DCDM1: Lessons Learned from the World's Most Energy Efficient Data Center

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Lessons Learned from the World's Most Energy Efficient Data Center

In this session we will discuss our holistic approach to design the world's most energy efficient data center, at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). This high-performance computing (HPC) data center has achieved a trailing twelve month average power usage effectiveness (PUE) of 1.04 and features a chiller-less design, component-level warm-water liquid cooling, and waste heat capture and re-use. We provide details of the demonstrated PUE and energy reuse effectiveness (ERE), and lessons learned during four years of production operation.

Recent efforts to dramatically reduce the water footprint will also be discussed. Johnson Controls partnered with NREL and Sandia National Laboratories to deploy a thermosyphon cooler (TSC) as a test bed at NREL's HPC data center that resulted in a 50% reduction in water usage during the first year of operation. The Thermosyphon Cooler Hybrid System (TCHS) integrates the control of a dry heat rejection device with an open cooling tower.

NREL's Dual Computing Mission

- Provide HPC and related systems expertise to advance NREL's mission, *and*
- Push the leading edge for data center sustainability.
- Demonstrate leadership in liquid cooling, waste heat capture, and re-use.
  - Holistic "chips to bricks" approaches to data center efficiency.
- Showcase data center at NREL's Energy Systems Integration Facility (ESIF).

Critical topics include:

- Liquid cooling and energy efficiency
- Water efficiency.

Planning for a New Data Center

- Started planning for new data center in 2006
- Based on HPC industry/technology trends, committed to direct liquid cooling
- **Holistic approach** - integrate racks into the data center, data center into the facility, the facility into the NREL campus
- Capture and use data center waste heat: office & lab space (now) and export to campus (future)
- Incorporate high power density racks - 60kW+ per rack
- Implement liquid cooling at the rack, no mechanical chillers
- Use chilled beam for office/lab space heating. Low grade waste heat use
- Considered two critical temperatures:
  - Information technology (IT) cooling supply – could produce 24°C (75°F) on hottest day of the year, ASHRAE "W2" class
  - IT return water – required 35°C (95°F) to heat the facility on the coldest day of the year

Build the World's Most Energy Efficient Data Center.

NREL Data Center

Showcase Facility

- ESIF 182,000 ft.^{2} research facility
- 10,000 ft.^{2} data center
- 10-MW at full buildout
- LEED Platinum Facility, **PUE ≤ 1.06**
- NO mechanical cooling (*eliminates expensive and inefficient chillers*).

Utilize the bytes and the BTUs!

Data Center Features

- Direct, component-level liquid cooling, 24°C (75°F) cooling water supply
- 35-40°C (95-104°F) return water (waste heat), captured and used to heat offices and lab space
- Pumps more efficient than fans
- High voltage 480-VAC power distribution directly to high power density 60-80-kW compute racks.

Compared to a typical data center:

Lower CapEx – costs less to build
Lower OpEx – efficiencies save

Integrated "chips to bricks" approach.

Cooling Efficiency

- Liquid conduits require 250-1000 times less space than air conduits for transporting the same quantity of heat energy.
- Liquids require 10-20 times less energy to transport energy.
- Liquid-to-liquid heat exchangers have closer approach temperatures than liquid-to-air (coils), yielding greater efficiency and increased economizer hours.
- ASHRAE TC9.9 liquid standards provide excellent guide.

Heat Transfer		Resultant Energy Requirements			
Rate	ΔT	Heat Transfer Medium	Fluid Flow Rate	Conduit Size	Theoretical Horsepower
10 Tons	12°F	Forced Air	9217 cfm	34" Ø	3.63 Hp
		Water	20 gpm	2" Ø	.25 Hp

Energy Efficient Data Centers

- Choices regarding power, packaging, cooling, and energy recovery in data centers **drive total cost of ownership**.

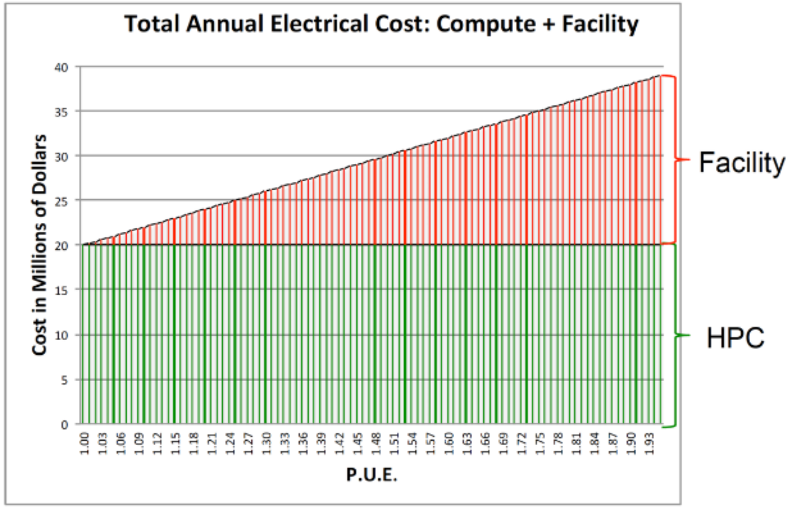
- Why should we care?
  - Water usage
  - Limited utility power
  - Mega$ per MW year
  - Cost: OpEx ~ IT CapEx!

- **Space Premium**: Ten 100-kW racks take much less space than the equivalent fifty 20-kW air cooled racks.

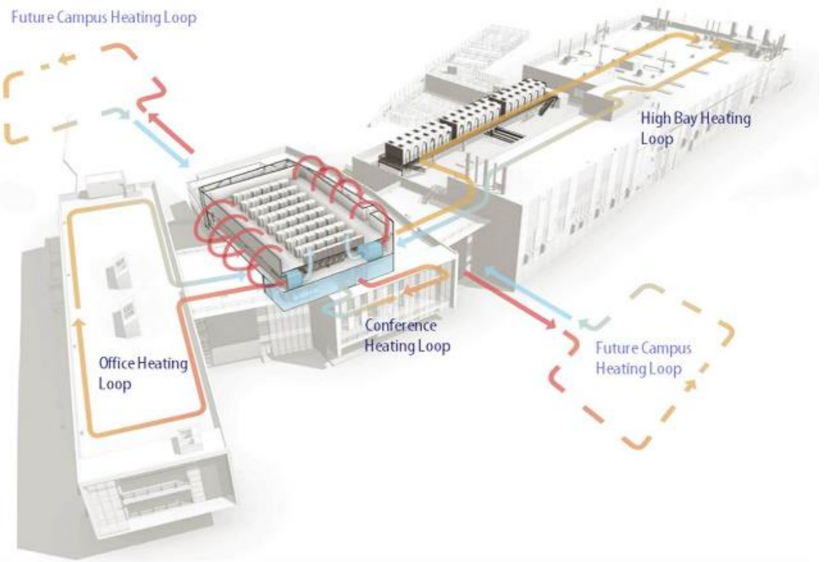
Metrics

$$PUE = \frac{\text{"Facility energy"} + \text{"IT energy"}}{\text{"IT energy"}}$$

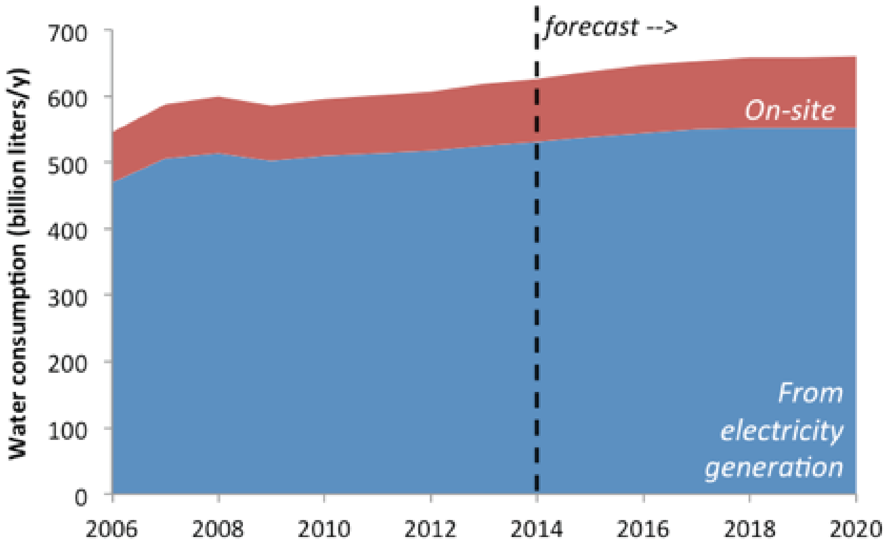
$$ERE = \frac{\text{"Facility energy"} + \text{"IT energy"} - \text{"Reuse energy"}}{\text{"IT energy"}}$$



Assume ~20MW HPC system & $1M per MW year utility cost.



Metrics



Source: Lawrence Berkeley National Laboratory

$$WUE = \frac{\text{“Annual Site Water Usage”}}{\text{“IT energy”}}$$

the units of WUE are liters/kWh

$$WUE_{SOURCE} = \frac{\text{“Annual Site Water Usage”} + \text{“Annual Source Energy Water Usage”}}{\text{“IT energy”}}$$

$$WUE_{SOURCE} = \frac{\text{“Annual Site Water Usage”}}{\text{“IT energy”}} + [EWIF \times PUE]$$

where EWIF is energy water intensity factor

HPC Applications

Renewable Fuels
Simulations of enzyme-plant cellulose interactions to reduce fuel costs

Advance Solar PV Materials
Computations drive search for new perovskite-like materials that are more stable and do not contain lead

Biomass Pyrolysis
Simulations guiding optimization of reactions and catalysts to reduce cost of fuel production

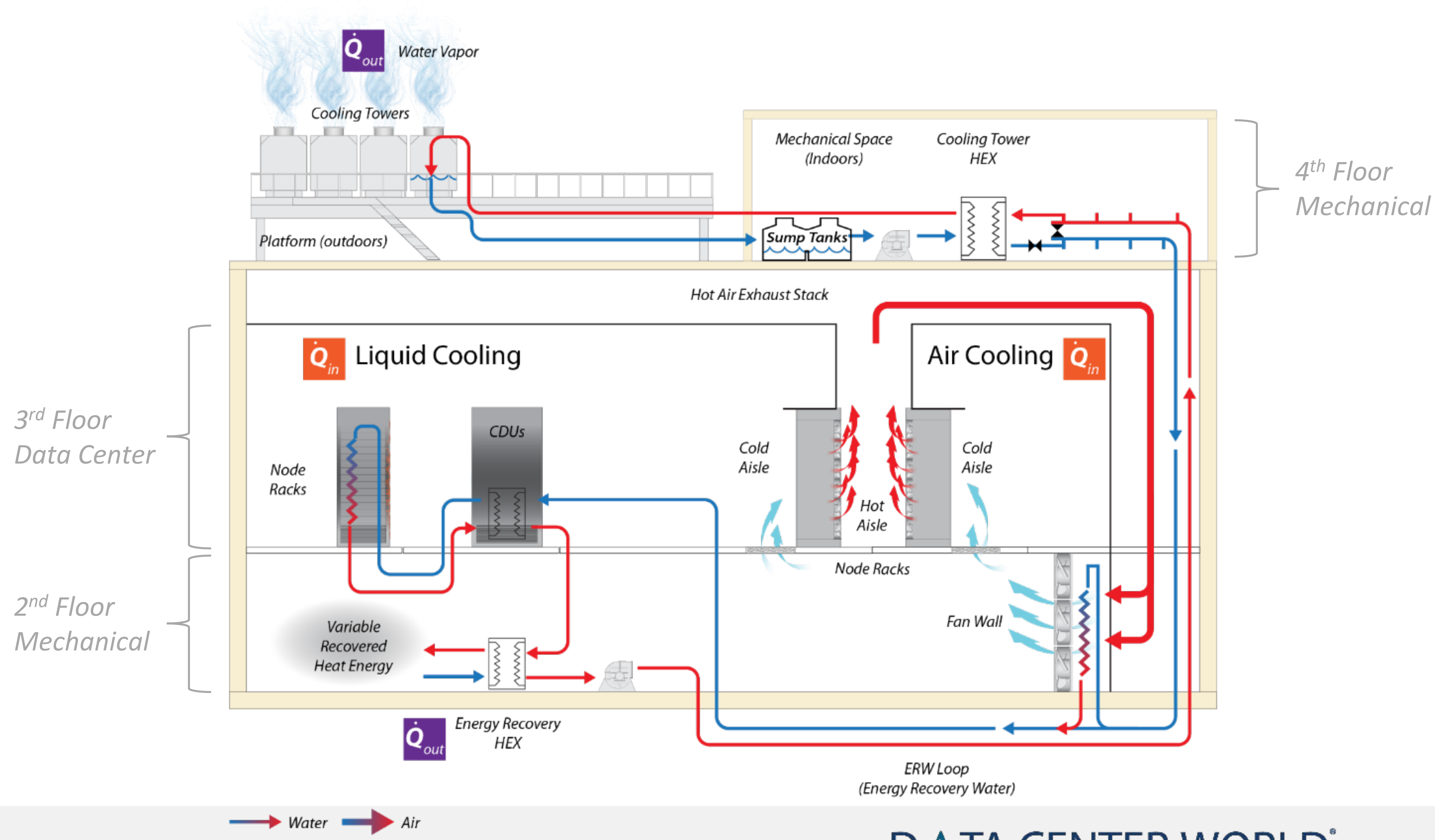
Wind Energy
Model wake fields and inflow conditions in wind plants with realistic terrain to reduce cost of electricity

Electric Vehicles
Multi-scale simulations of electric drive vehicle battery systems to create cutting-edge battery simulation tools to aid safe affordable designs

Energy System Integration
Modeling the Eastern Interconnect at native spatial scales under different renewable penetration scenarios

Materials by Design
Develop new techniques to predict material properties of novel alloys and design materials with prescribed physical properties

System Schematic: Original Configuration



Air-cooled to Liquid-cooled Racks

Traditional Air-cooled

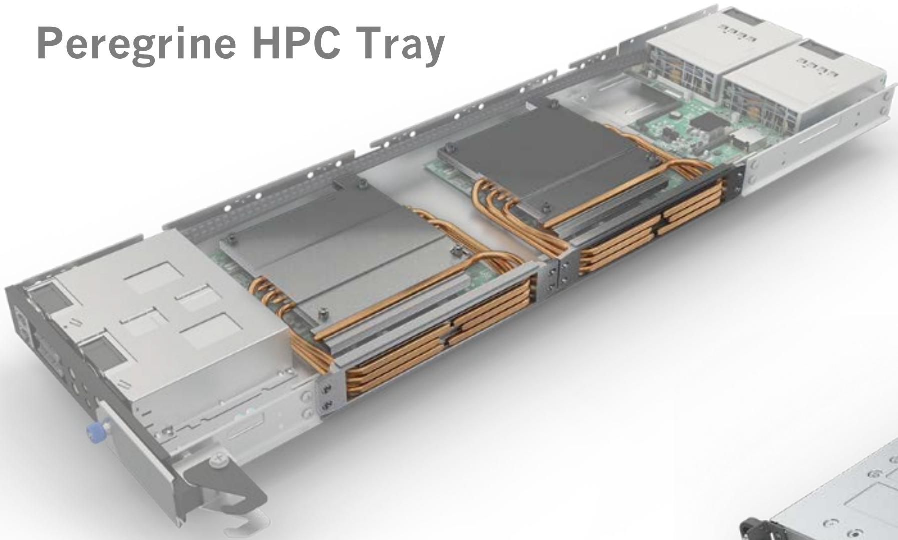
- Allow for rack power densities of 1kW – 5kW

Require Liquid-cooled when rack power densities in 5kW – 80kW range, have several options:

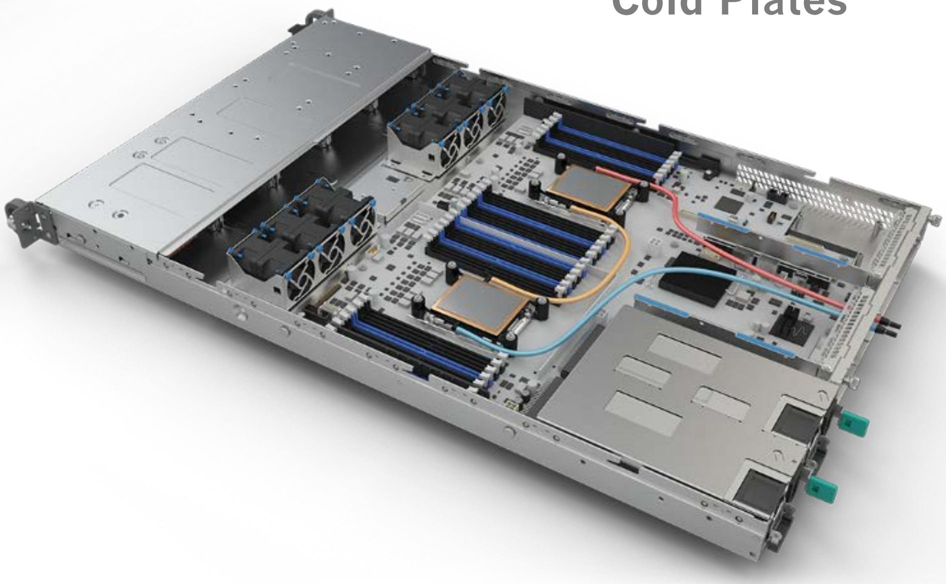
Chilled Door

Liquid Cooled Server Options

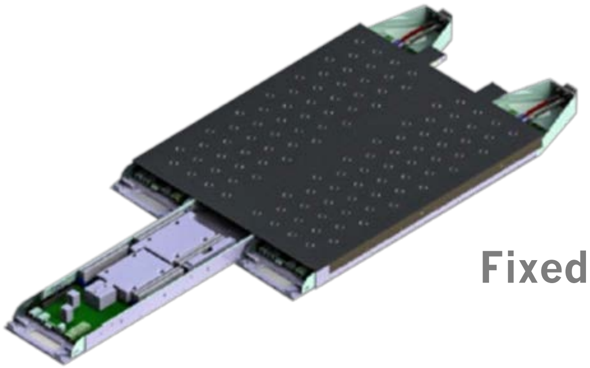
Peregrine HPC Tray



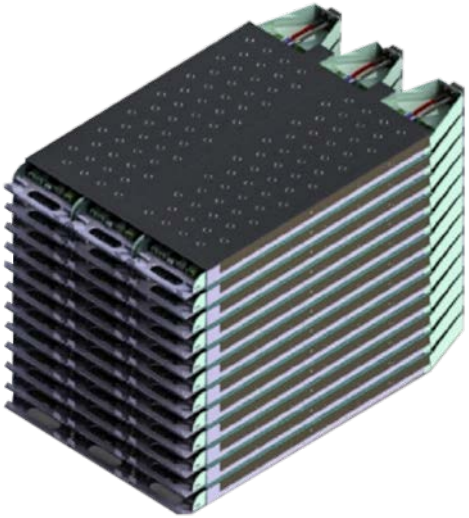
Cold Plates

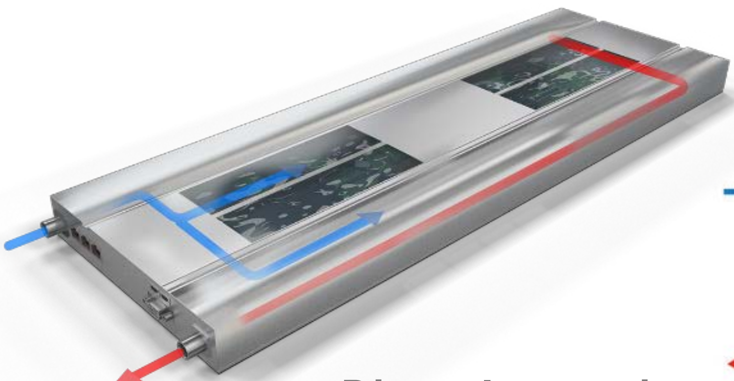


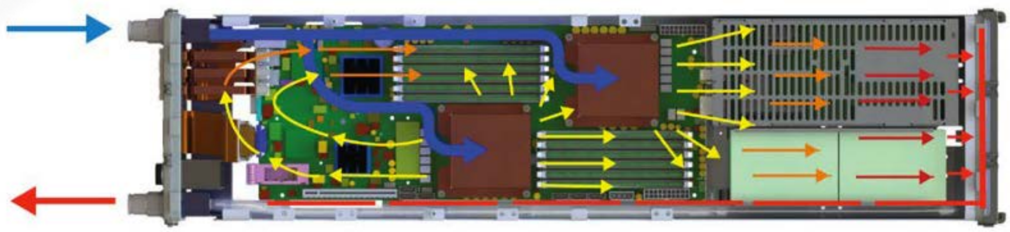
Fanless Liquid Cooled Server Options



Fixed Cold Plate

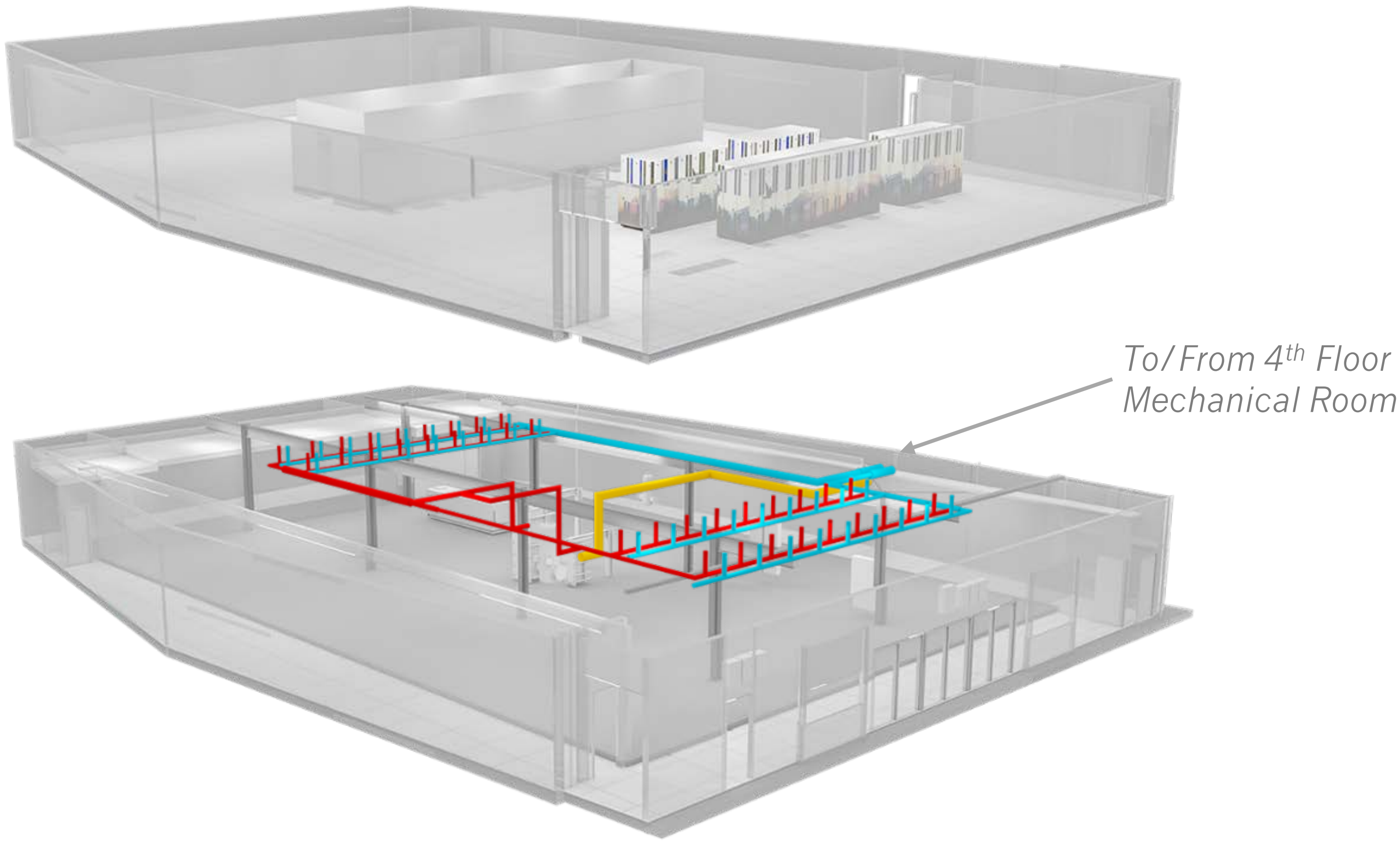






Direct Immersion

Data Center Water Distribution



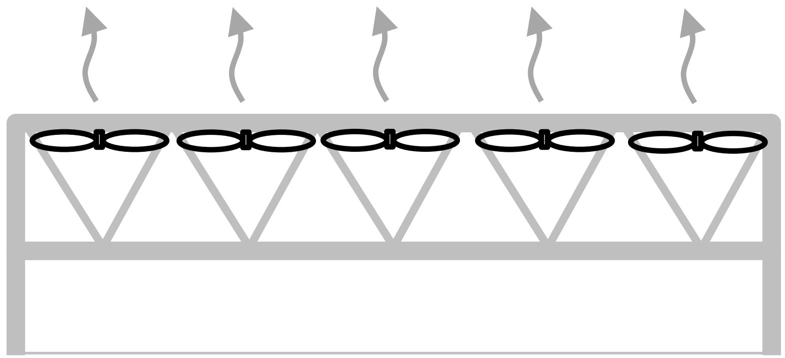
Liquid Cooling – Considerations

- Liquid cooling essential at high power density
- Compatible metals and water chemistry is crucial
- Cooling distribution units (CDUs)
  - Efficient heat exchangers to separate facility and server liquids
  - Flow control to manage heat return
  - System filtration (with bypass) to ensure quality
- Redundancy in hydronic system (pumps, heat exchangers)
- Plan for hierarchy of systems
  - Cooling in series rather than parallel
  - Most sensitive systems get coolest liquid
- At least 95% of rack heat load captured directly to liquid.

Air- and Water-Cooled System Options

Air-Cooled System

- Design day is based on **DRY BULB** temperature
- Consumes no water (no evaporative cooling)
- Large footprint/requires very large airflow rates.



Water-Cooled System

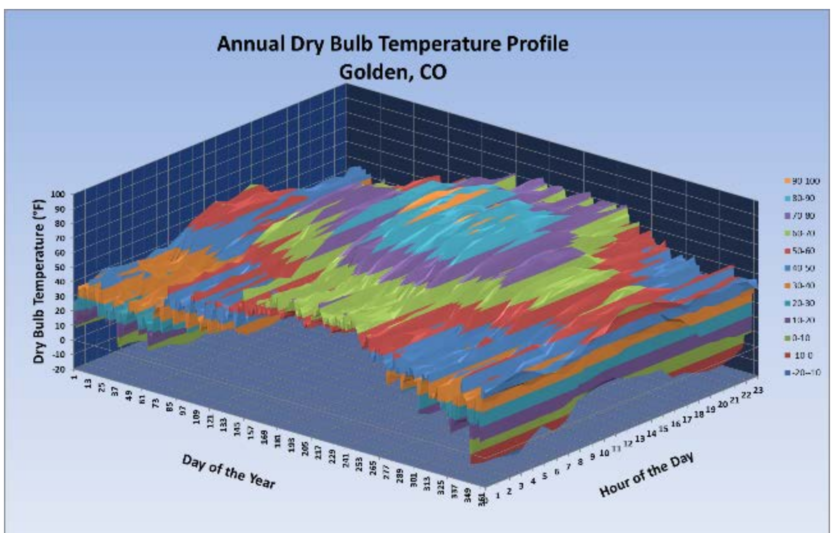
- Design day is based on the lower **WET BULB** temperature
- Evaporative cooling process uses water to improve cooling efficiency
  - **80% LESS AIRFLOW → lower fan energy**
  - Lower cost and smaller footprint.
- Colder heat rejection temperatures improve system efficiency.

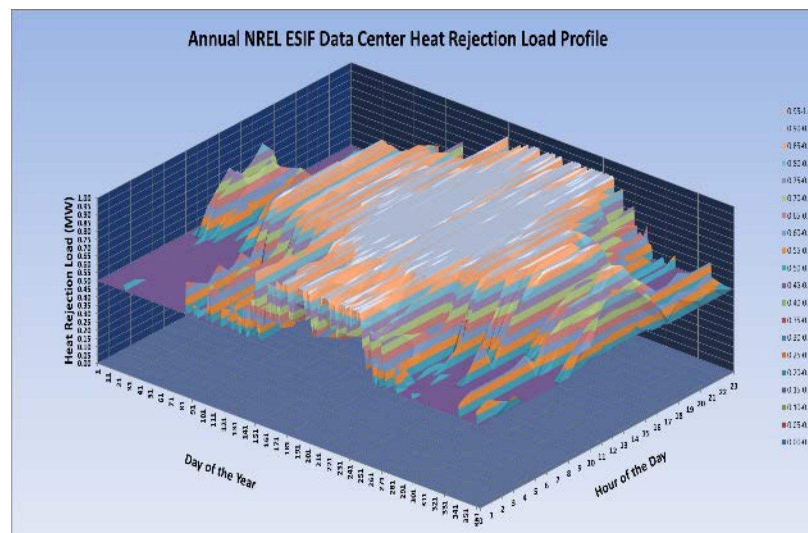
However, water-cooled systems depend on a reliable, continuous source of low-cost water.

Weather and Load Variations: Opportunities for Hybrid Wet/Dry Solutions

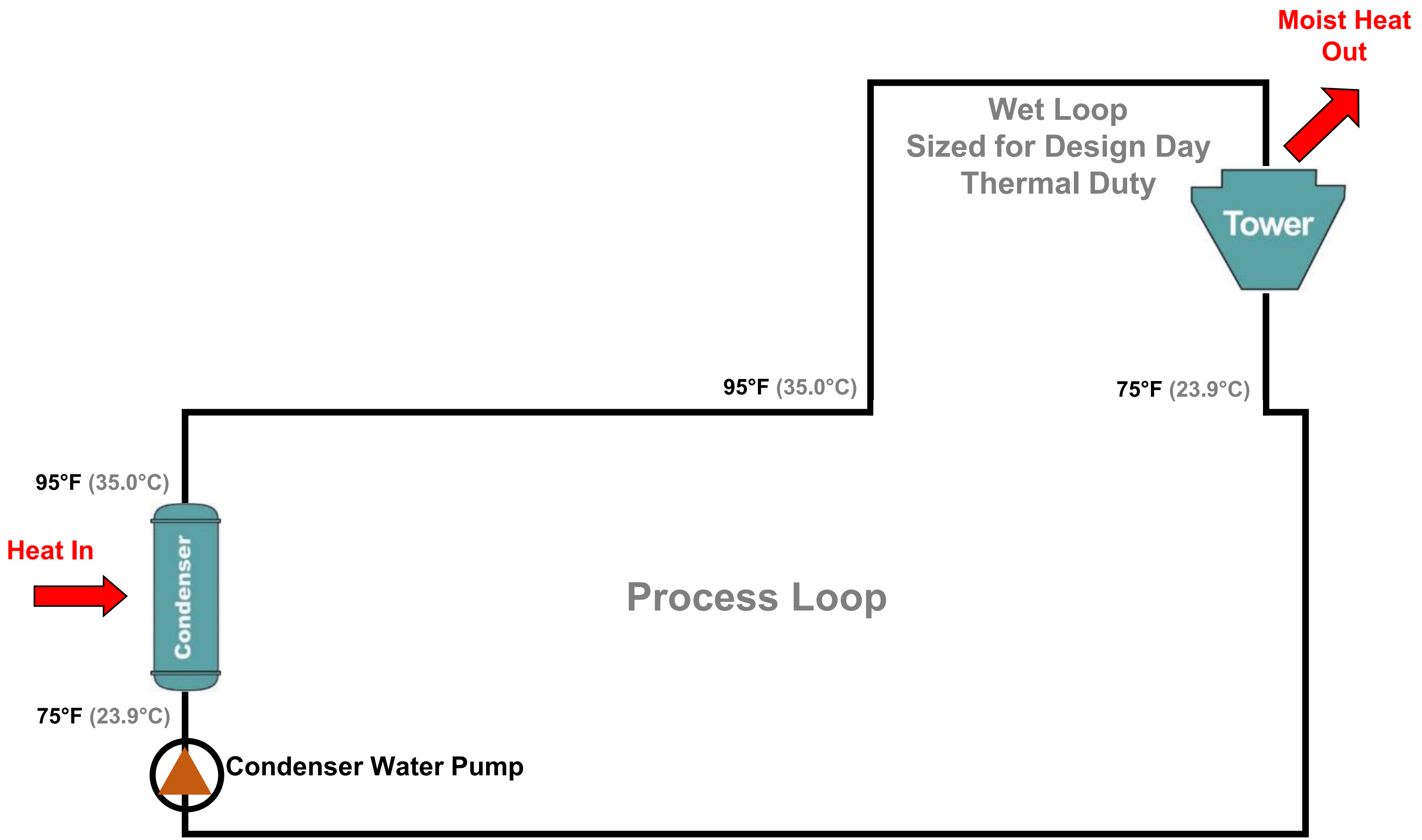
Basic principles:

- Operates **wet** during peak design periods to save energy (high temperatures and loads)
- Operates **dry** during low design periods to save water (lower temperatures and loads)
- Depending on the design, system might operate either as **wet** or **dry** or might be able to operate both **wet** and **dry**.

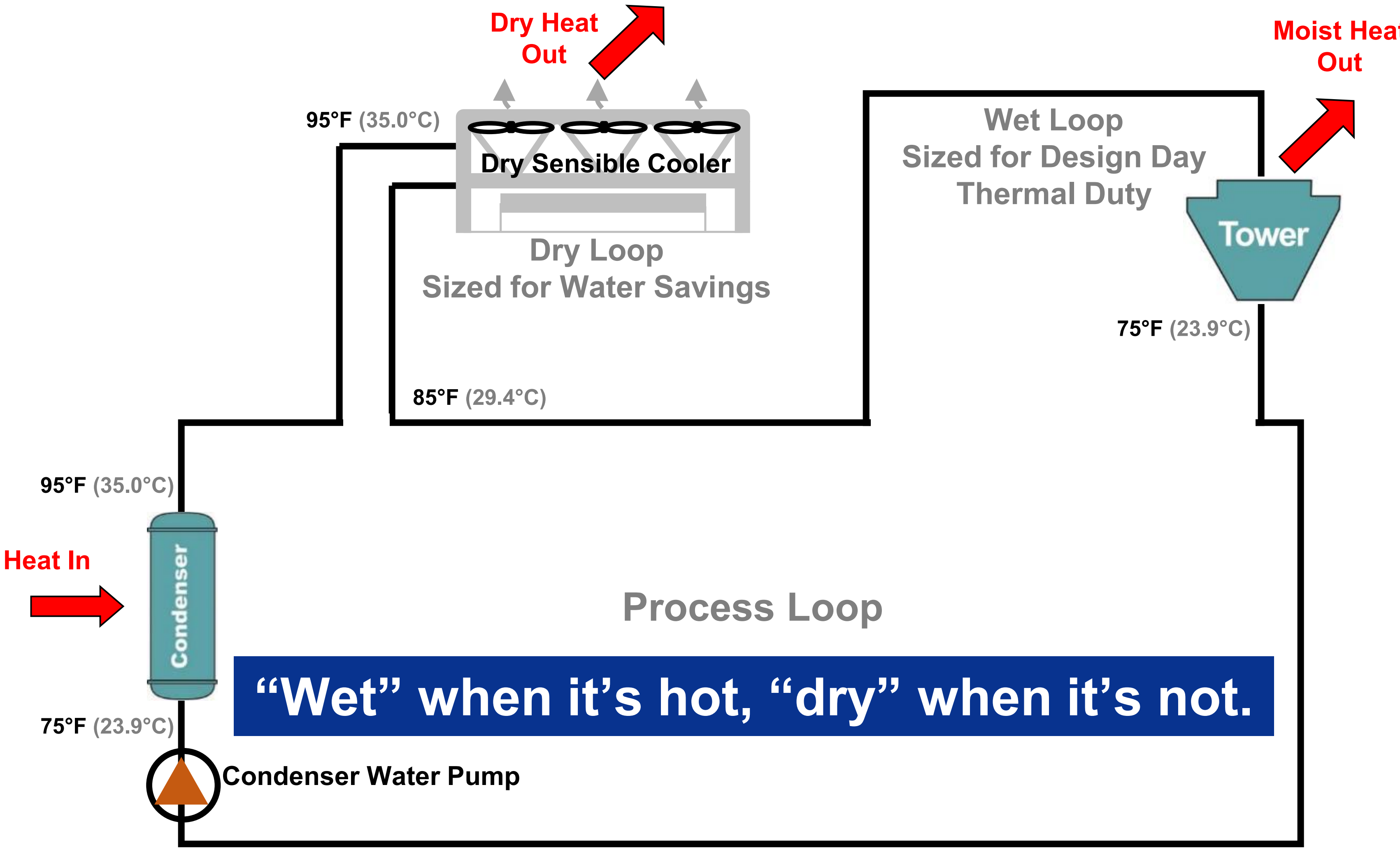




Traditional Wet Cooling System

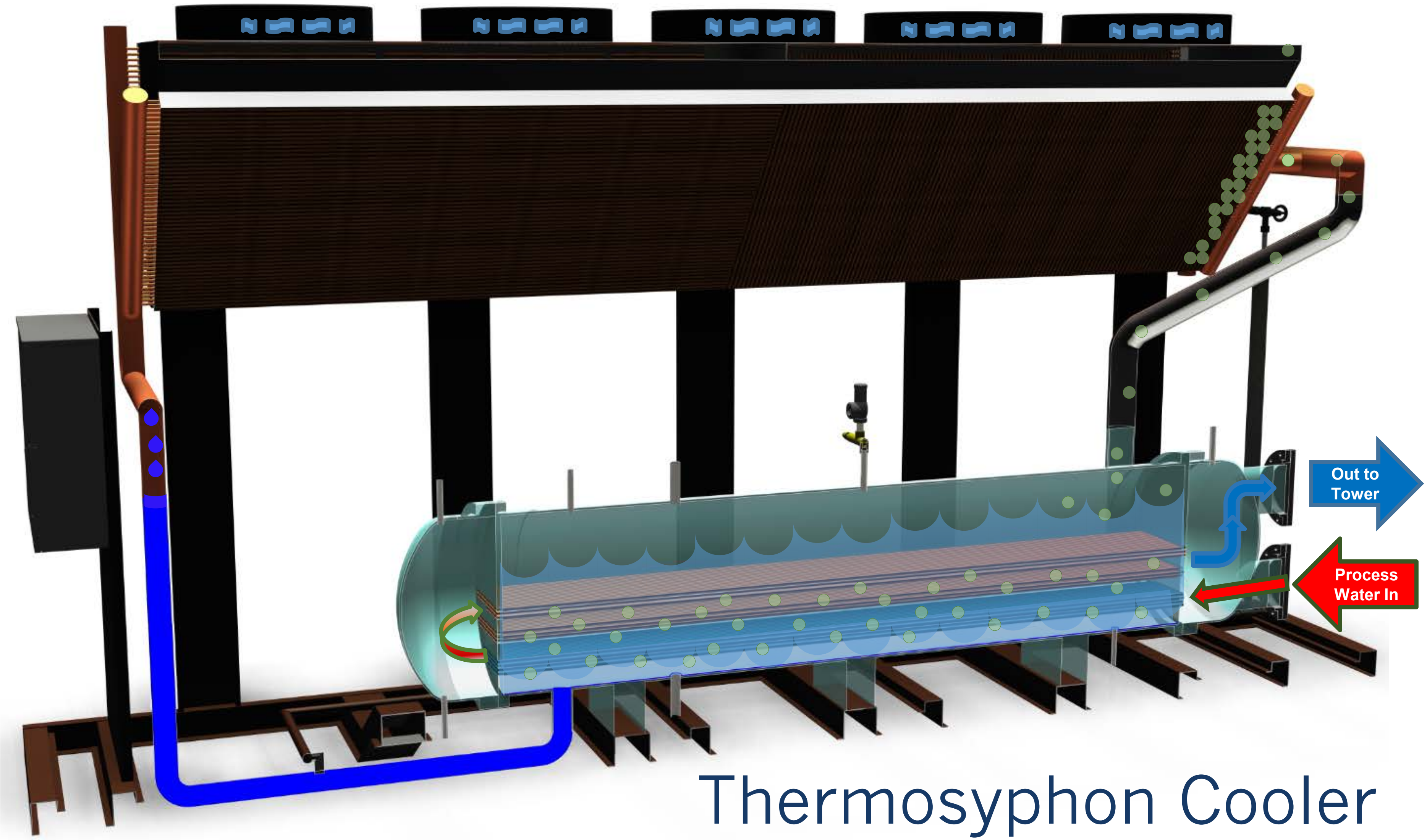


Basic Hybrid System Concept

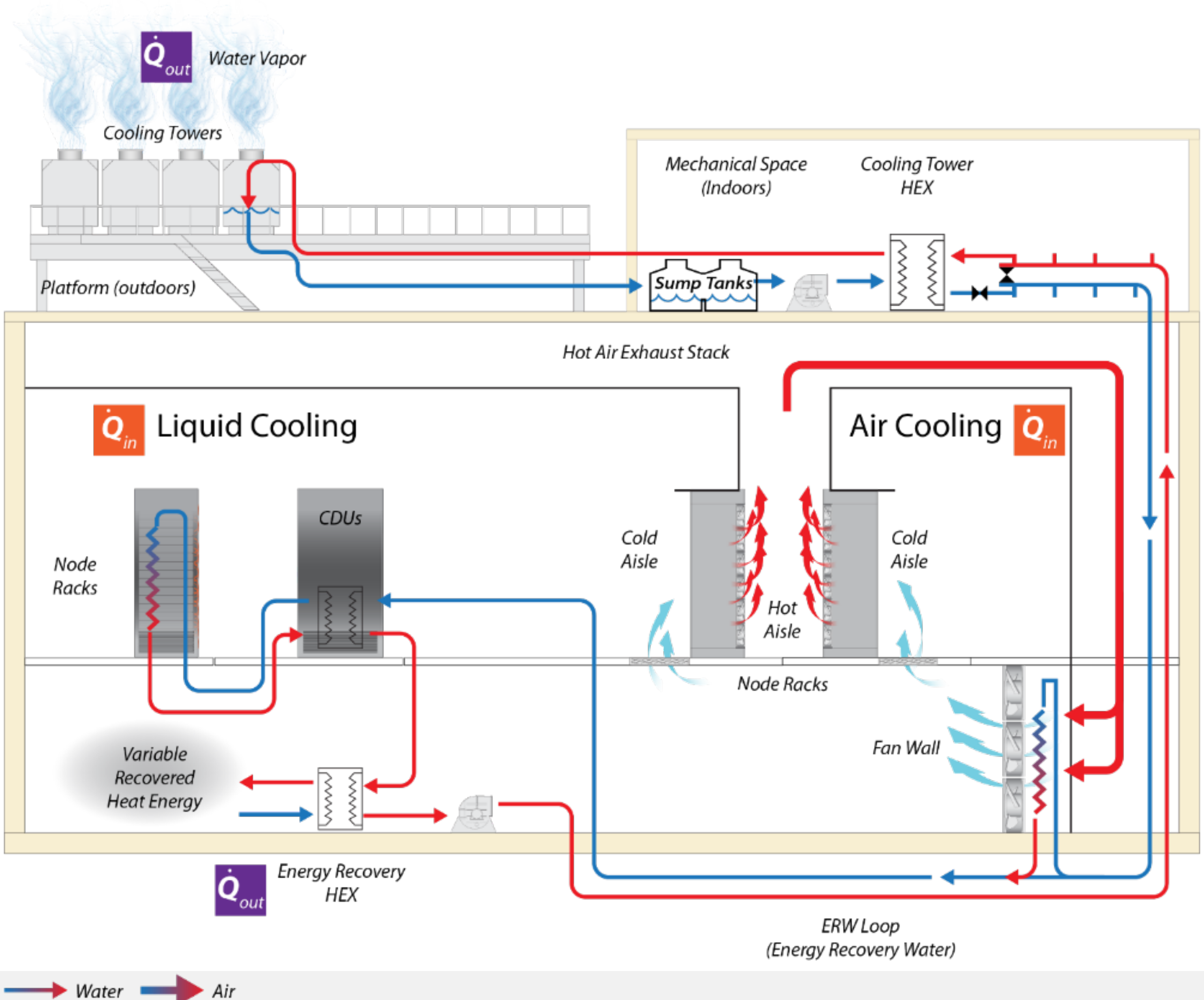


"Wet" when it's hot, "dry" when it's not.

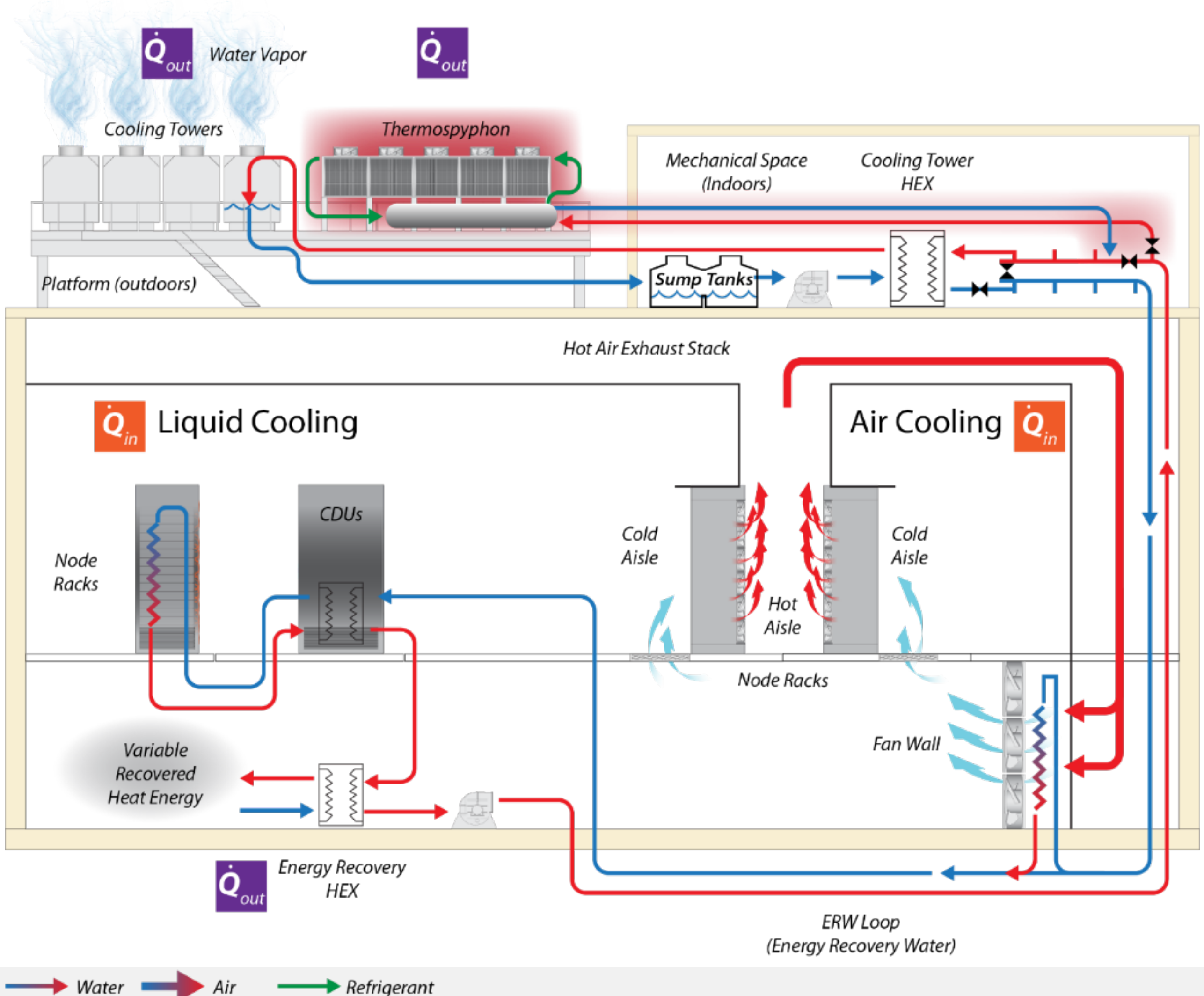
Thermosyphon Cooler



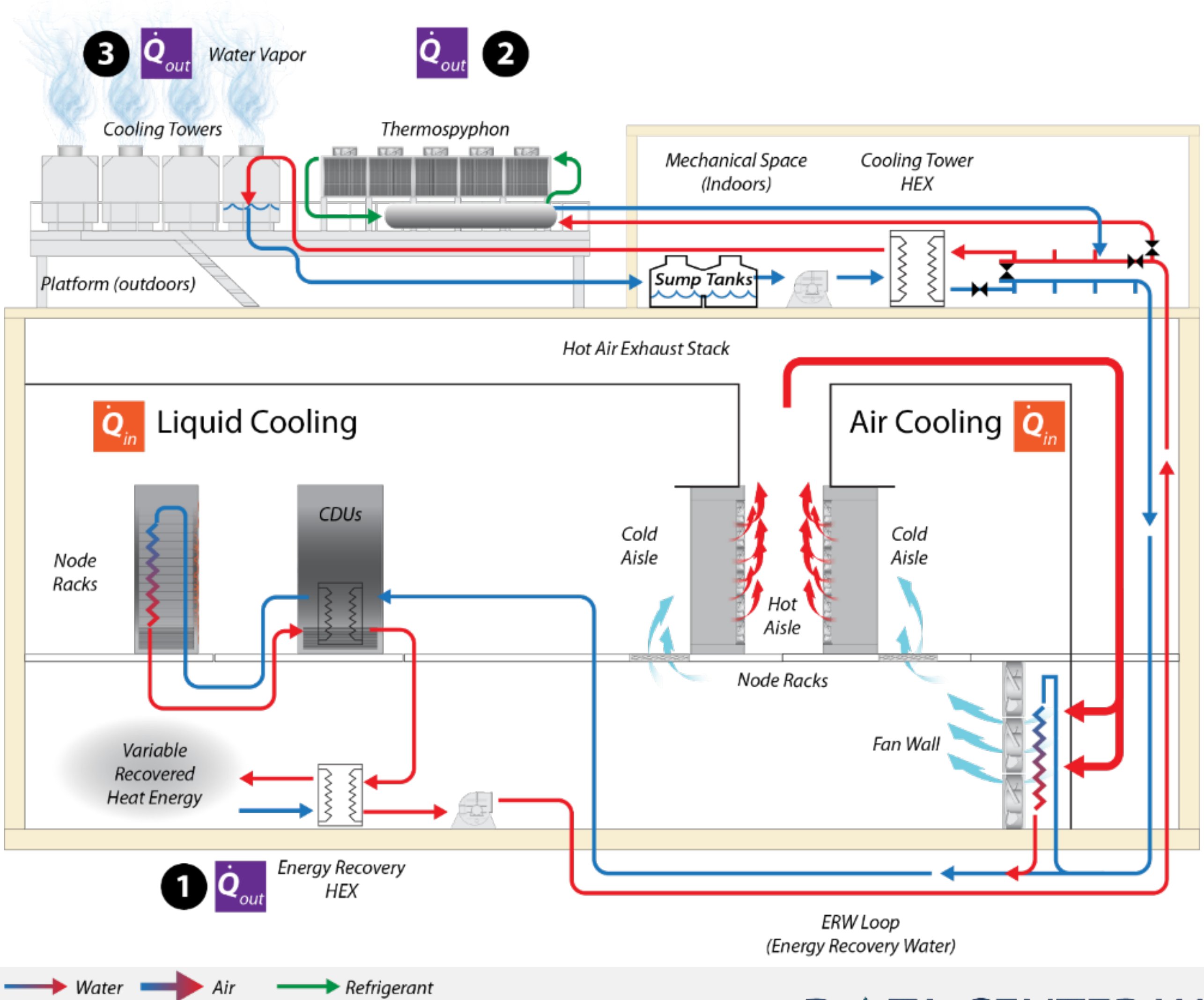
System Schematic: Original Configuration



System Schematic: Thermosyphon Mod



System Schematic: Heat Rejection Steps



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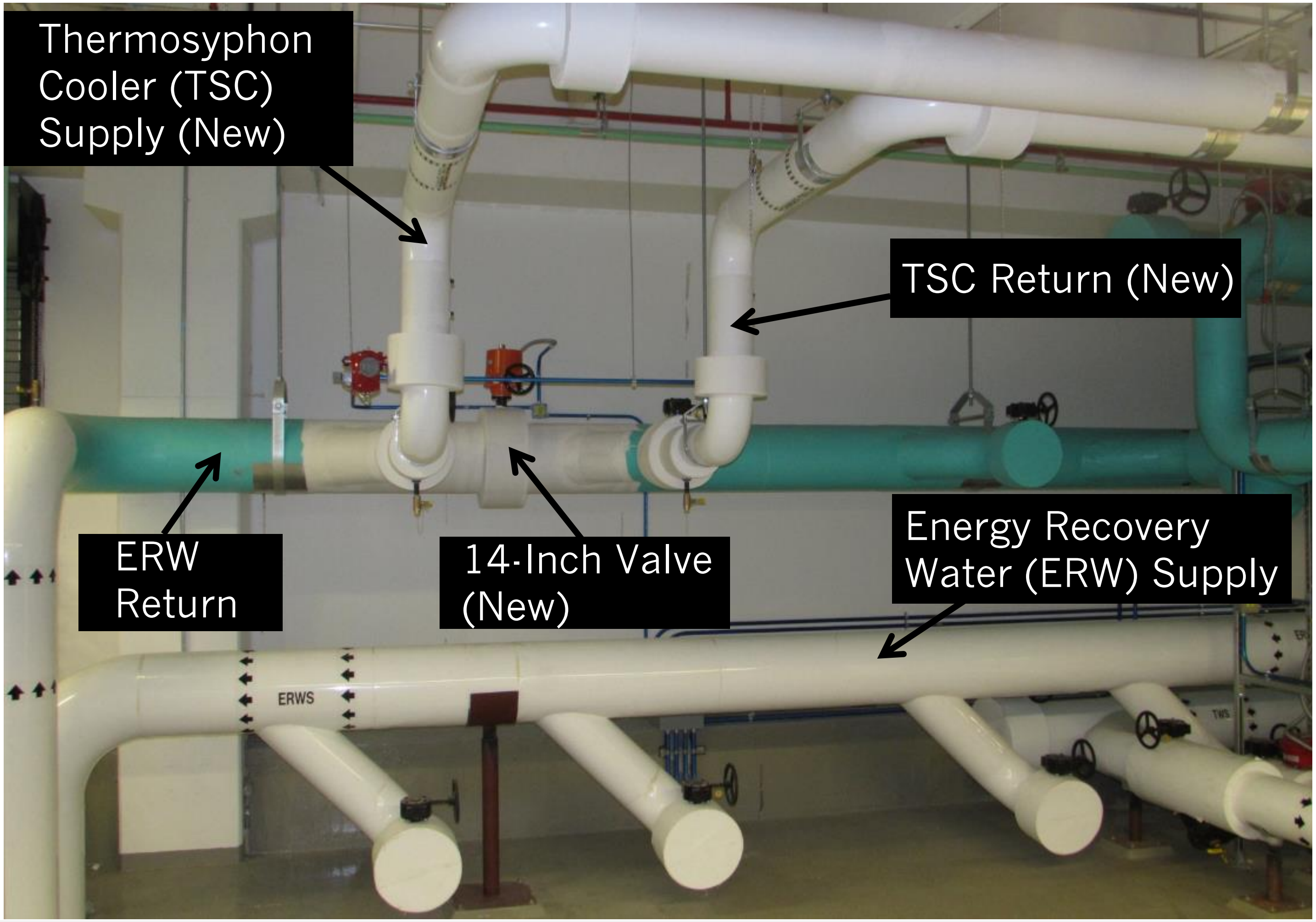
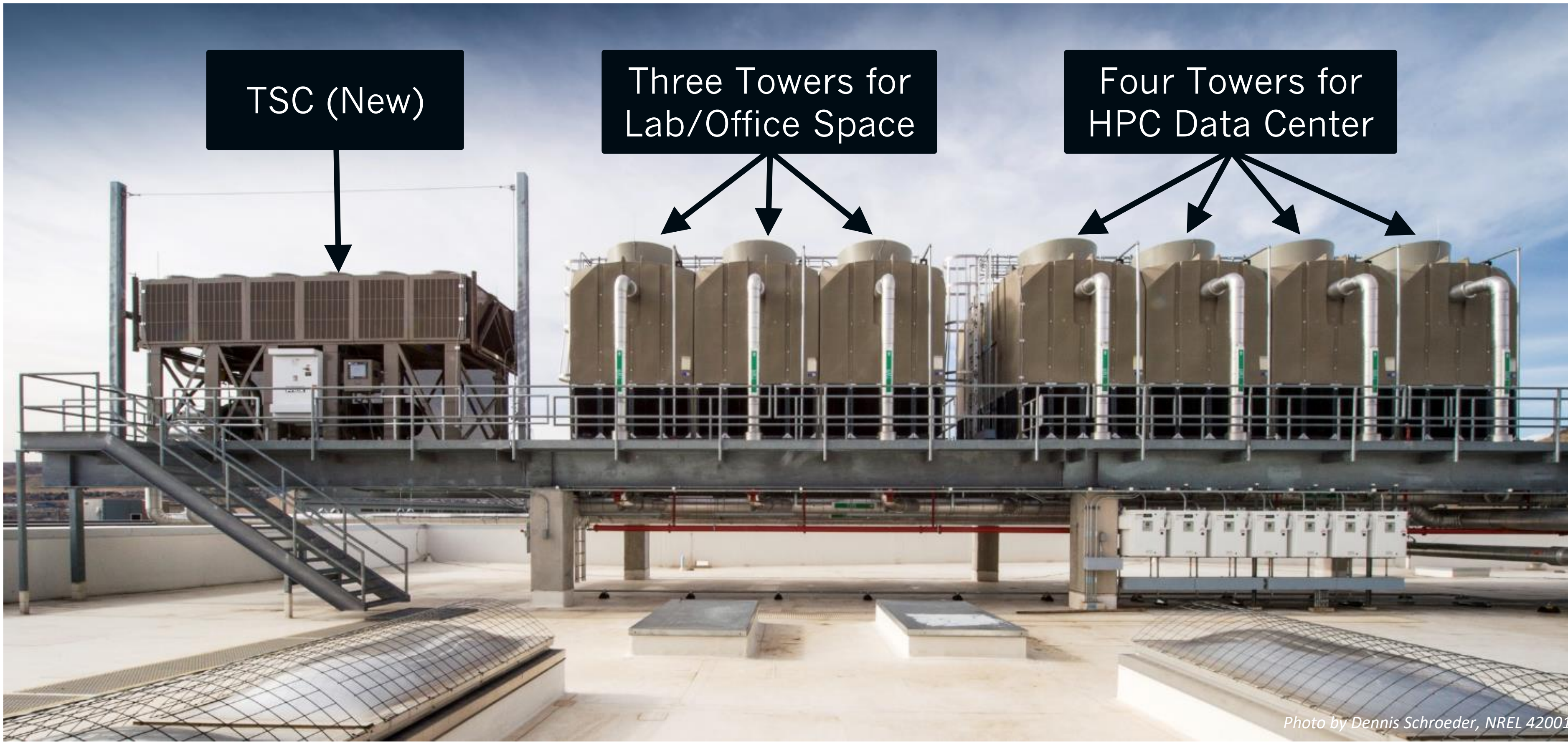
System Modification



Thermosyphon Cooler Installation



System Modeling Program

Version: C9

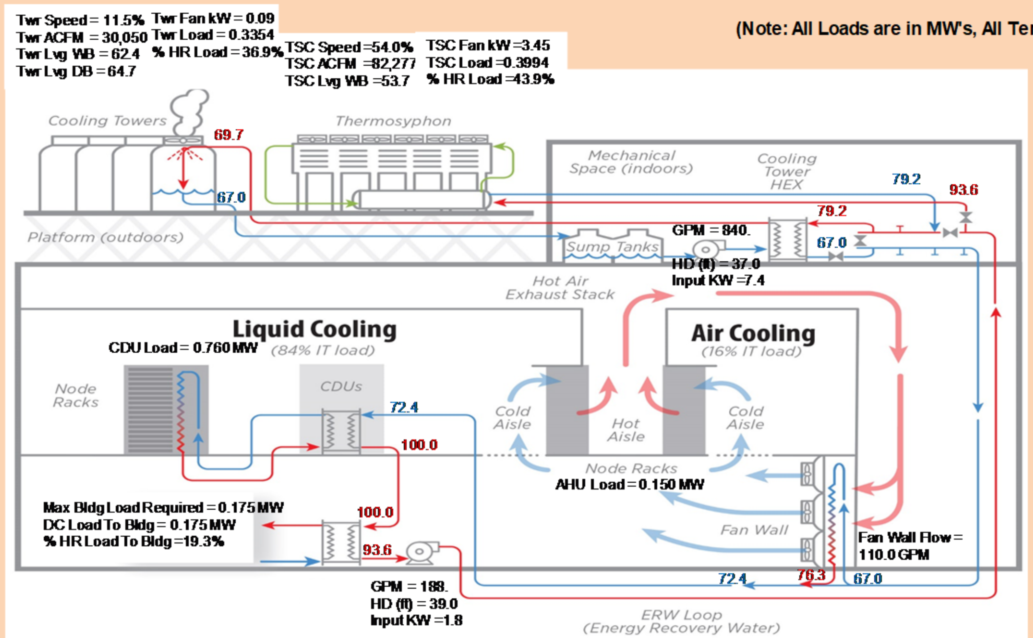
(Note: All Loads are in MW's, All Temperatures are in °F)

Golden, CO

Row = 2331

WB = 46.4
DB = 57.2
Atmos = 23.987

Monday
April 7
10AM to 11AM

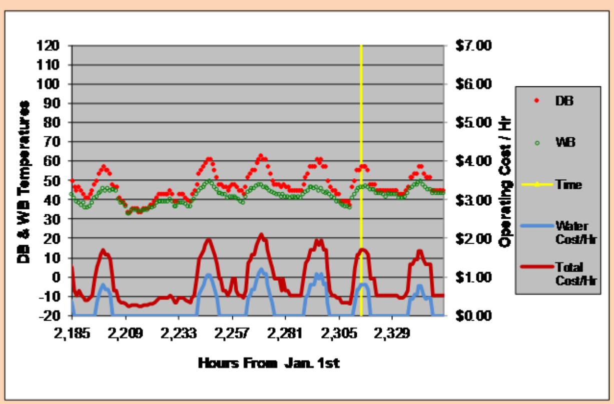


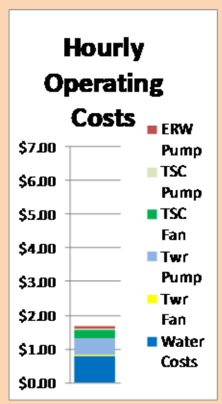
	Hourly	Annual
Total DC Load	0.910	7,972
Load to Atmos	0.735	5,748
Bldg Heat Required	0.175	3,461
Load to Bldg Heat	0.175	2,223.2
Load to Aux CWS	0.000	0
Electrical Energy (kWh)	12.7	77,293
Water Usage (Gal)	132.0	978,089
HR System PUE	1.014	1.010
WUE (L/kWh)	0.549	0.464
ERF	0.077	0.112

Energy = $0.07/kWh
Water = $6.08/kgal

Plot Interval

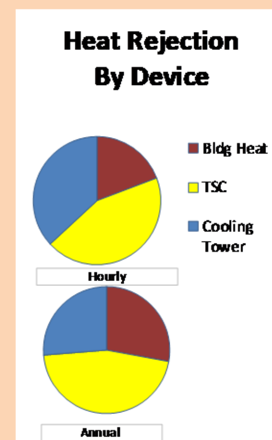
- Yearly
- Monthly
- Weekly
- Daily



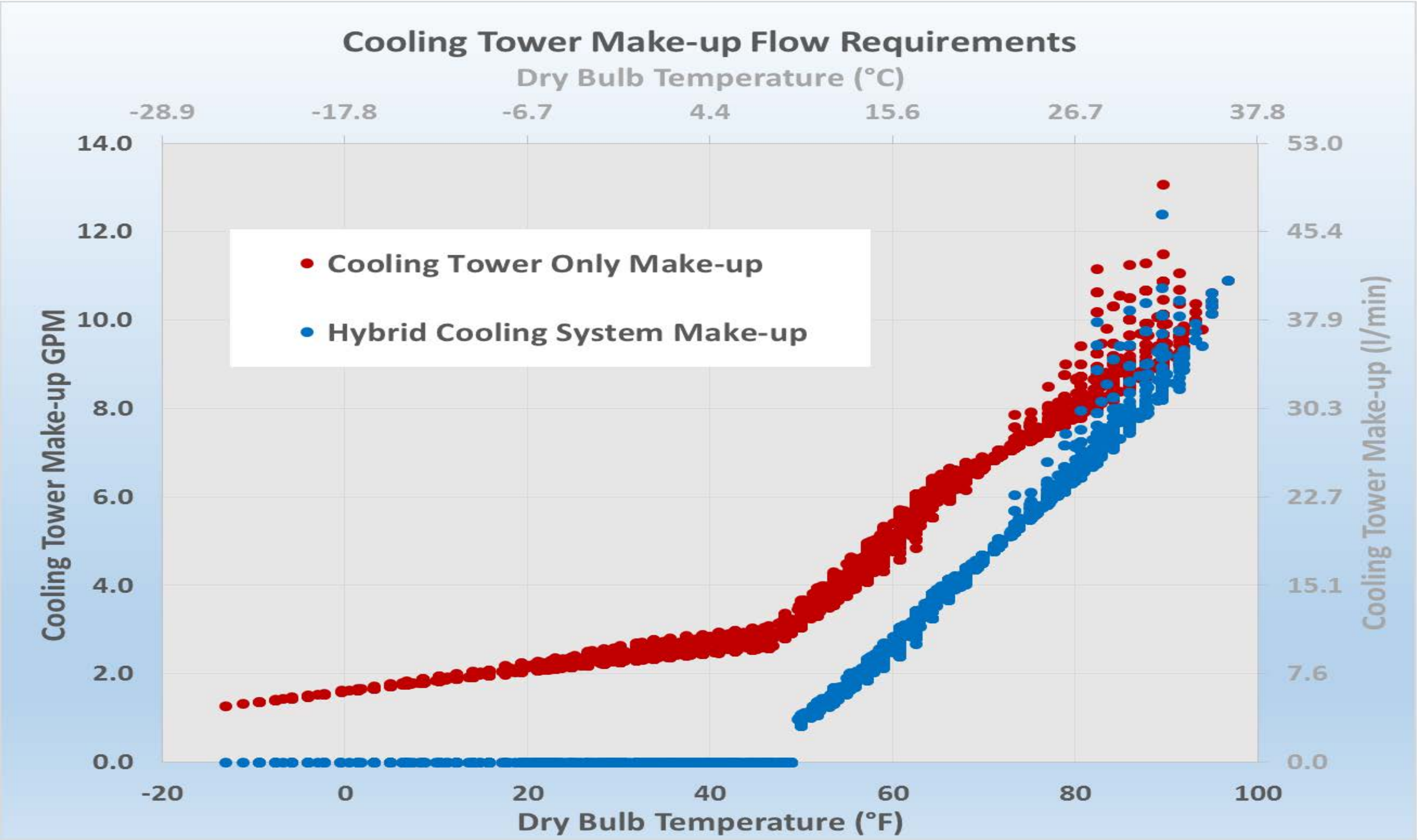


Hourly Costs		%
ERW Pump	$0.094	6%
TSC Pump	$0.029	2%
TSC Fan	$0.241	14%
Twr Pump	$0.518	31%
Twr Fan	$0.006	0%
Water Costs	$0.803	47%
Total	$1.69	100%

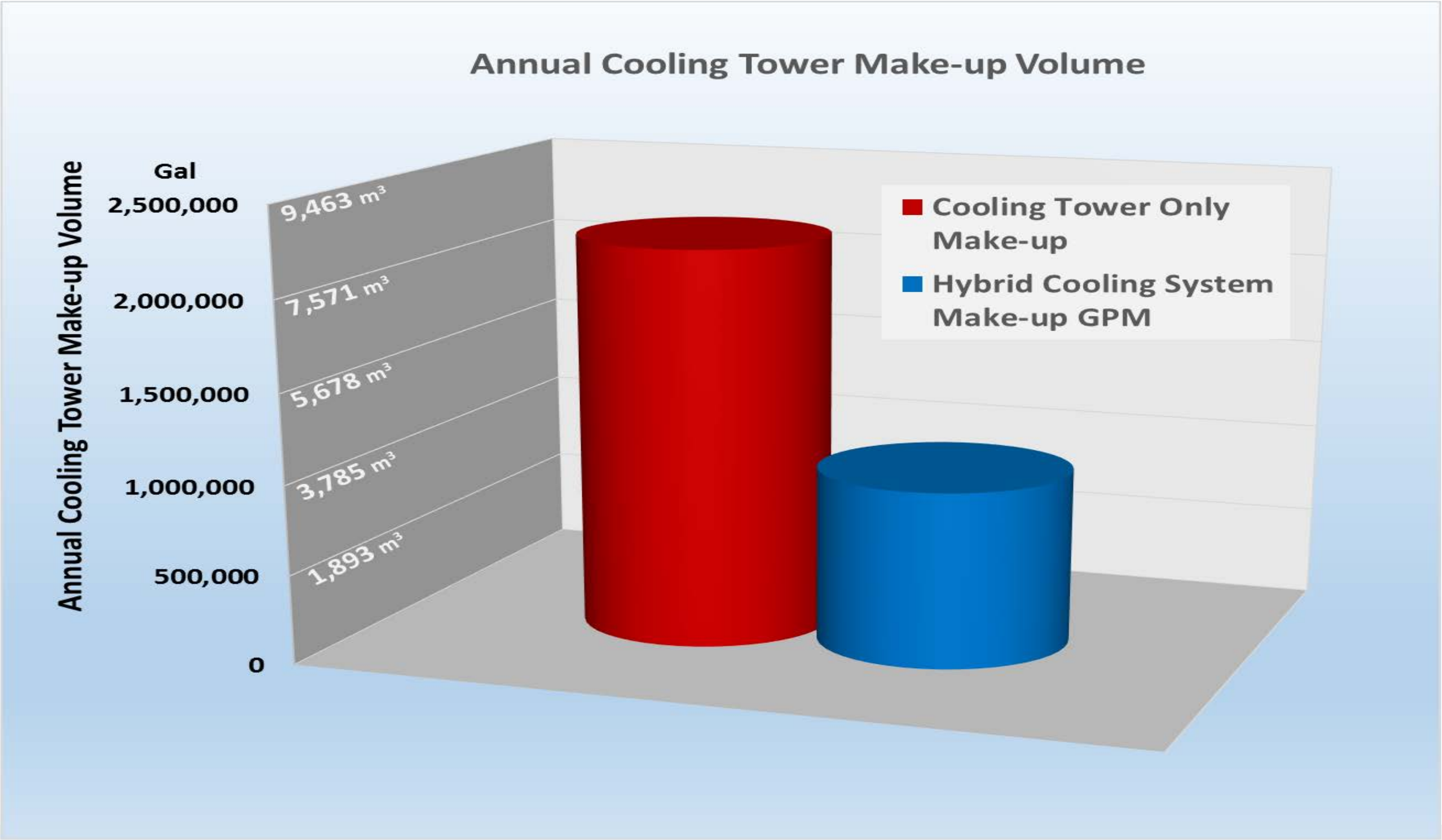
Annual Costs		%
Elect. Costs	$5,411	48%
Water Costs	$5,950	52%
Total Costs	$11,361	100%



Modeling Results: Make-Up GPM vs. Dry Bulb



Modeling Results: Overall Water Use



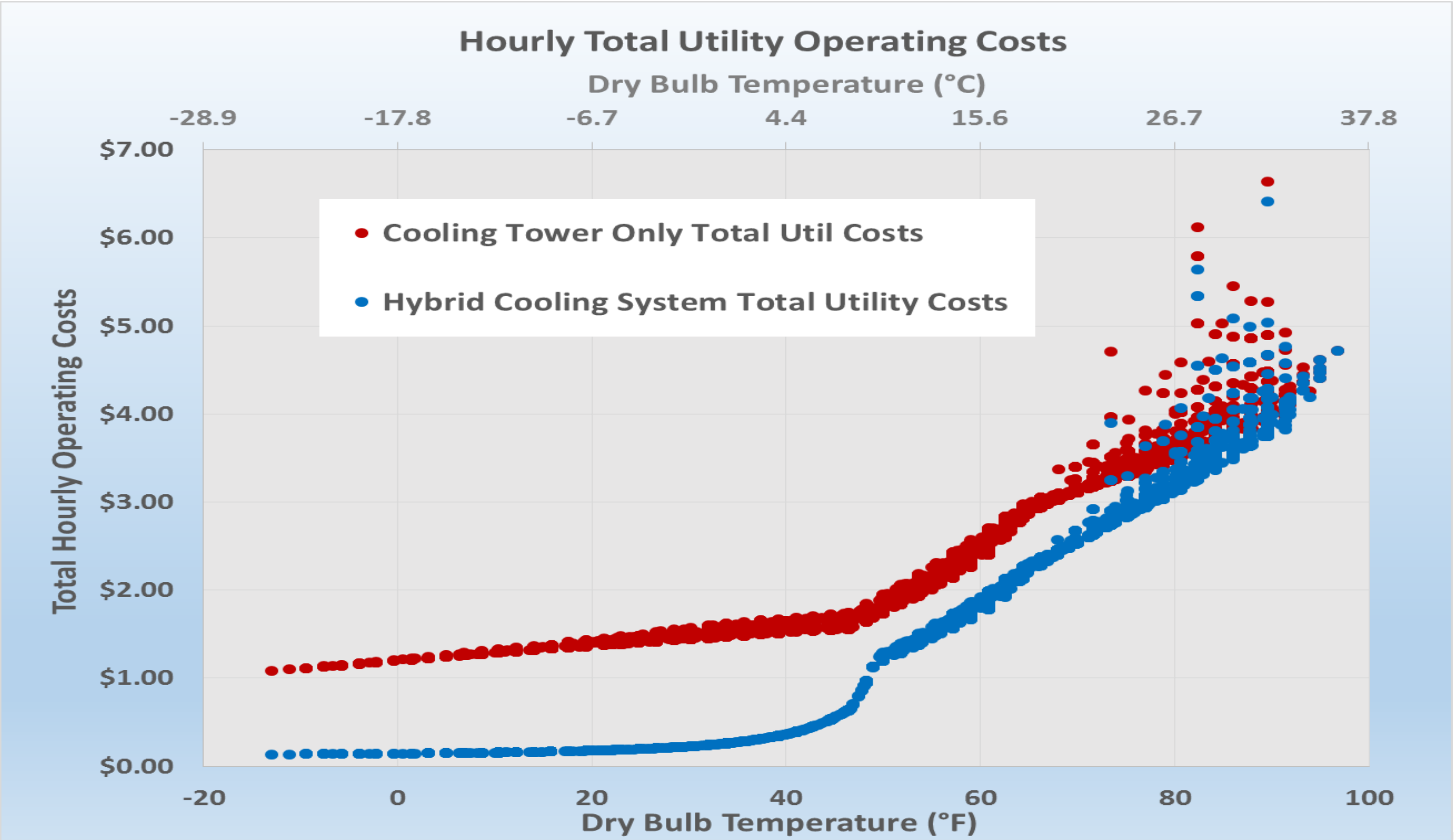
Controls Allow for Saving Both Water and Operational Cost Savings

WECER = Water-to-Energy Cost Equivalence Ratio:

- **WECER = cost of water/cost of electricity**
- **WECER = ($/1,000 gal water) / ($/kWh)**
- **WECER = kWh/1,000 gal.**

TSC fan speed = *f*(WECER and (entering water–DB)).

Modeling Results: Operational Cost

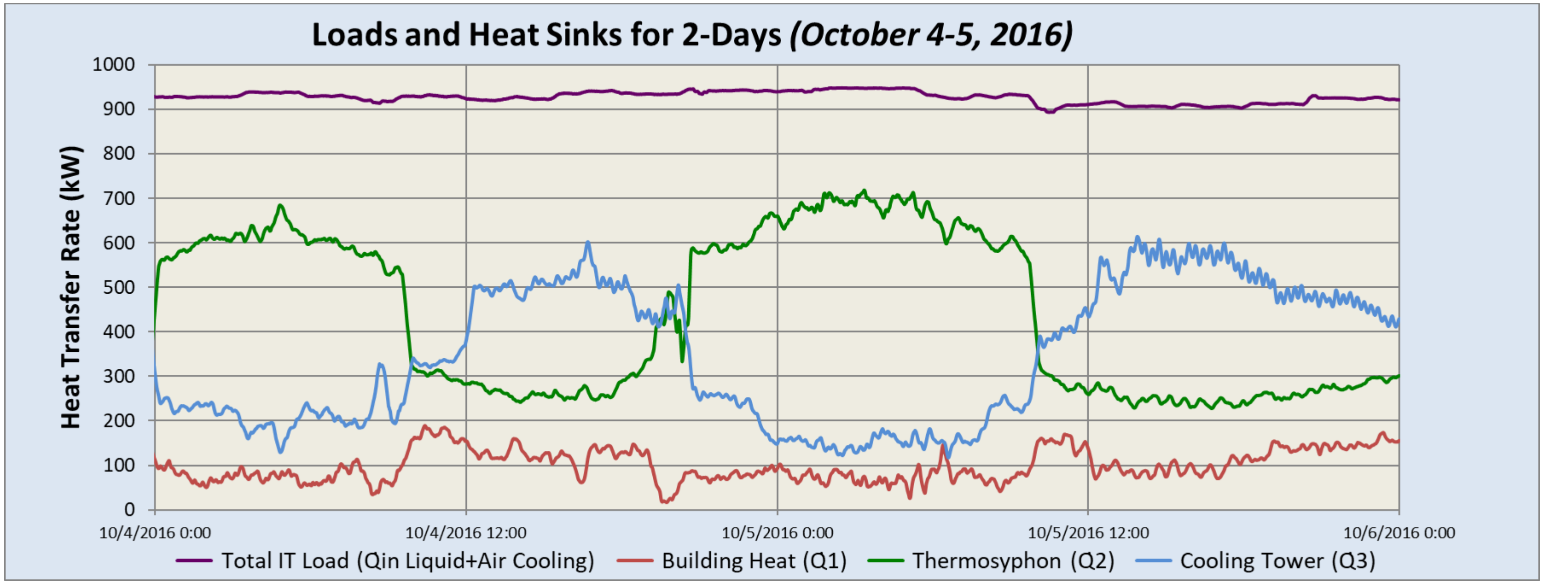


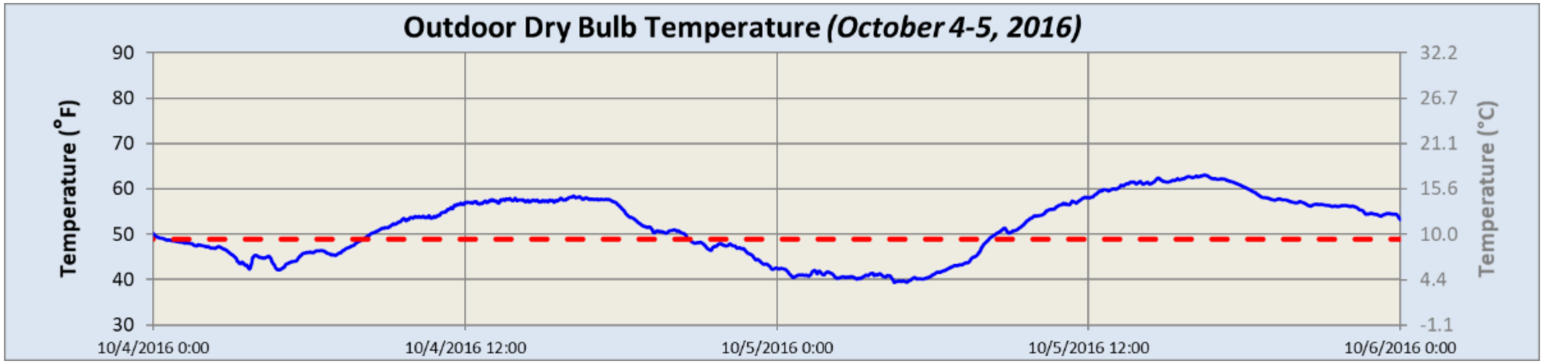
Any application using an open cooling tower is a potential application for a hybrid cooling system, but certain characteristics will increase the potential for success.

Favorable application characteristics:

- Year-round heat rejection load (24/7, 365 days is best)
- Higher loop temperatures relative to average ambient temperatures
- High water and wastewater rates or actual water restrictions
- Owner's desire to mitigate risk of future lack of continuous water availability (water resiliency)
- Owner's desire to reduce water footprint to meet water conservation targets.

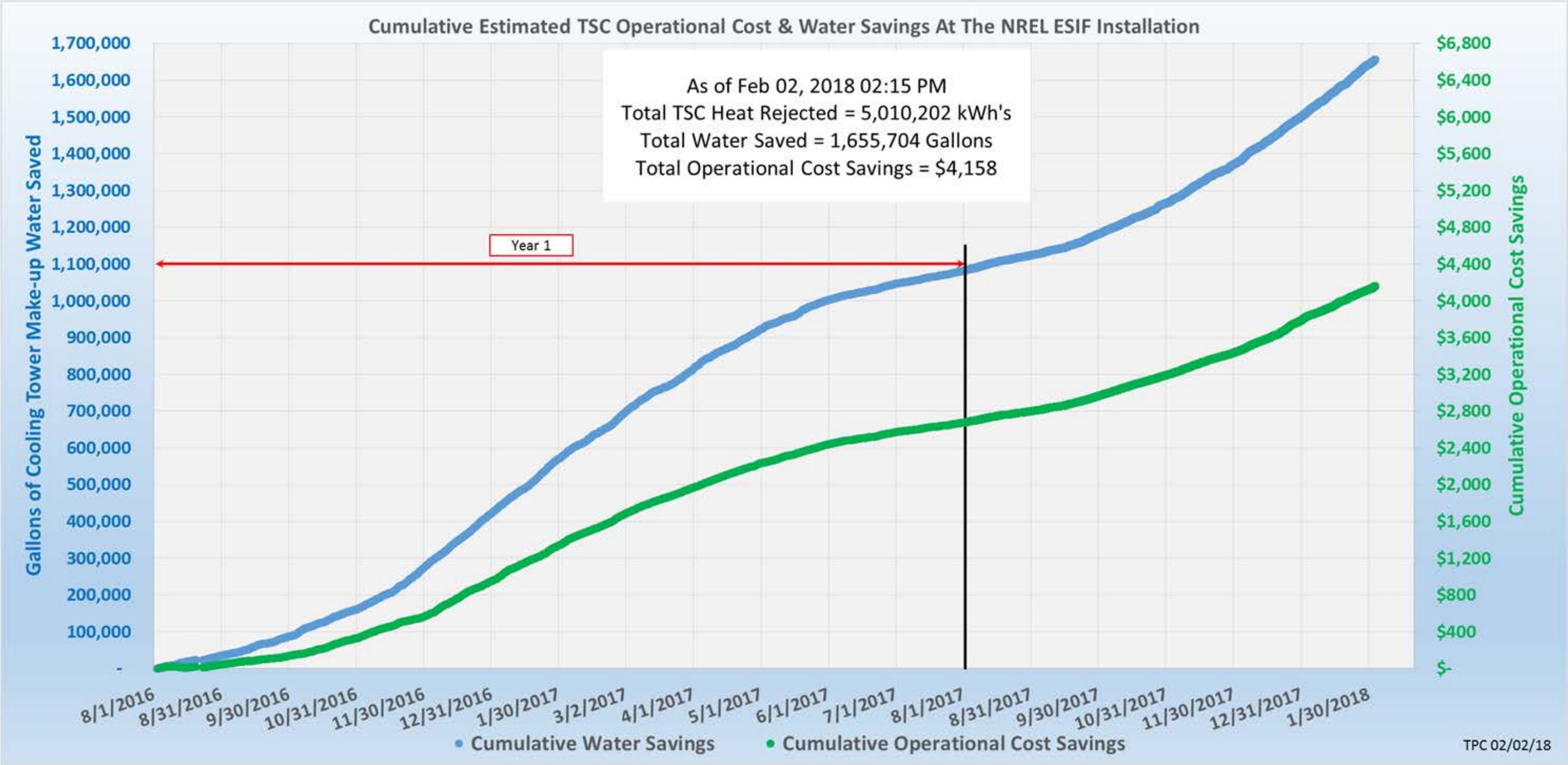
Sample Data: Typical Loads & Heat Sinks



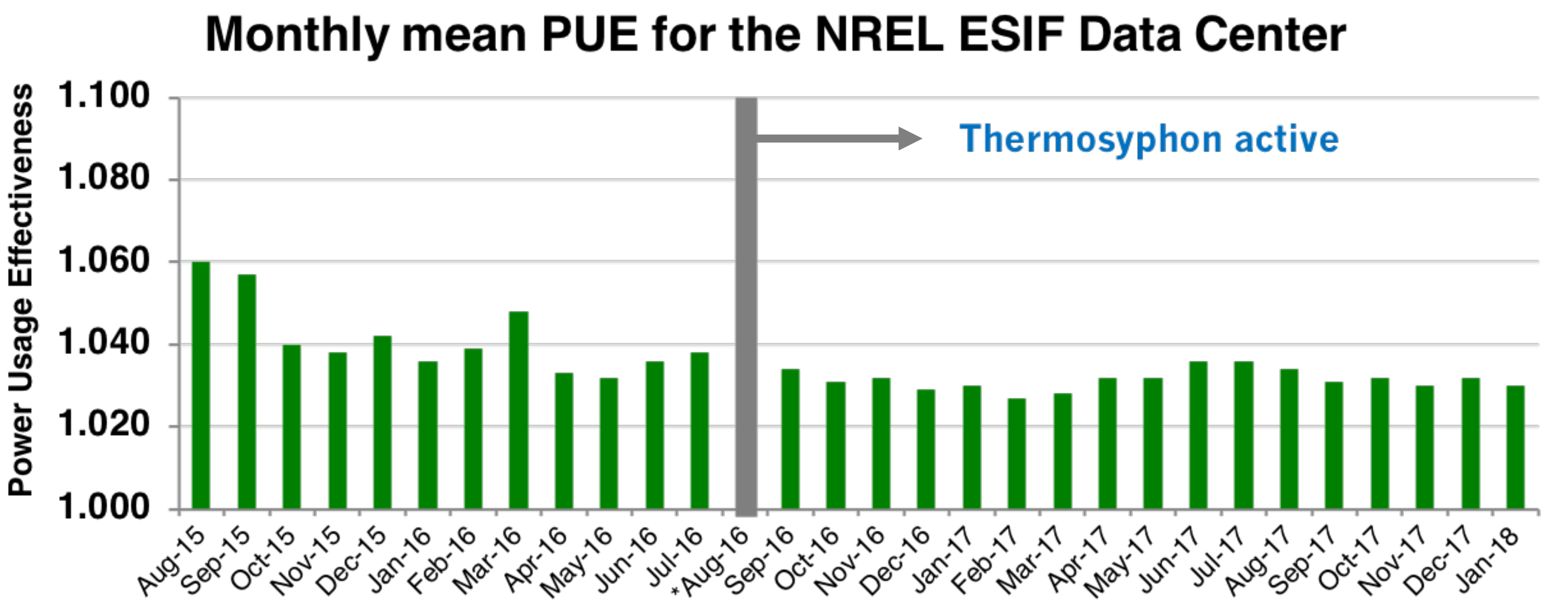


Cumulative Water and Cost Savings

Energy = $0.07/kWh
Water = $5.18/kgal



Performance Notes



- Average entering water temperature to TSC 28.9°C (84°F)
- Avoided outage for cooling tower loop repair

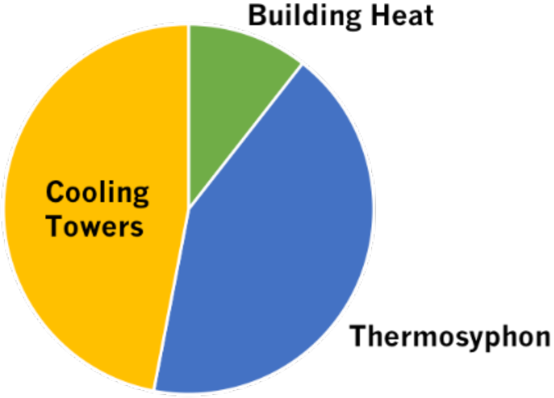
Data Center Metrics

First year of TSC operation (9/1/2016 – 8/31/2017)

Hourly average IT Load = 888 kW

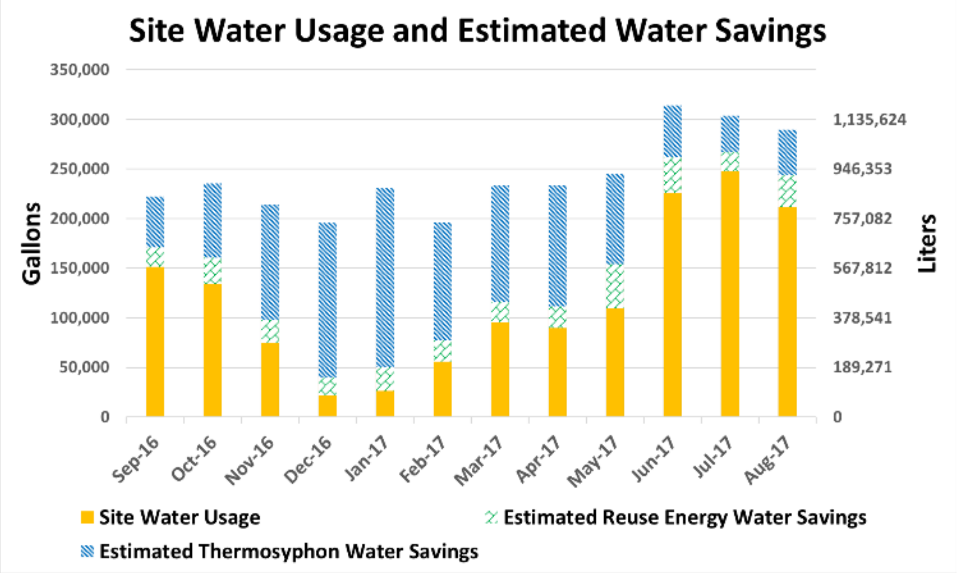
PUE = 1.034

ERE = 0.929



WUE = 0.7 liters/kWh

(with only cooling towers, WUE = 1.42 liters/kWh)

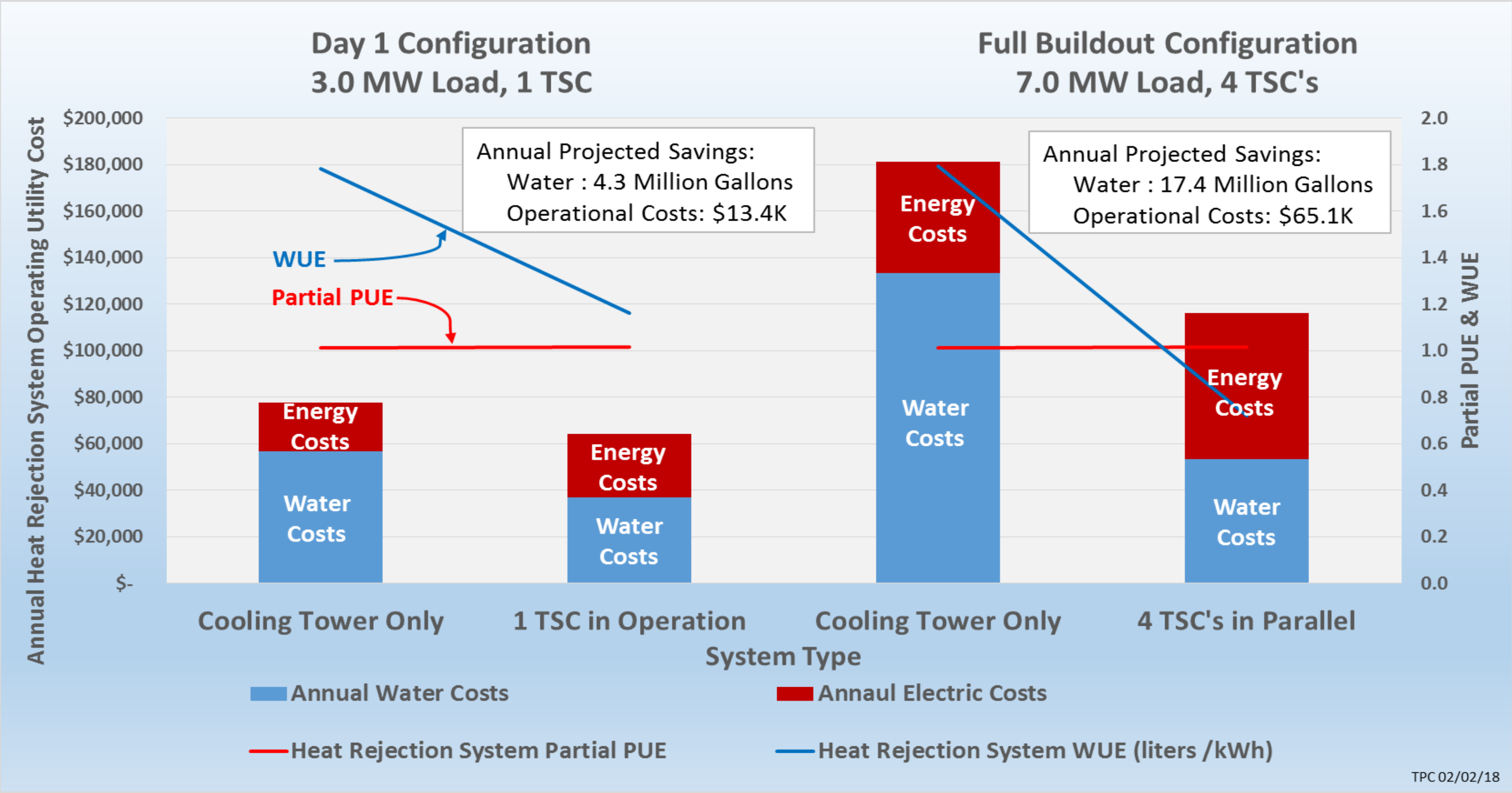


WUE_{SOURCE} = 5.4 liters/kWh

using EWIF 4.542 liters/kWh for Colorado

Project Partner Update:

Sandia National Laboratories – New Expansion



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Conclusions

- Warm-water liquid cooling has proven very energy efficient in operation.
- Modeling of a hybrid system showed that it was possible to save significant amounts of water while simultaneously reducing total operating costs.
    - System modification was straightforward.
    - System water and operational cost savings are in line with modeling.
- Hybrid system increased operational resiliency.

Three Key Things You Have Learned During this Session:

1. How a warm-water liquid cooling system, used to capture heat generated by computer systems, can operate at very high energy efficiencies.
2. Annualized metrics beyond PUE that include energy reuse (ERE) and water usage (WUE) effectiveness.
3. How a dry cooling device, installed upstream and in series with a cooling tower, can be used to reduce both annual water consumption and overall utility operating costs.

Thank you

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