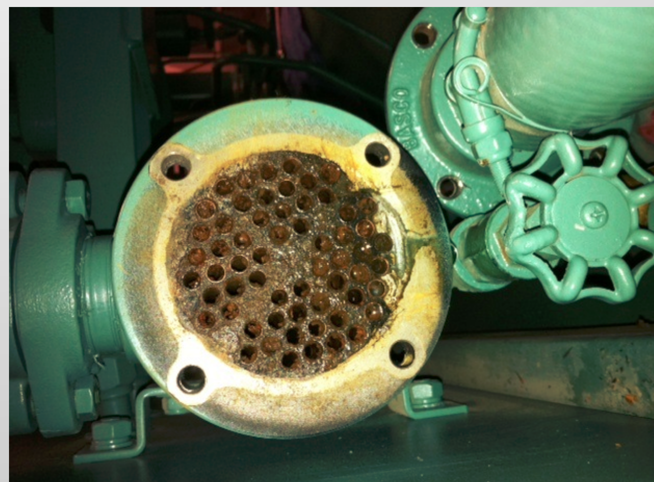
Each type of water requires a different analysis

1. Reclaimed water for make-up
2. Water for cooling of generated electricity at the source
   - <u>The embedded value of this water is rolled into the price of electricity</u>
3. Water for cooling on site
   - This corresponds to the water evaporated into air stream or at the cooling towers
   - <u>The value of this water is paid for by the owner to the water district</u>

With respect to MECHANICAL DESIGN, there are different types of water (cont'd)

1. Reclaimed water for make-up
   - Reclaimed water is delivered to the site by the local utility at greatly reduced price
   - This sounds like a GREAT deal*
     - Doesn't use "new" water, therefore zero source usage
     - Costs less than ground or surface water

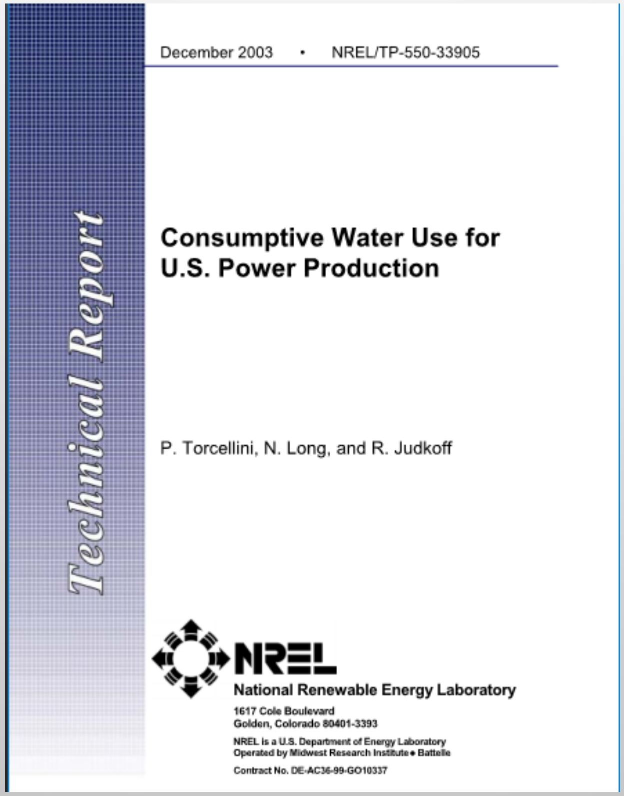
*…provided that the owner is prepared to pay for increased maintenance costs, early replacement of damaged cooling equipment, and losses related to increased risk to equipment and downtime for the data center



   - More applicable for irrigation than for cooling, especially in a critical facility
   - If site has access to reclaimed water for "other" uses, perhaps can use as backup for cooling make-up water

With respect to MECHANICAL DESIGN, there are different types of water (cont'd)

2. Water for cooling of generated electricity at source
   – Cost is embedded in the utility rate
   – Use more electricity --> use more water at the source


December 2003 • NREL/TP-550-33905

Technical Report

Consumptive Water Use for U.S. Power Production

P. Torcellini, N. Long, and R. Judkoff

NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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Contract No. DE-AC36-99-GO10337

With respect to MECHANICAL DESIGN, there are different types of water (cont'd)

Table 3. United States Water Consumption per kWh of Energy Consumed by State

State	Thermoelectric Site Power million kWh/Year	Hydroelectric[1] Site Power million kWh/Year	Thermoelectric Site Water Gallons/kWh	Hydroelectric Site Water Gallons/kWh	Weighted Total Site Water Gallons/kWh
Alabama	81,708	3,459	0.14	37.00	2.50
Alaska	3,611	0	0.31	N/A	0.27
Arizona	62,551	8,763	0.32	64.85	7.85
Arkansas	35,825	0	0.29	N/A	0.26
California	72,800	9,130	0.05	20.87	4.64
Colorado	29,312	1,176	0.51	17.91	1.20
Connecticut	26,342	0	0.08	N/A	0.07
Delaware	5,805	0	0.01	N/A	0.01
D.C.	181	0	1.61	N/A	1.61
Florida	142,726	0	0.14	N/A	0.14
Georgia	88,797	41	0.60	47.42	1.65
Hawaii	6,102	0	0.04	N/A	0.04
Idaho	0	6,093	0.00	8.51	7.85
Illinois	140,811	0	1.05	N/A	1.05
Indiana	100,579	0	0.41	N/A	0.41
Iowa	31,227	0	0.12	N/A	0.11
Kansas	36,496	0	0.58	N/A	0.58
Kentucky	67,627	892	1.10	154.34	5.32
Louisiana	51,918	0	1.56	N/A	1.47
Maine	4,406	0	0.29	N/A	0.12
Maryland	41,381	1,281	0.03	6.72	0.21
Massachusetts	32,568	0	0.00	N/A	0.00
Michigan	92,628	0	0.50	N/A	0.48
Minnesota	39,561	0	0.44	N/A	0.41
Mississippi	25,001	0	0.39	N/A	0.37
Missouri	60,922	0	0.31	N/A	0.30
Montana	8,401	8,172	0.96	36.77	16.74
Nebraska	22,798	346	0.19	2.18	0.30
Nevada	18,104	2,510	0.56	73.33	7.25
New Hampshire	13,411	0	0.12	N/A	0.10
New Jersey	22,606	0	0.07	N/A	0.07
New Mexico	27,875	94	0.63	68.00	1.13
New York	72,896	5,487	0.85	5.57	1.62
North Carolina	89,467	875	0.23	10.37	0.55
Virginia	48,757	0	0.07	N/A	0.06

With respect to MECHANICAL DESIGN, there are different types of water (cont'd)

3. Water for cooling on site
   - Ground source
     - Capital investment in equipment, wells, etc.
     - Regulatory issues (maybe)
     - Like for reclaimed water, use well water as a backup source only
   - Water from water district
     - Local district meters the usage
     - Charges by the gallon, cu. ft., "billing units," etc.

With respect to MECHANICAL DESIGN, there are different types of water (cont’d)

- For designing of a data center cooling system in dry climates, must balance competing costs:
  - reduced usage of water at site (e.g. air-cooled chillers)
    - INCREASES consumption of electricity
    - INCREASES consumption of water at source
  - Increased usage of water at site (e.g. water-cooled chillers)
    - REDUCES consumption of electricity
    - REDUCES consumption of water at source

Spectrum of water consumption in data center mechanical design

- Water-cooled chiller plant
  - This is a good baseline for purpose of comparison because it exceeds "standard of care" in most parts of the country
  - Main points to consider for energy and water
    - Heat rejected by evaporation in cooling towers
    - Very efficient chiller plant
      - ~0.6-0.7 kW/ton of cooling
    - Water must be evaporated at all times
      - Rate proportional to 1.25 times the IT load
  - Main points to consider for capital cost
    - Water-cooled Chiller plant is expensive
    - Make-up water storage must be kept on site

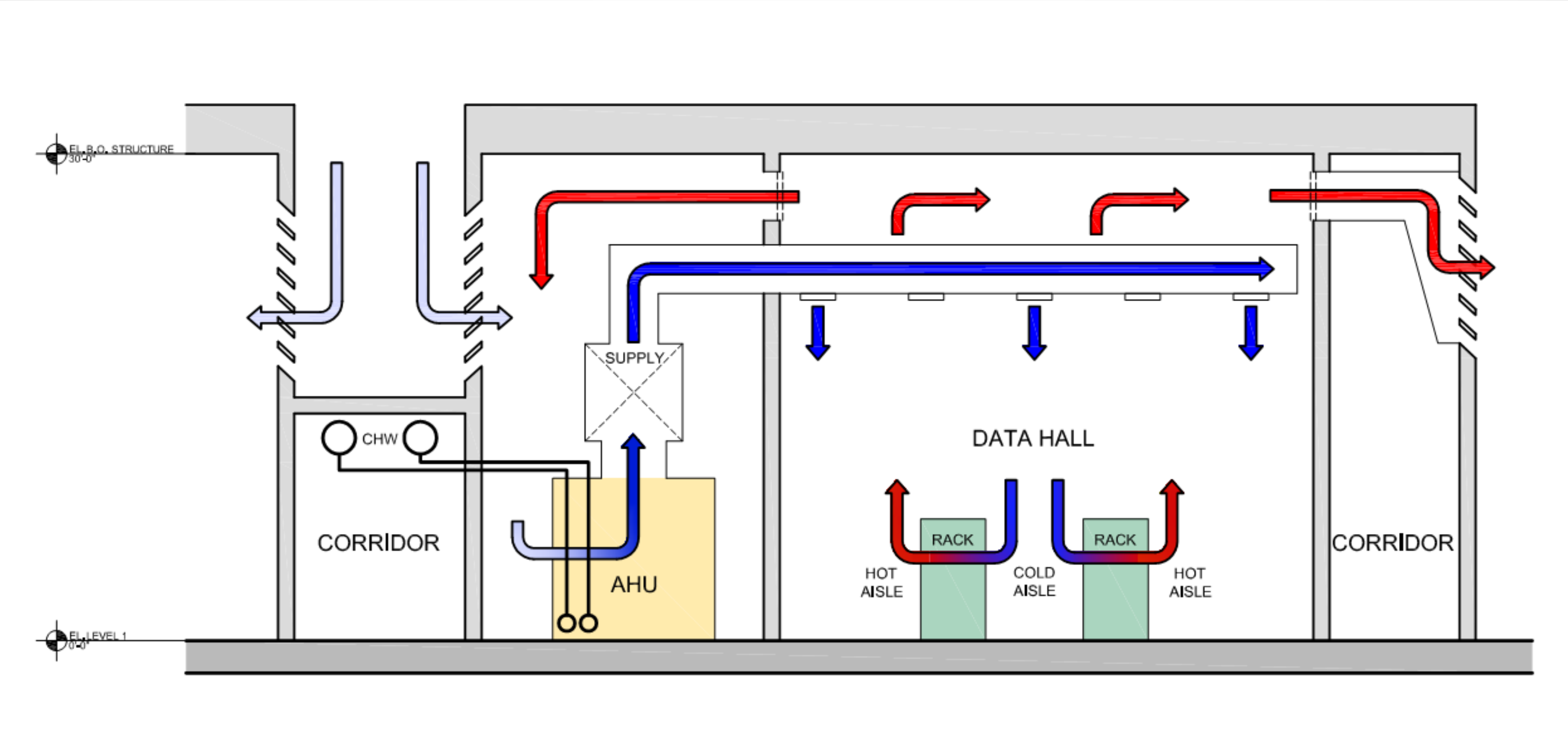
- Air-cooled chiller plant
  - This is a good baseline for purpose of comparison because it usually meets "standard of care" in most parts of the country
  - Main points to consider for energy and water
    - Heat rejected by dry coolers (outdoor condensers)
    - Relatively efficient chiller plant
      - ~1.0 kW/ton of cooling
    - No water is evaporated
  - Main points to consider for capital cost
    - Air-cooled Chiller plant is less expensive
    - No make-up water storage is required
    - Due to higher kW demand of air-cooled chillers, will require more generator capacity

Spectrum of water consumption in data center mechanical design (cont'd)

- Water-cooled chiller plant with waterside economizer
  - An improvement over the straight water-cooled chiller plant
  - Main points to consider for energy and water
    - Heat rejected by evaporation in cooling towers
    - Very efficient chiller plant (~0.6-0.7 kW/ton of cooling) when in mechanical cooling mode
    - Even more efficient (~0.2-0.3 kW/ton of cooling) when in free-cooling mode
    - Water must be evaporated at all hours
      - Rate proportional to 1.0→1.25 x kW of the IT load
    - Easily implements continuous cooling
  - Main points to consider for capital cost
    - Chiller plant is expensive
    - Heat exchanger for the economizer adds <5% to the cost of the facility
    - Make-up water storage must be kept on site

Spectrum of water consumption in data center mechanical design (cont'd)

- Let's correct a misconception – Does an evaporatively cooled air system use MORE water than a water-cooled chiller plant?
  - NO! (that applies even when a waterside economizer is used



Spectrum of water consumption in data center mechanical design (cont'd)

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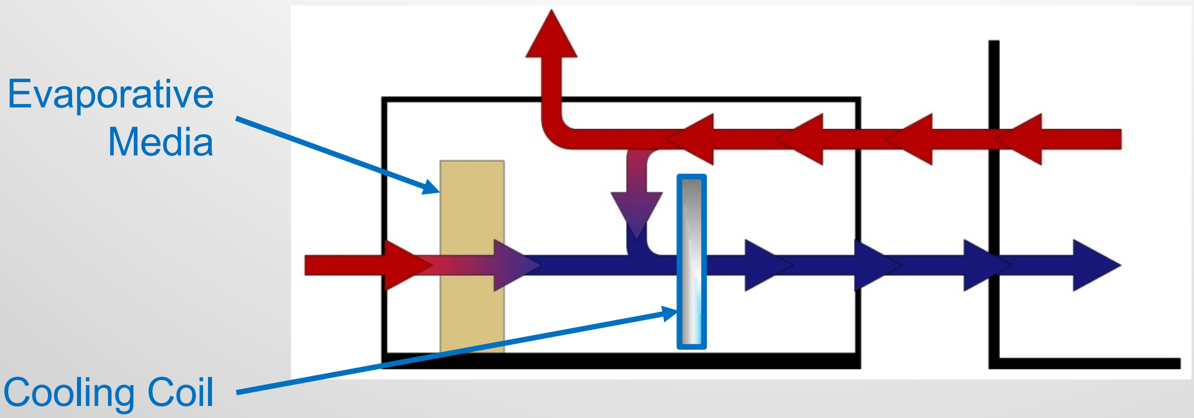


DIRECT EVAPORATIVE COOLING OPEN AIR LOOP

Location	1% Coincident		Direct LAT	
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
Albuquerque, NM	93	60	62.9	60
Denver, CO	90	59	61.8	59
El Paso, TX	98	64	67.0	64
Los Angeles, CA	81	64	65.5	64
Las Vegas, NV	106	66	69.6	66
Phoenix, AZ	108	70	73.4	70
Sacramento, CA	97	69	71.5	69
Salt Lake City, UT	94	62	64.8	62
San Jose, CA	89	66	68.0	66

Spectrum of water consumption in data center mechanical design (cont'd)

- Water-cooled chiller plant (with waterside economizer)
  - Main points to consider for energy and water
    - Energy consumption
      - ~0.6-0.7 kW/ton when mech cooling
      - ~0.20-0.25 kW/ton when in econo mode
    - Water consumption:
      - ~ 1.25 x kW of the IT load when mech cooling
      - ~1.00 x kW of the IT load when in econo mode

- Direct evaporative cooler (with air-cooled chiller plant)
  - Main points to consider for energy and water
    - Energy consumption
      - ~1.0 kW/ton when mech cooling
      - ~0.1 kW/ton when in econo mode
    - Water consumption
      - No water is consumed when in mech cooling
      - ~1.00 x kW of IT load when in econo mode

Spectrum of water consumption in data center mechanical design (cont'd)

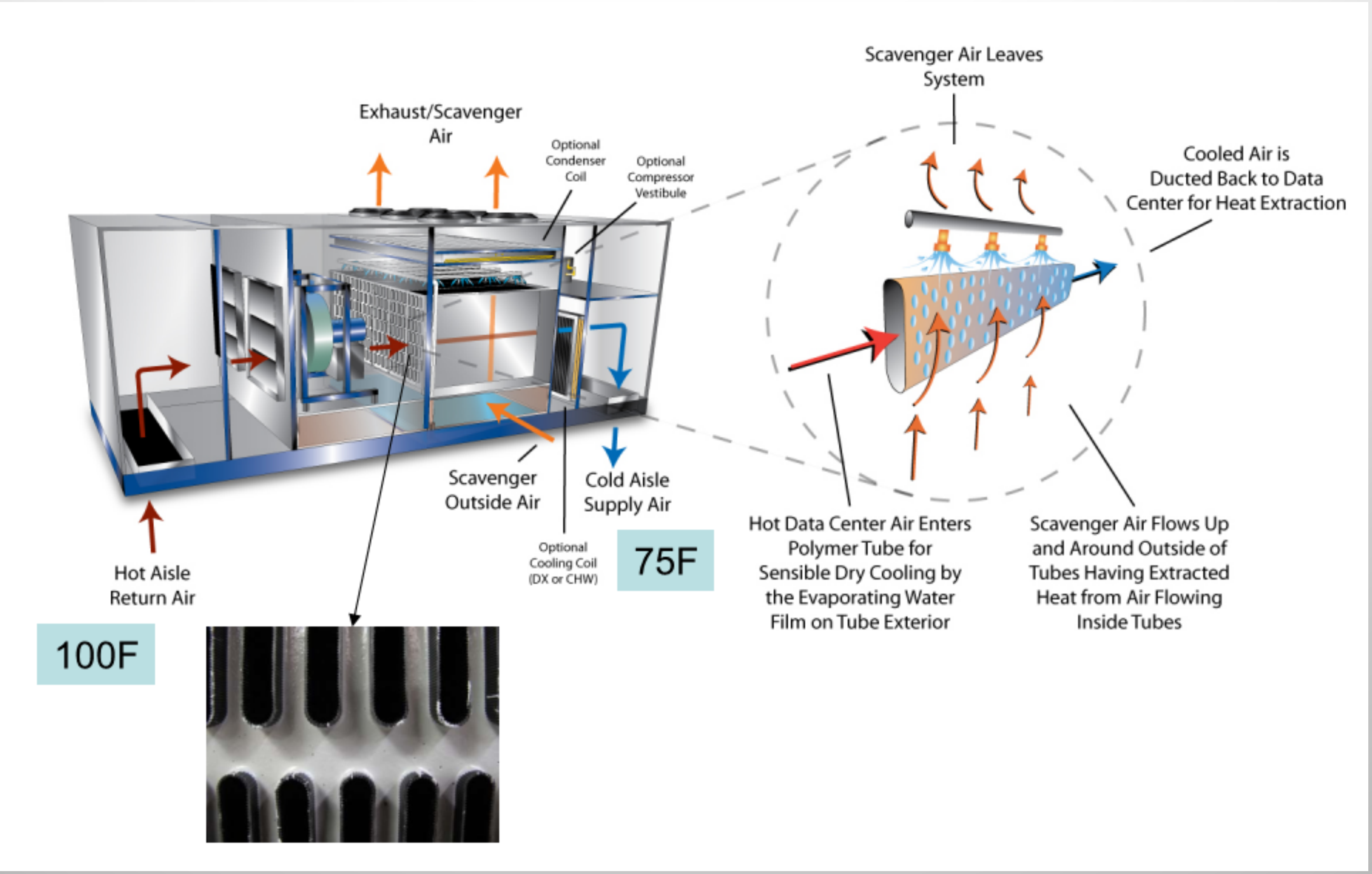
- Direct evaporative cooler with air-cooled chiller plant (airside economizer)
  - This can be an improvement over both previous options, depending on hours of available free cooling
  - Main points to consider for energy and water
    - Cooling provided partly by injecting moisture into incoming outside air
      - air-cooled chillers operate when evaporation is not advantageous
    - Less efficient chiller (~1.2 kW/ton of cooling) when in mechanical cooling
    - Extremely efficient (~0.1-0.2 kW/ton of cooling) when in free cooling mode
    - Water must be evaporated only when it is hot and dry outdoors
      - Rate proportional to <<1.0 x kW of the IT load
    - Easily implements continuous cooling

Spectrum of water consumption in data center mechanical design (cont'd)

- Direct evaporative cooler with air-cooled chiller plant (airside economizer) – [CONT'D]
  - Main points to consider for capital cost
    - Preferable to use large scale AHUs (more costly, but more efficient than CRAHs)
    - Must have large opening for intake and exhaust air
    - Data center footprint is greater than the other systems
    - Building is usually taller
    - Make-up water storage not required
    - Generators supporting the air-cooled chillers must have ~20-30% more capacity

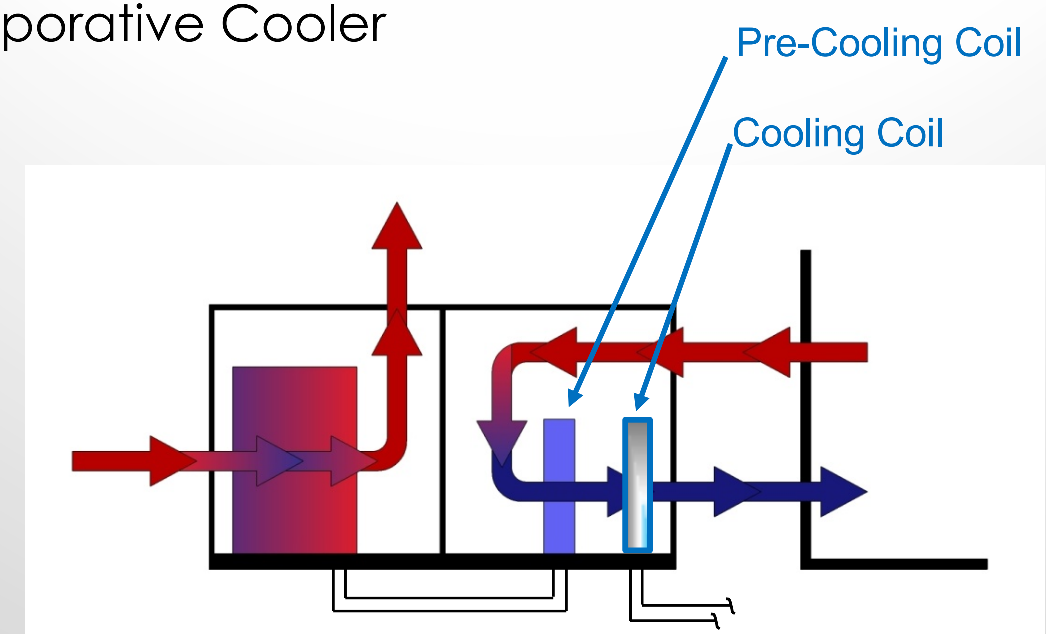
Spectrum of water consumption in data center mechanical design (cont'd)

- Indirect Evaporative Cooler



Spectrum of water consumption in data center mechanical design (cont'd)

- Indirect Evaporative Cooler



INDIRECT EVAPORATIVE COOLING CLOSED AIR LOOP

Location	1% Coincident		Indirect LAT	
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
Albuquerque, NM	93	60	69.6	50.9
Denver, CO	90	59	72.2	50
El Paso, TX	98	64	73.6	56.3
Los Angeles, CA	81	64	74.9	57
Las Vegas, NV	106	66	76.2	59.8
Phoenix, AZ	108	70	79.5	65.2
Sacramento, CA	97	69	78.4	63.9
Salt Lake City, UT	94	62	72	53.5
San Jose, CA	89	66	76.3	59.9

Spectrum of water consumption in data center mechanical design (cont'd)

- Indirect Evaporative Cooler
  - This is a very efficient system, especially in the dry climates
  - Main points to consider for energy and water
    - Heat rejection by cooling outside air by evaporation
    - Almost always pair air-cooled or DX system for mechanical cooling
      - This is because the economizer is ALWAYS available
      - DX system needs to be sized only for trim cooling
    - DX system is inefficient (~1.5kW/ton of cooling) when in mechanical cooling, but is is NOT sized for 100% of the load
    - Extremely efficient (~0.1-0.2kW/ton of cooling) when in free cooling mode
    - If continuous cooling is needed, DX cooling must be on UPS
    - Water must be evaporated only when it is hot and dry outdoors
      - Rate proportional to <<1.0 x kW of the IT load

Spectrum of water consumption in data center mechanical design (cont'd)

- Indirect Evaporative Cooler – [CONT'D]
  - Main points to consider for capital cost
    - Custom AHUs are very large
    - Custom AHUs are expensive
    - Building is usually taller
    - Make-up water storage is required for peak load operation of the indirect evaporative coolers, but not as much as for the other options
    - Generators supporting the mechanical load can be downsized significantly from the systems noted above

Spectrum of water consumption in data center mechanical design (cont'd)

- Air-cooled Chiller Plant
  - Not as efficient as the water-cooled options, but better than DX systems
  - Main points to consider for energy and water
    - Heat rejection via dry condenser coil
    - Moderately efficient chiller plant (~1.2 kW/ton of cooling at all times)
    - Free cooling is not usually implemented
    - NO WATER is evaporated
    - Uses more energy, therefore more water is consumed at source
    - Easily implements continuous cooling
  - Main points to consider for capital cost
    - Chiller plant is not as expensive as water-cooled plants
    - No water needs to be kept on site
    - Generators supporting the mechanical load must have ~20-30% more capacity

Spectrum of water consumption in data center mechanical design (cont'd)

- DX
  - Least efficient of the options
  - Main points to consider for energy and water
    - Heat rejection by dry cooler
    - Inefficient DX (~1.5+ kW/ton of cooling at all times)
    - Free cooling is not available
    - NO WATER is evaporated
    - Uses most energy, therefore most water is consumed at source
    - Does not easily provide continuous cooling
  - Main points to consider for capital cost
    - DX system is least expensive of the mechanical options
    - No water needs to be kept on site
    - Generators supporting the mechanical load must have ~50-100% more capacity
    - For continuous cooling, all DX must be on UPS

Spectrum of water consumption in data center mechanical design (cont'd)

- There are other systems
  - Indirect Evaporative Coolers
    - Very efficient – analogous to direct evaporative coolers but with less annualized energy and water consumption
  - Compressorized + pumped refrigerant systems
    - Efficient in economizer mode, uses not water
  - Pumped refrigerant to rear-door coolers
    - Water and energy efficiency is closest to waterside economizer system
  - In-row coolers
    - Analogous to either of the chiller plant options

- That's all that will be said about these systems for now.

How to Reconcile the Inter-related Issues of Water and Energy Consumption

- The Problem:
  - Which is preferred?
    - More energy consumption, less water consumption,   OR
    - Less energy consumption, more water consumption
  - Let's not forget that energy use at SITE can be equated to SOURCE Water Usage…

- The Solution:
  - The last thing the industry needs is a new metric…
  - But what the hell! A metric will help us resolve this problem.

- Call it…

How to Reconcile the Inter-related Issues of Water and Energy Consumption

- \$UE – "Dollar Usage Effectiveness"

$$\$UE = \frac{\sum \text{Site Annual Water Cost} + \sum \text{Annual Energy Cost}}{\sum \text{Annual IT Equipment Energy Cost}}$$

- Main points to consider:
  - Important to use cost because it is the ONLY way to evaluate the relative impact of water consumption vs. energy consumption. (Comparing kWh vs. gallons is meaningless.)
  - If local, state, or federal agencies want to incentivize conservation, either water or energy, the incentive is included in the cost AND in the metric.
  - Local, regional variations in utility costs (and mix of energy sources) is accounted for.

How to Reconcile the Inter-related Issues of Water and Energy Consumption

- $UE – "Dollar Usage Effectiveness"

$$\$UE = \frac{\sum \text{Site Annual Water Cost} + \sum \text{Annual Energy Cost}}{\sum \text{Annual IT Equipment Energy Cost}}$$

- More points to consider:
  - PUE is not site specific (but it is geographically dependent)
    - This has not stopped bleeding edge data center companies from using it to boast of how energy efficient their facility is ("My design is better than your design!")
  - WUE is not site specific either, and no one uses it to boast anything!

How to Reconcile the Inter-related Issues of Water and Energy Consumption

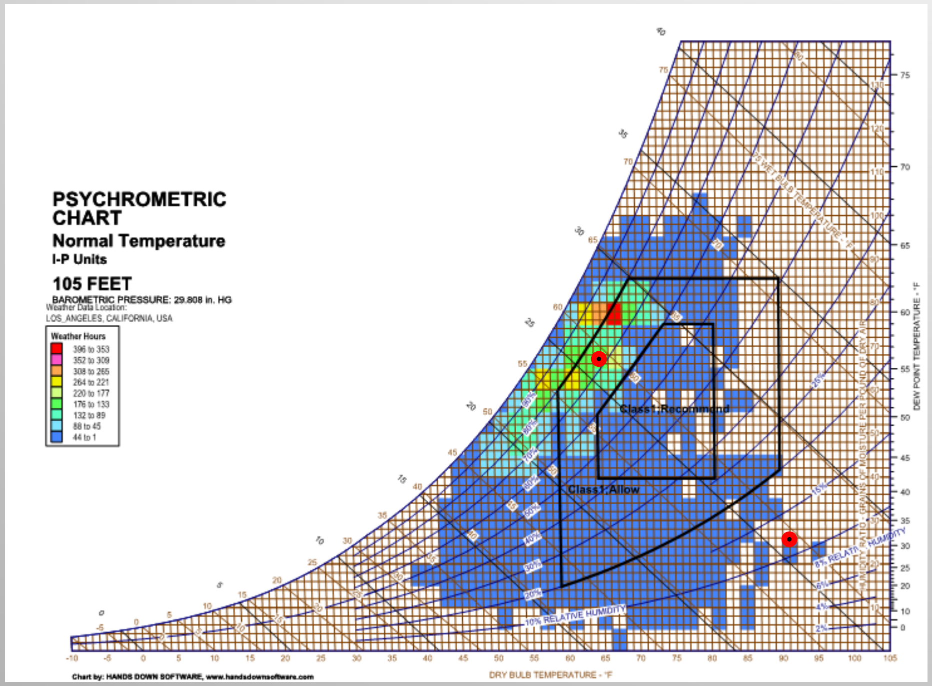
- $UE – "Dollar Usage Effectiveness"

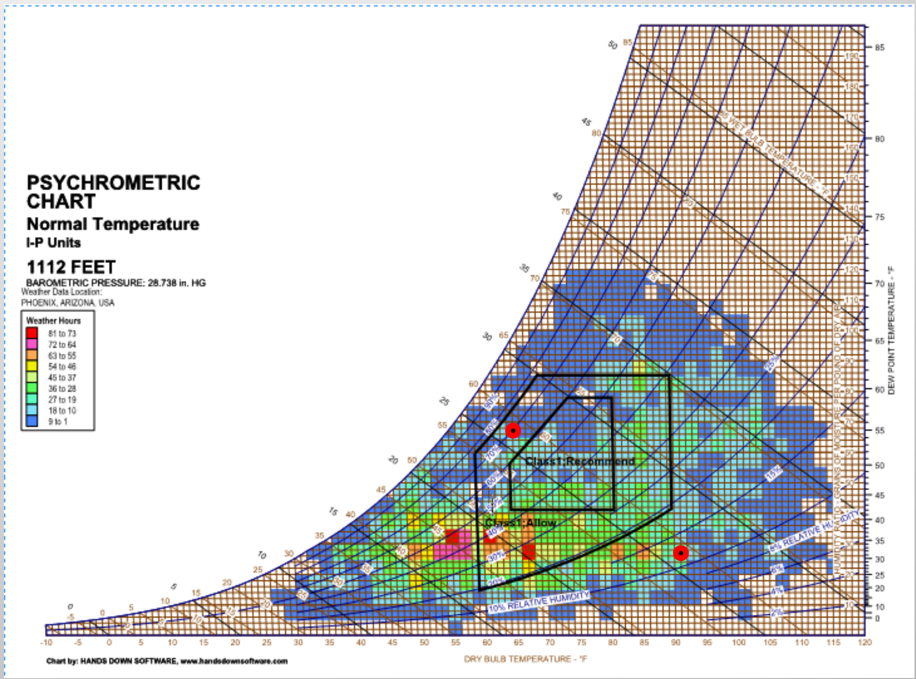
$$\$UE = \frac{\sum \text{Site Annual Water Cost} + \sum \text{Annual Energy Cost}}{\sum \text{Annual IT Equipment Energy Cost}}$$

- More points to consider:
  - $UE is site specific
    - CANNOT be used to compare to other sites and/or designs
    - Can say "My design is more mindful of the societal cost of all resources than yours!"
    - Can easily use $UE to track performance of a building over time knowing total utility $$$
    - Assumes market forces work
      - Nothing is free (TANSTAAFL), esp. water consumed at source
      - Taxes, incentives, rebates, etc. account for the value society places on the resources used
      - When the imposed values change, $UE changes, too!

Case Studies

- Assume a baseline 1 MW facility
- Consider two “water-challenged” cities
  - Phoenix
  - Los Angeles
- Look at energy, water use, PUE





Case Studies

- Phoenix

Phoenix - 1 MW Data Center							
	Hours of Free Cooling/Year	Annualized PUE	Peak PUE (For Generator Sizing)	Total kWh/Year	Gallons Water/Year (Site)	Gallons Water/Year (Source)	Total Gallons Water/Year (Source+Site)
Baseline (Water-Cooled Chiller)	-	1.60	1.60	14,016,000	4,641,951	110,025,600	114,667,551
Water-Cooled Chiller with Waterside Economizer	3,167	1.39	1.60	12,201,800	4,167,078	95,784,130	99,951,208
Direct Evaporative Cooler with Air-Cooled Chillers	4,647	1.39	2.00	12,215,150	1,096,911	95,888,928	96,985,839
Indirect Evaporative Cooler	6,479	1.25	1.40	10,950,000	4,000,000	61,032,180	65,032,180
Air-Cooled Chiller	-	1.90	1.90	16,644,000	-	130,655,400	130,655,400
Direct Expansion Coolers	-	2.10	2.10	18,396,000	-	144,408,600	144,408,600

Case Studies

- Phoenix
  - Assume ~$0.09/kWh; $0.009/gallon of site water

Phoenix - 1 MW Data Center	Hours of Free Cooling/Year	Annualized PUE	Peak PUE (For Generator Sizing)	Total kWh/Year	Gallons Water/Year (Site)	Gallons Water/Year (Source)	Total Gallons Water/Year (Source+Site)	Cost of Electricity/ Year ($)	Cost of Site Water/Year ($)	Cost of IT Energy ($)	$UE
Baseline (Water-Cooled Chiller)	-	1.60	1.60	14,016,000	4,641,951	110,025,600	114,667,551	1,261,440	41,778	788,400	1.65
Water-Cooled Chiller with Waterside Economizer	3,167	1.39	1.60	12,201,800	4,167,078	95,784,130	99,951,208	1,098,162	37,504	788,400	1.44
Direct Evaporative Cooler with Air-Cooled Chillers	4,647	1.39	2.00	12,215,150	1,096,911	95,888,928	96,985,839	1,099,364	9,872	788,400	1.41
Indirect Evaporative Cooler	6,479	1.25	1.40	10,950,000	4,000,000	61,032,180	65,032,180	985,500	36,000	788,400	1.30
Air-Cooled Chiller	-	1.90	1.90	16,644,000	-	130,655,400	130,655,400	1,497,960	-	788,400	1.90
Direct Expansion Coolers	-	2.10	2.10	18,396,000	-	144,408,600	144,408,600	1,655,640	-	788,400	2.10

Case Studies

- Los Angeles

Los Angeles - 1 MW Data Center	Hours of Free Cooling/Year	Annualized PUE	Peak PUE (For Generator Sizing)	Total kWh/Year	Gallons Water/Year (Site)	Gallons Water/Year (Source)	Total Gallons Water/Year (Source+Site)
Baseline (Water-Cooled Chiller)	-	1.60	1.60	14,016,000	4,641,951	65,034,240	69,676,191
Water-Cooled Chiller with Waterside Economizer	1,644	1.43	1.60	12,485,000	4,245,567	57,930,400	62,175,967
Direct Evaporative Cooler with Air-Cooled Chillers	6,502	1.36	2.00	11,933,800	342,819	55,372,832	55,715,651
Indirect Evaporative Cooler	8,672	1.20	1.40	10,406,400	4,000,000	48,285,696	52,285,696
Air-Cooled Chiller	-	1.90	1.90	16,644,000	-	77,228,160	77,228,160
Direct Expansion Coolers	-	2.10	2.10	18,396,000	-	85,357,440	85,357,440

Case Studies

- Los Angeles
  - Assume $0.14/kWh; $0.006/gallon of site water

Los Angeles - 1 MW Data Center	Hours of Free Cooling/Year	Annualized PUE	Peak PUE (For Generator Sizing)	Total kWh/Year	Gallons Water/Year (Site)	Gallons Water/Year (Source)	Total Gallons Water/Year (Source+Site)	Cost of Electricity/ Year ($)	Cost of Site Water/Year ($)	Cost of IT Energy ($)	$UE
Baseline (Water-Cooled Chiller)	-	1.60	1.60	14,016,000	4,641,951	65,034,240	69,676,191	1,962,240	27,852	1,226,400	1.62
Water-Cooled Chiller with Waterside Economizer	1,644	1.43	1.60	12,485,000	4,245,567	57,930,400	62,175,967	1,747,900	25,473	1,226,400	1.45
Direct Evaporative Cooler with Air-Cooled Chillers	6,502	1.36	2.00	11,933,800	342,819	55,372,832	55,715,651	1,670,732	2,057	1,226,400	1.36
Indirect Evaporative Cooler	8,672	1.20	1.40	10,406,400	4,000,000	48,285,696	52,285,696	1,456,896	24,000	1,226,400	1.21
Air-Cooled Chiller	-	1.90	1.90	16,644,000	-	77,228,160	77,228,160	2,330,160	-	1,226,400	1.90
Direct Expansion Coolers	-	2.10	2.10	18,396,000	-	85,357,440	85,357,440	2,575,440	-	1,226,400	2.10

Conclusions

- Water usage is a complex issue to understand and use in any decision making process
  - Water consumption and electrical consumption are closely related
  - Saving water at site may inadvertently INCREASE water usage at source
  - Source water usage varies by locality, geography, and climate
- Recommendations
  - Calculate TCO to include energy and water at site
  - Assume that cost of water from source is included in the energy cost (market and societal forces are at work)
  - Evaluate risk and other intangibles to inform the preliminary decision that was based on TCO
- Consider use of New Metric - $UE ("see-you-ee")
  - Can be used to select most appropriate system designs based on sustainability goals
  - Can be used to monitor performance of data center over time

Conclusions (Future Development?)

- Metric can be expanded to include normalized capital costs
  - $$\$UE_{mod} = \frac{\Sigma \text{ Site Annual Water Cost} + \Sigma \text{ Annual Energy Cost} + \Sigma \text{ Amortized Capital Costs} + \Sigma \text{ Annual Maintenance Cost}}{\Sigma \text{ Annual IT Equipment Energy Cost}}$$

- Coordinate with utilities, NREL, and other regulatory agencies to update the source water usage charts

Questions & Answers

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