NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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

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EUCI Utilities, Data Centers, and Renewable Energy Summit

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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 and 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 24ºC (75ºF) on hottest day of the year, ASHRAE “W2” class
  - IT return water—required 35ºC (95ºF) 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, 24ºC (75ºF) cooling water supply
- 35-40ºC (95-104ºF) 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 to 1,000 times less space than air conduits for transporting the same quantity of heat energy.
- Liquids require 10 to 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**.

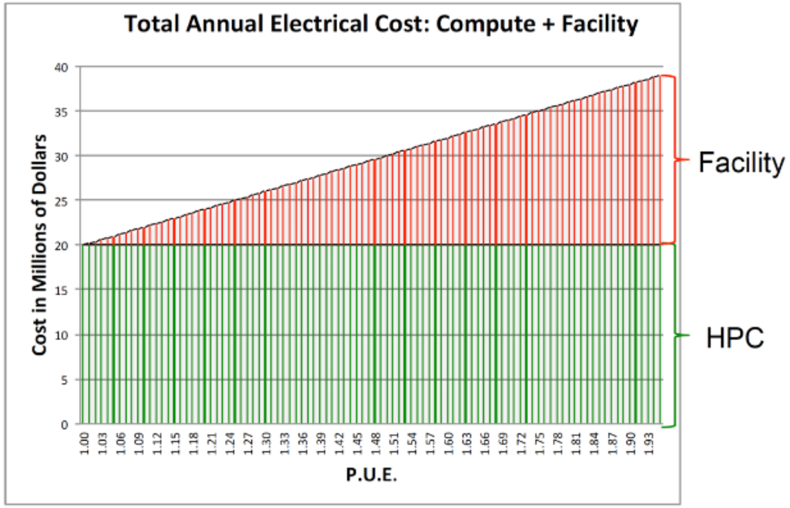
- Why should we care?
  - Water usage
  - Limited utility power
  - Mega$ per MW year
  - Cost: OpEx ~ IT CapEx!

- **Space Premium**: Ten 100-kW racks take much less space than the equivalent 50 20-kW air cooled racks.

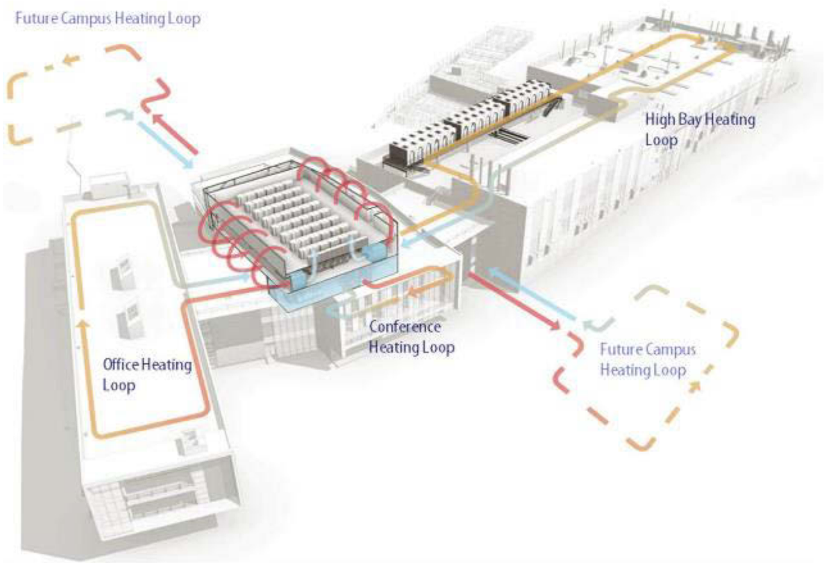
Metrics

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

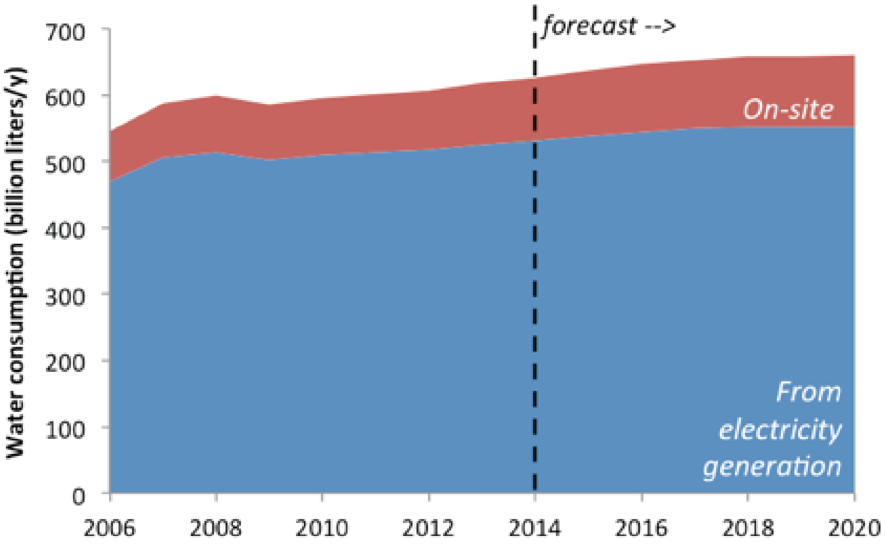
$$ERE = \frac{\text{"Facility energy"} + \text{"IT energy"} - \text{"Reuse energy"}}{\text{"IT energy"}}$$



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



Metrics



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

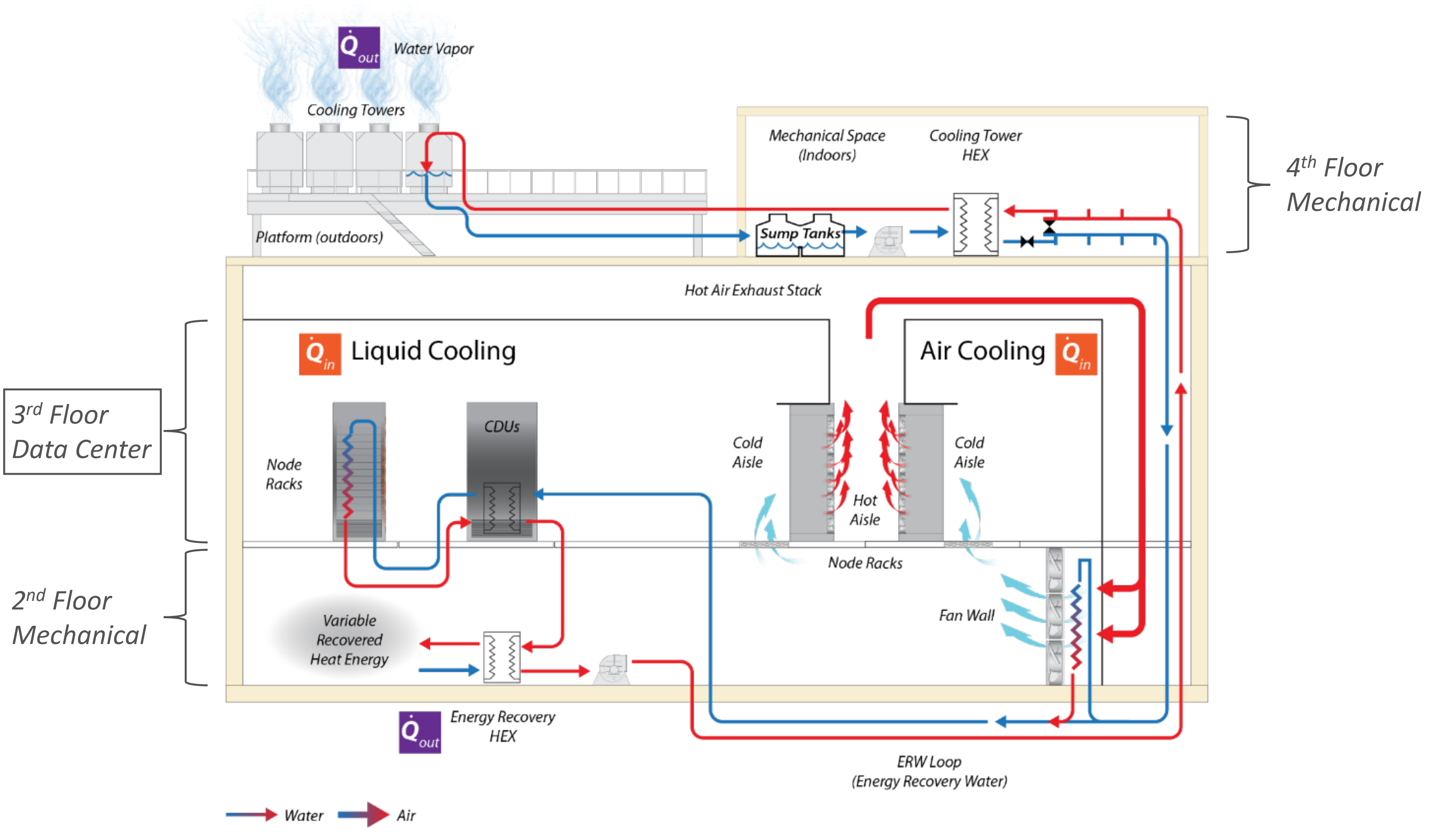
the units of WUE are liters/kWh

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

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

where EWIF is energy water intensity factor

System Schematic: Original Configuration



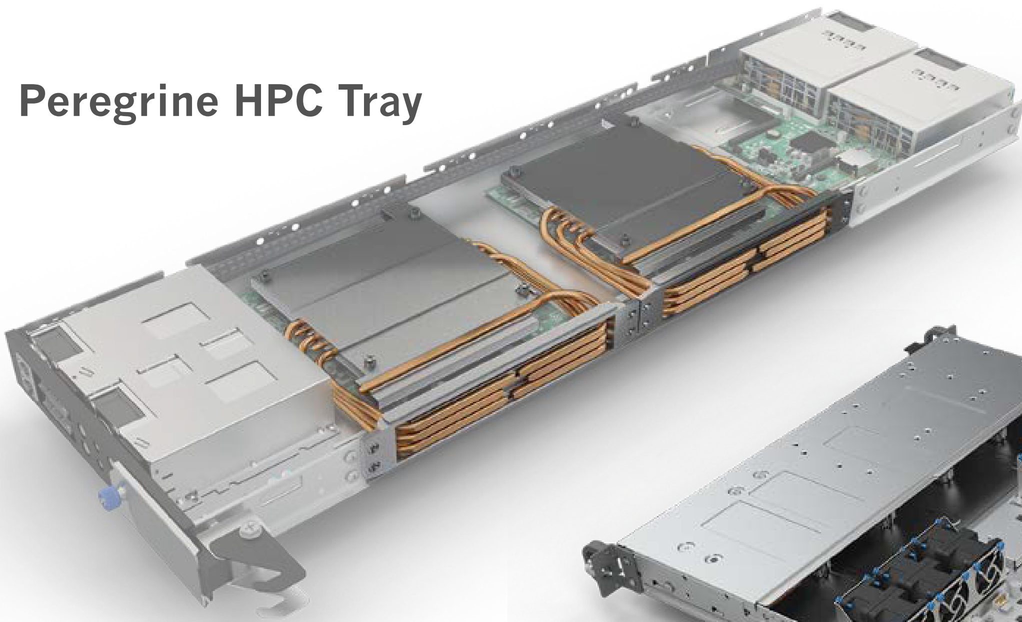
Air-Cooled to Liquid-Cooled Racks

Traditional **air-cooled** allow for rack power densities of 1kW-5kW

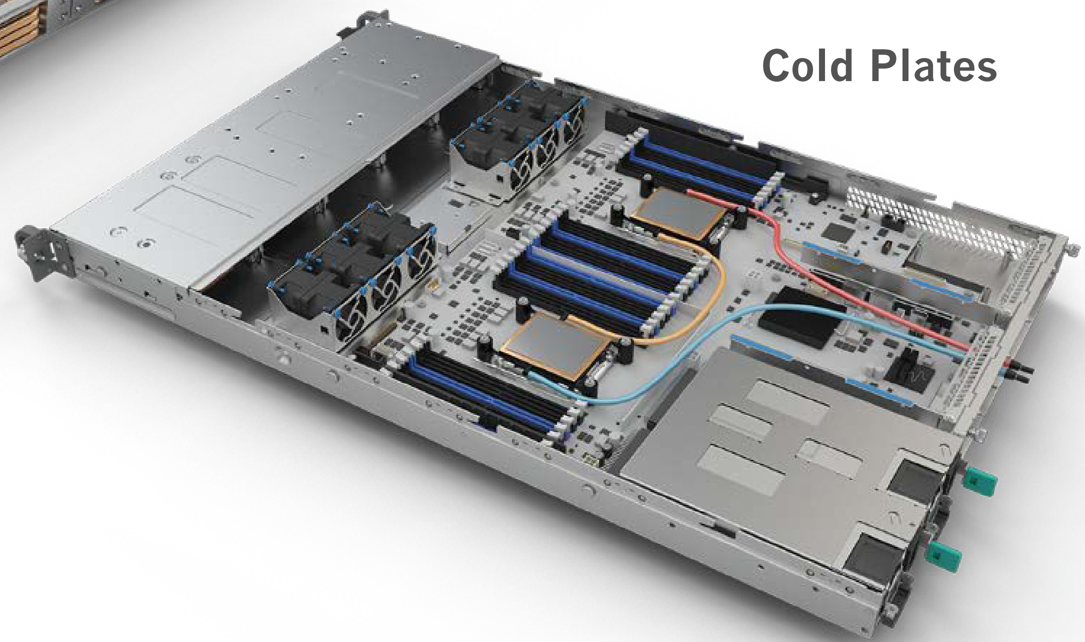
Require **liquid-cooled** when rack power densities in 5kW to 80kW range, have several options

Liquid-Cooled Server Options

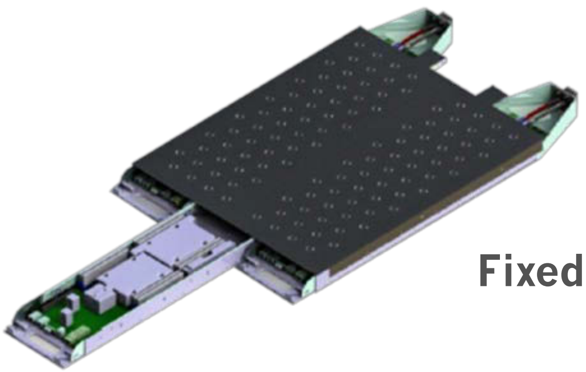
Peregrine HPC Tray

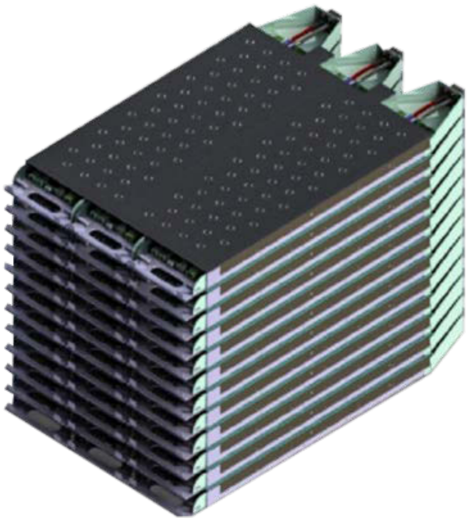


Cold Plates

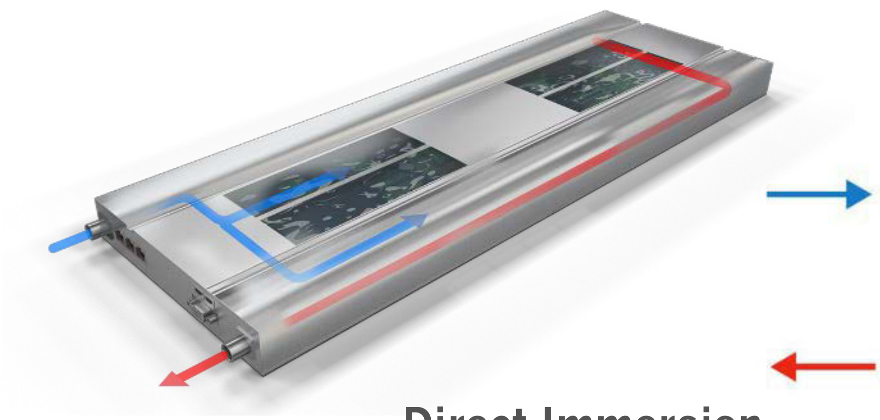


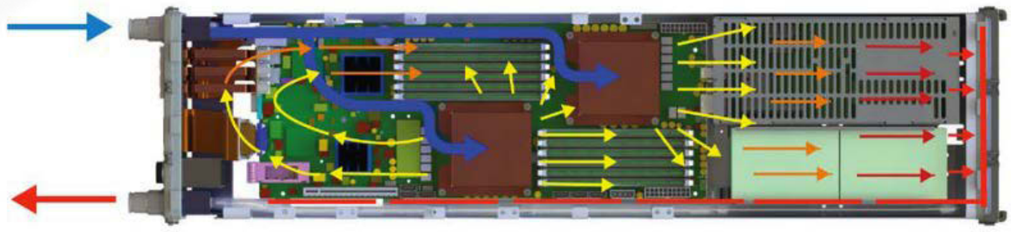
Fanless Liquid-Cooled Server Options





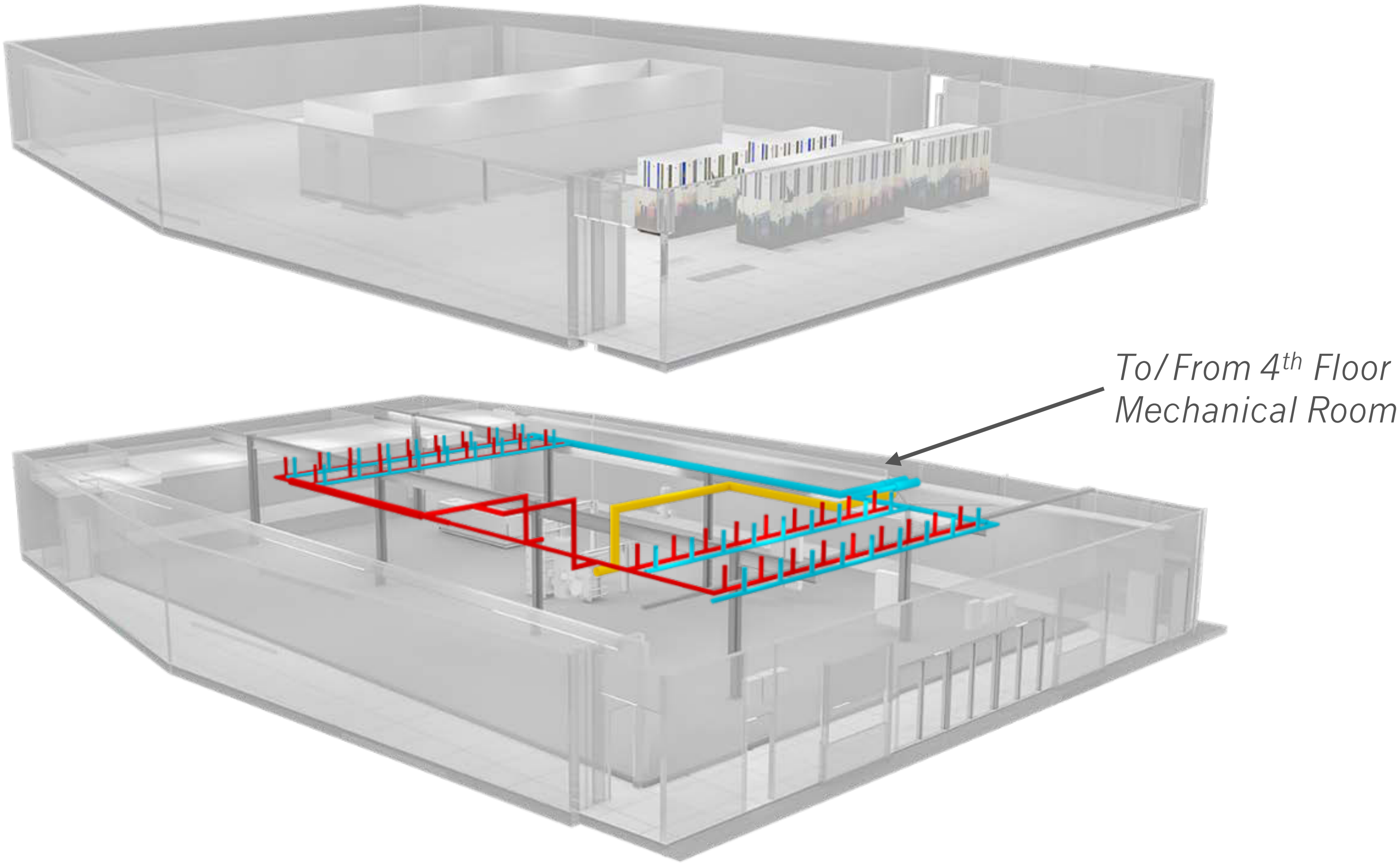
Fixed Cold Plate





Direct Immersion

Data Center Water Distribution



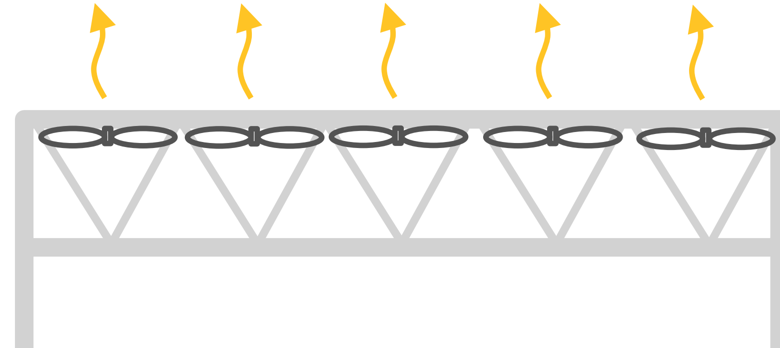
Liquid Cooling—Considerations

- 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

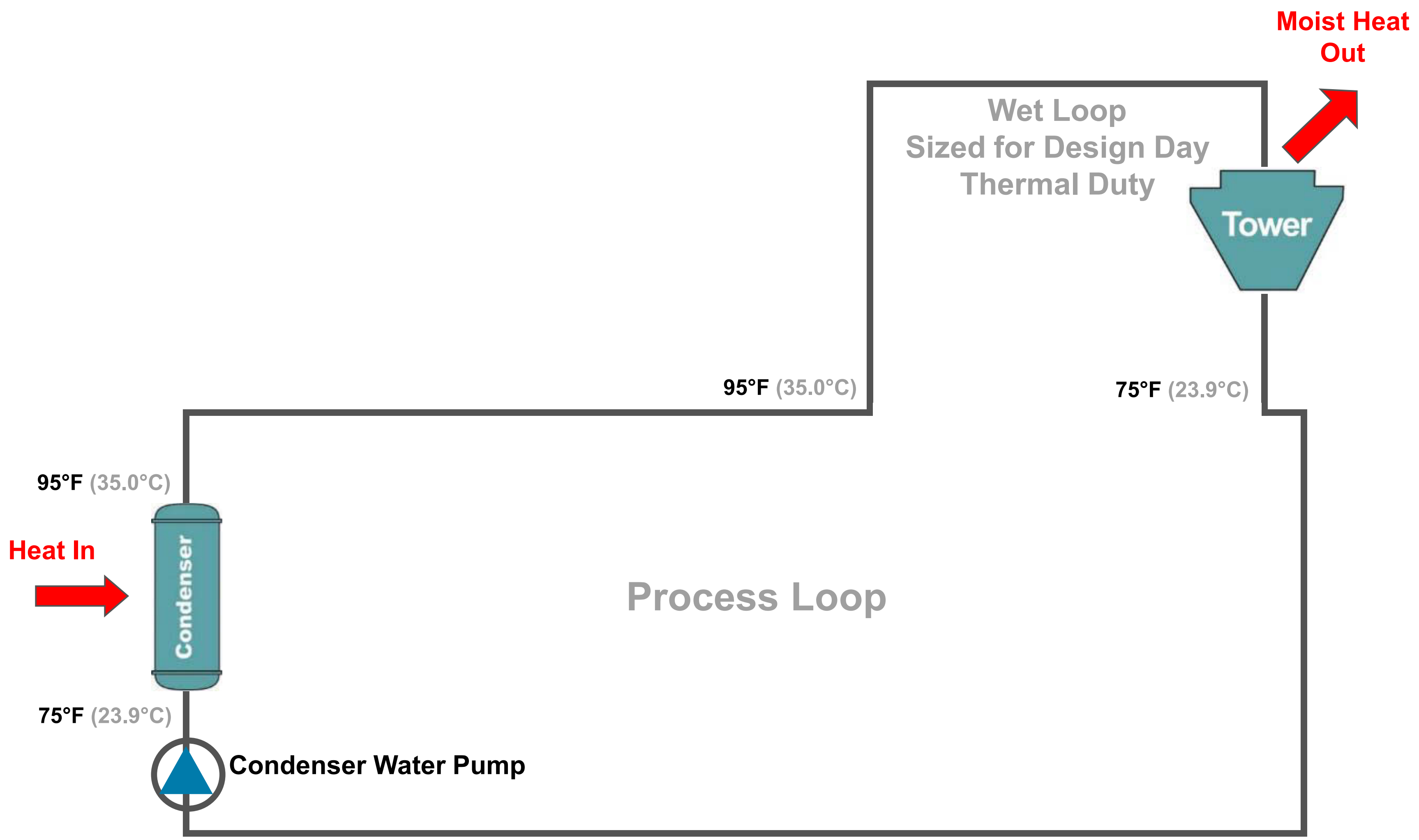


Water-Cooled System

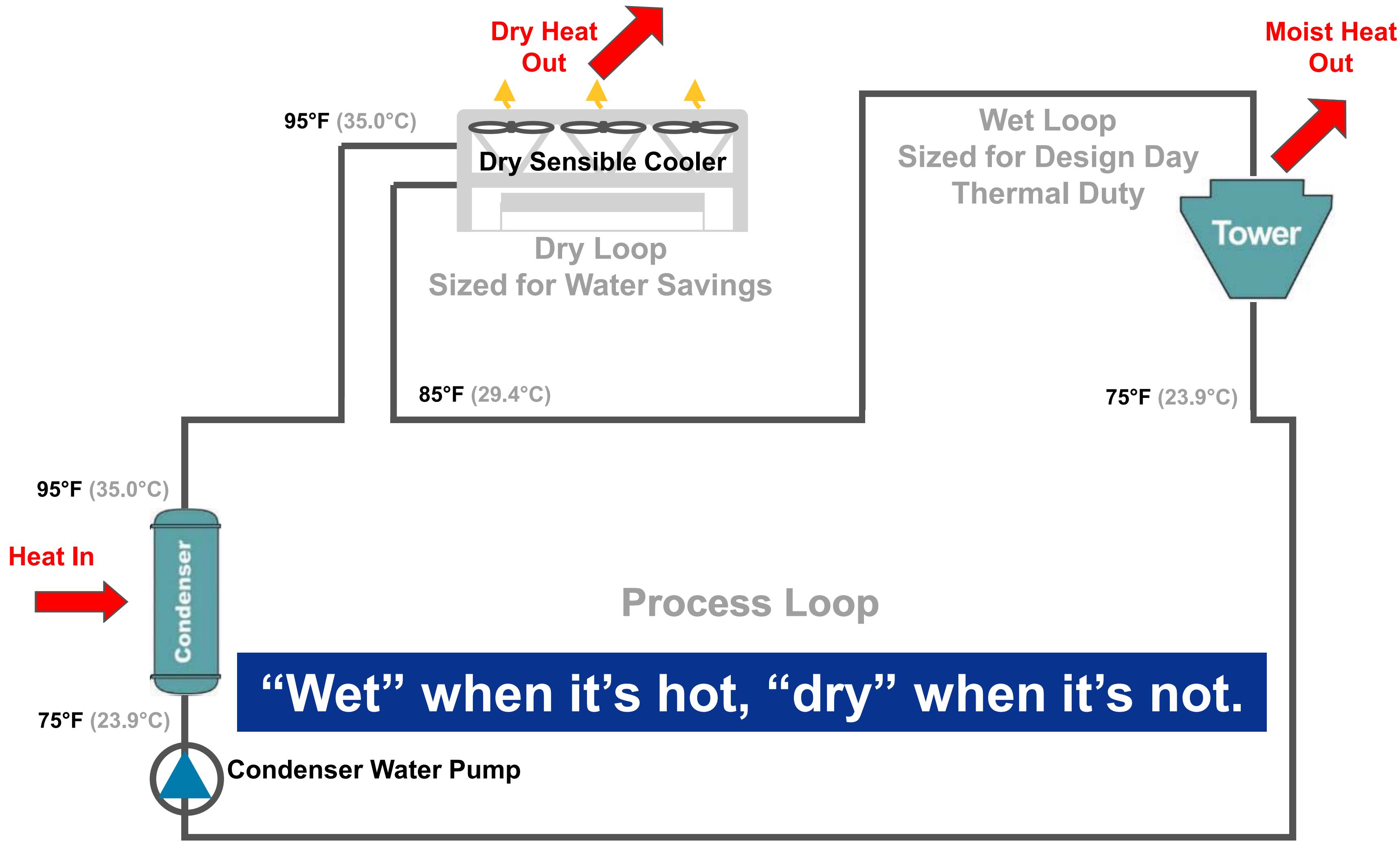
- Design day is based on the lower **WET BULB** temperature
- Evaporative cooling process uses water to improve cooling efficiency
    - **80% LESS AIRFLOW → lower fan energy**
    - Lower cost and smaller footprint.
- Colder heat rejection temperatures improve system efficiency

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

Traditional Wet Cooling System

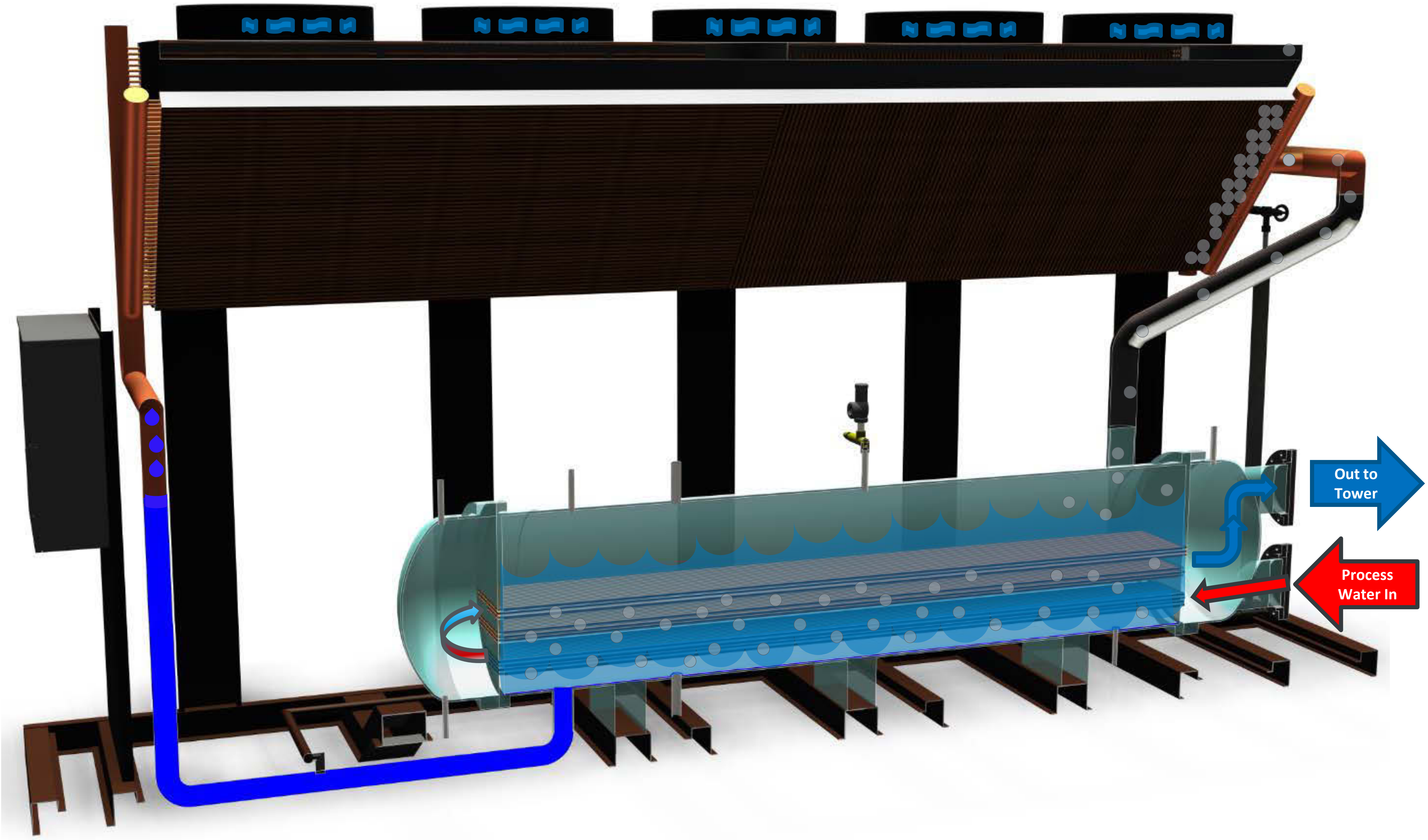


Basic Hybrid System Concept

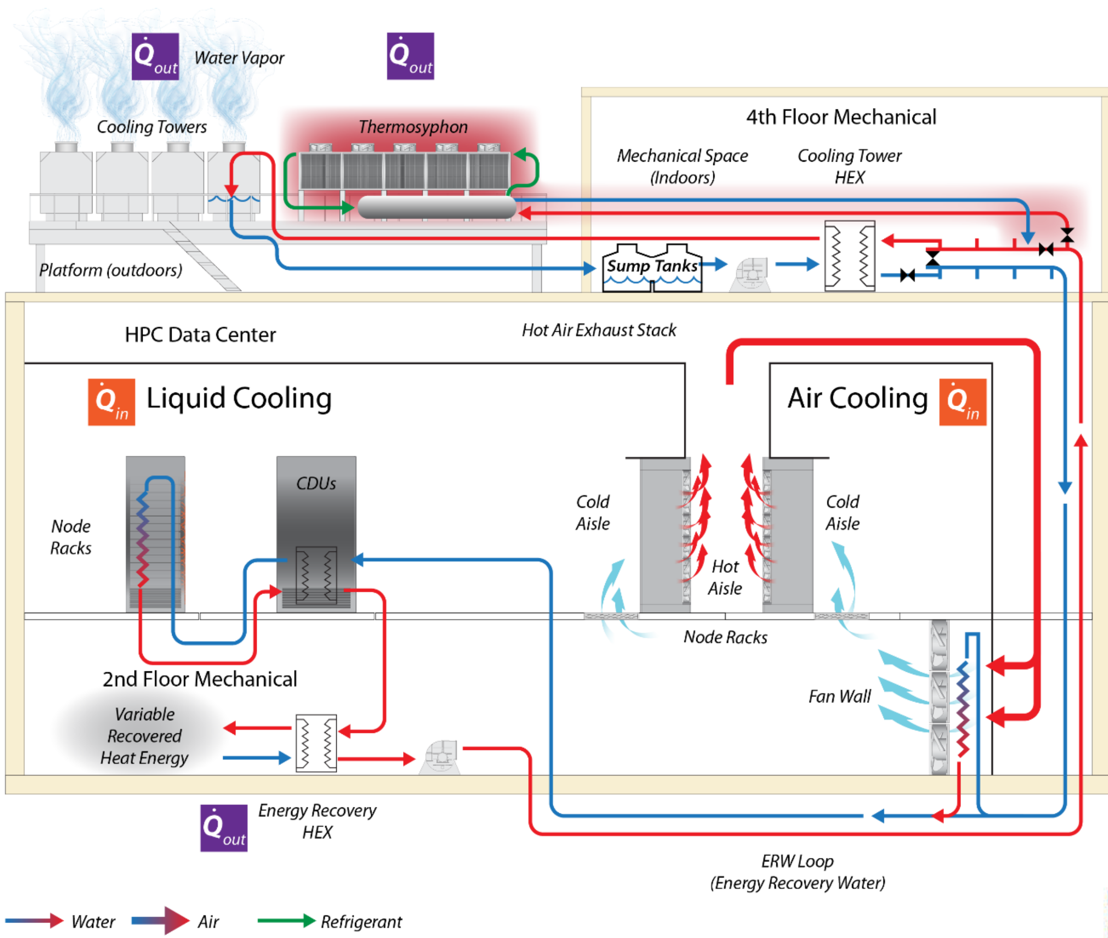


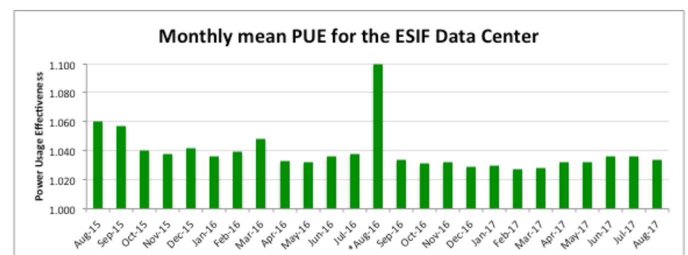
"Wet" when it's hot, "dry" when it's not.

Thermosyphon Cooler



Improved WUE—Thermosyphon





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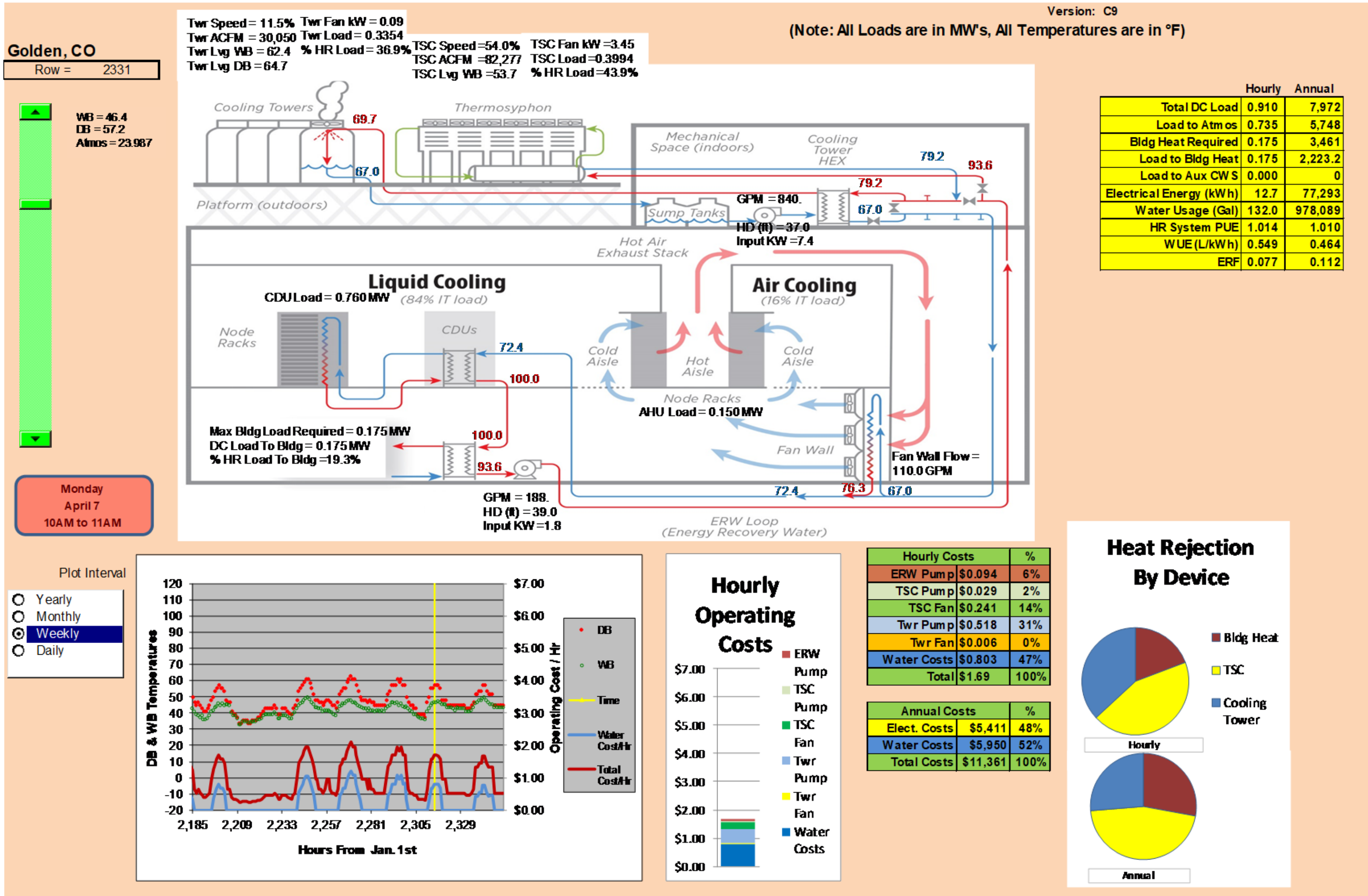
Johnson Controls

Sandia National Laboratories

System Modeling Program



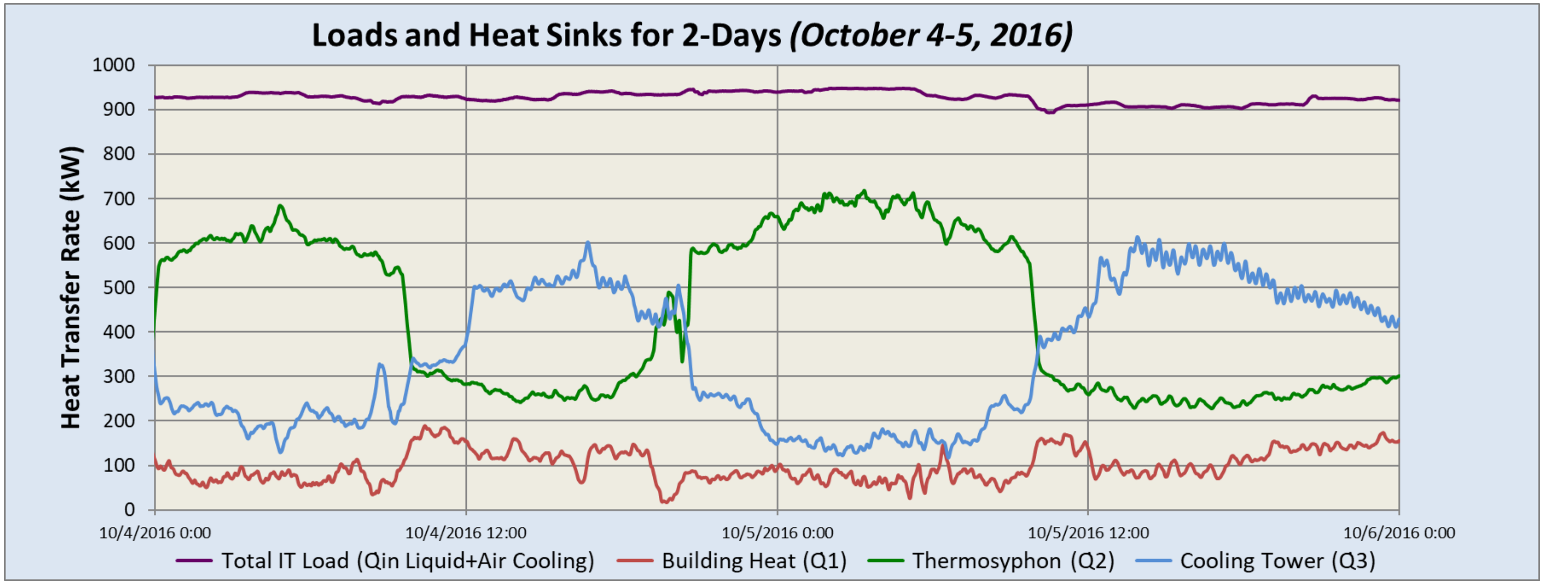
Applications

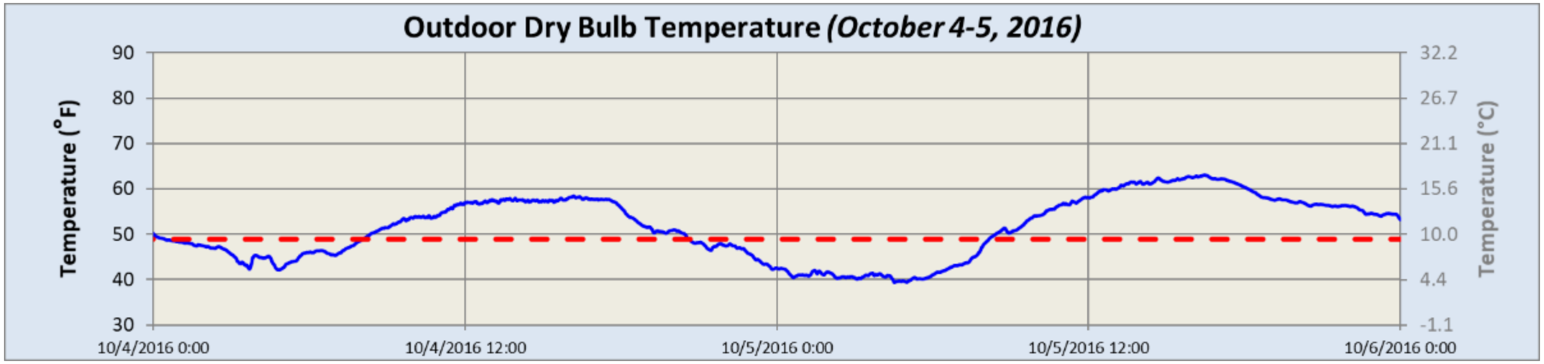
Any application using an open cooling tower is a potential application for a hybrid cooling system, but certain characteristics will increase the potential for success.

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

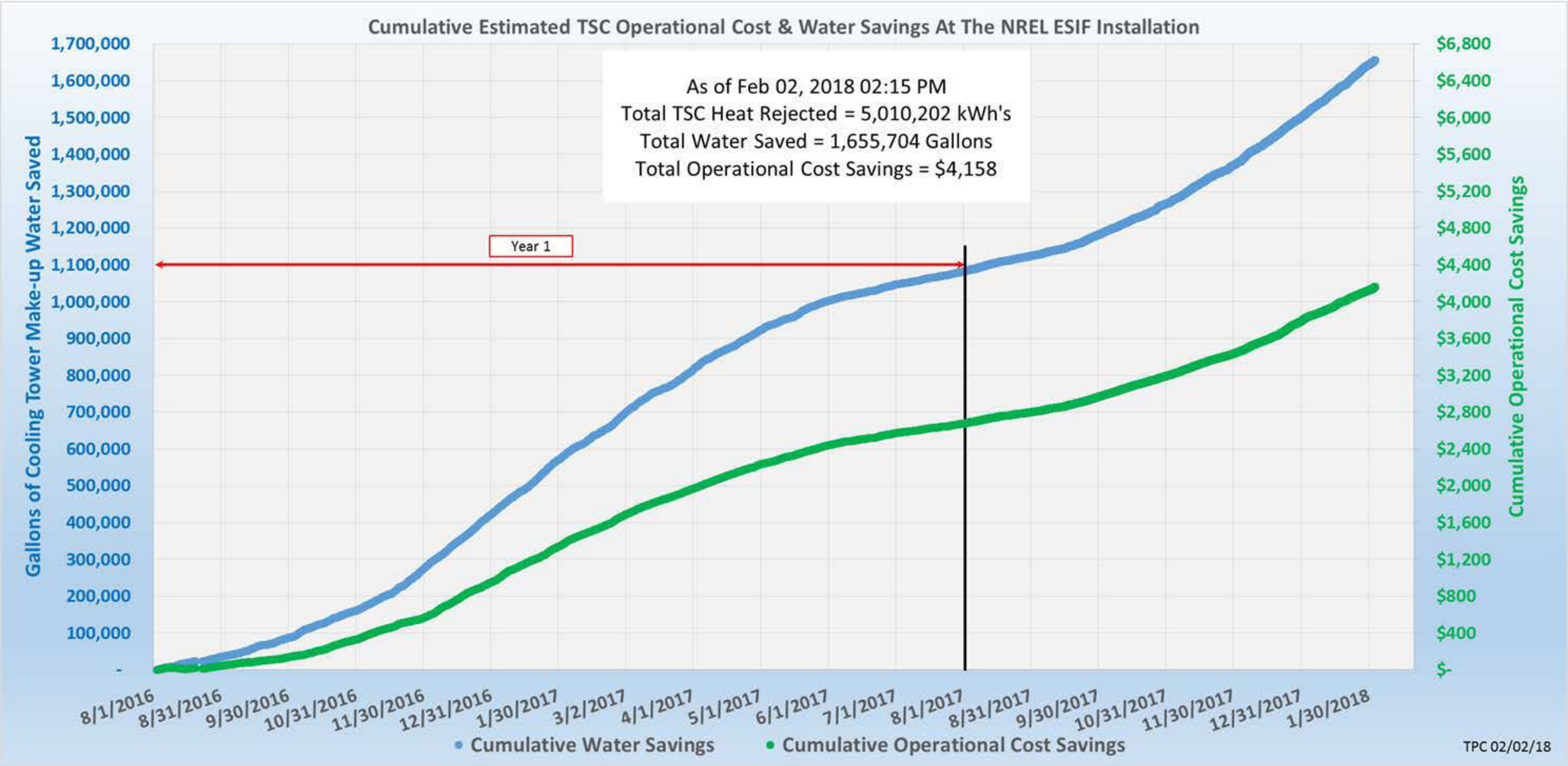
Sample Data: Typical Loads and Heat Sinks





Cumulative Water and Cost Savings

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



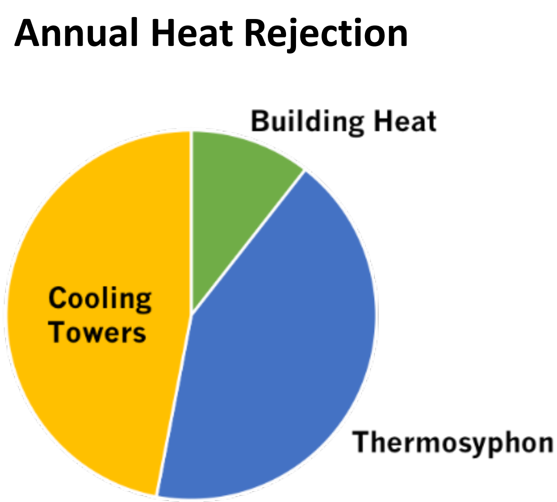
Data Center Metrics

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

Hourly average IT Load = 888 kW

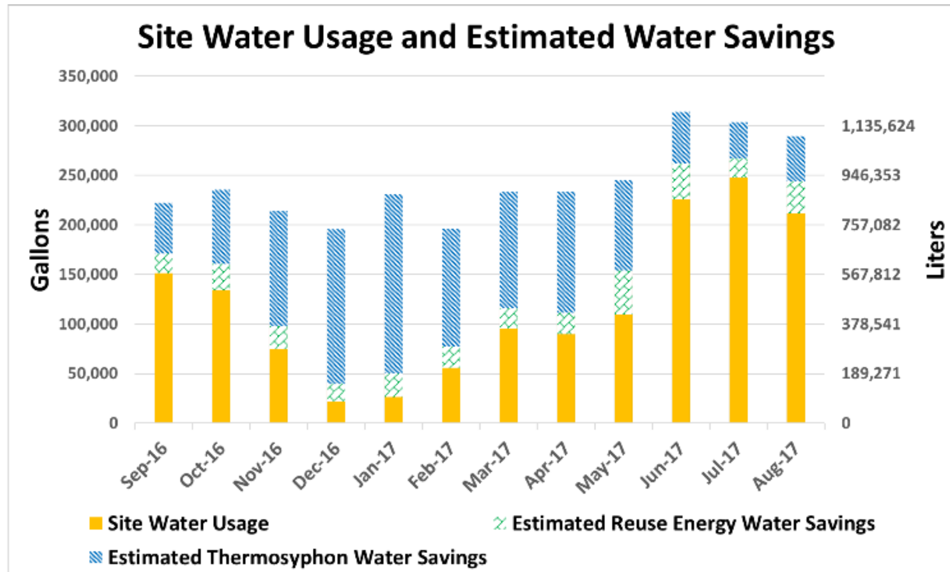
PUE = 1.034

ERE = 0.929



WUE = 0.7 liters/kWh

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



WUE_{SOURCE} = 5.4 liters/kWh

WUE_{SOURCE} = 4.9 liters/kWh if energy from 720 kW PV (10.5%) is included

using EWIF 4.542 liters/kWh for Colorado

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

Questions

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720 KW
50 KW
1,156 KW
408 KW
94 KW
449 KW
524 KW
NREL PV Systems - South Table Mesa Campus

Notice

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