U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Liquid Cooling Options and Challenges: Futureproofing Data Centers

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BERKELEY LAB

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Agenda: Liquid Cooling

1. Introduction
2. Liquid cooling techniques and requirements
   - ✓ In-rack liquid cooling
   - ✓ Rear-door heat exchangers
   - ✓ On-board/cold plate cooling
   - ✓ Liquid immersion
3. Relative performance and performance drivers
4. Issues, challenges, and the future
   - ✓ Wet and dry “free” cooling
   - ✓ Local heat sinks
   - ✓ Waste heat reuse
   - ✓ Open specifications
5. Future proofing - LBNL case study
6. Conclusion

Introduction

- Early mainframes were liquid cooled
- Mainframes to distributed and parallel, to cloud, to edge
- As densities increase need to return to liquid cooling
- Significant energy and water savings opportunities

Moving (Back) to Liquid Cooling

- As heat densities rise, liquid solutions become more attractive
- Volumetric heat capacity comparison:

(1.5 m^3)

Water

=

(5,380 m^3)

Air

Benefits of Liquid Cooling

- **Higher compute densities**
- **Higher efficiency**
  - Cooling at higher temperatures
    - Improved cooling efficiency
    - Increased economizer hours
    - Potential use of waste heat
    - Can reduce CapEx and OpEx
  - Reduced transport energy (x14)

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

➢ Vision: Eliminate compressor based cooling and water consumption

Liquid Cooling Techniques

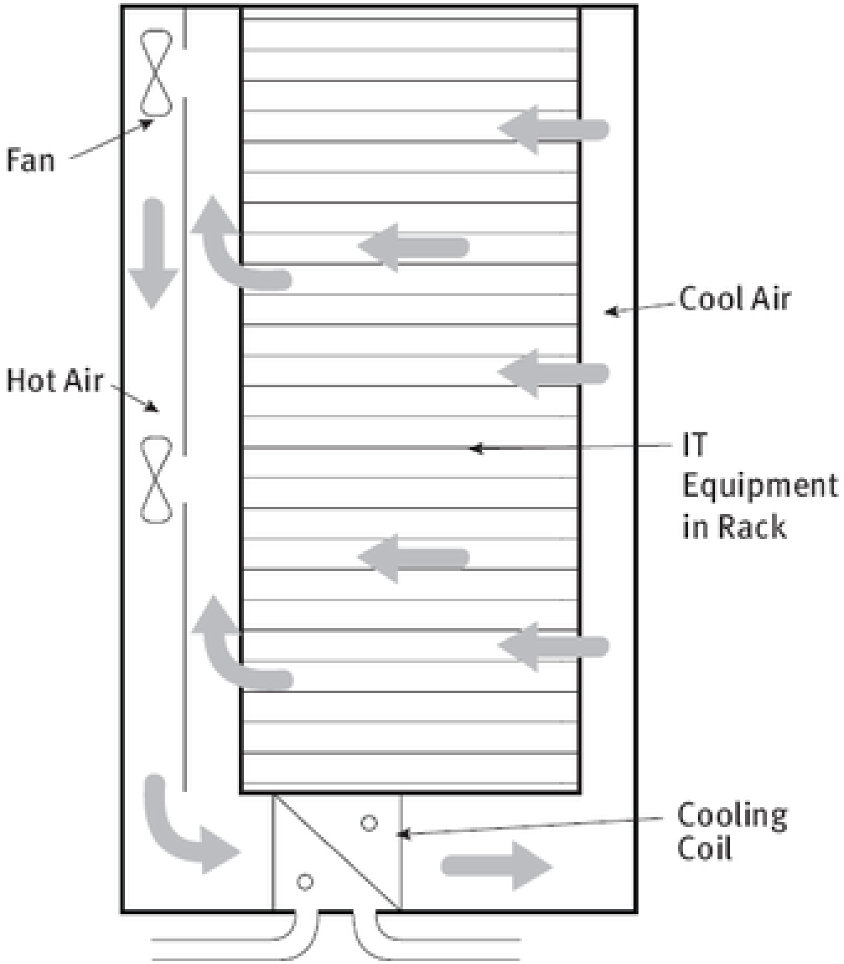
- CRAH, overhead, and in-row liquid cooling
- In-rack liquid cooling (enclosed cabinet)
- Rear door – passive and fan powered
- Cold plate
- Immersion

Far from Heat Source → Close to Heat Source

- CRAH
- Overhead
- InRow™
- Enclosed Cabinet
- Rear Door Heat Exchanger
- Conduction
- CPU Cold Plate
- Immersion

In-Rack Liquid Cooling

- Racks with integral coils and full containment:



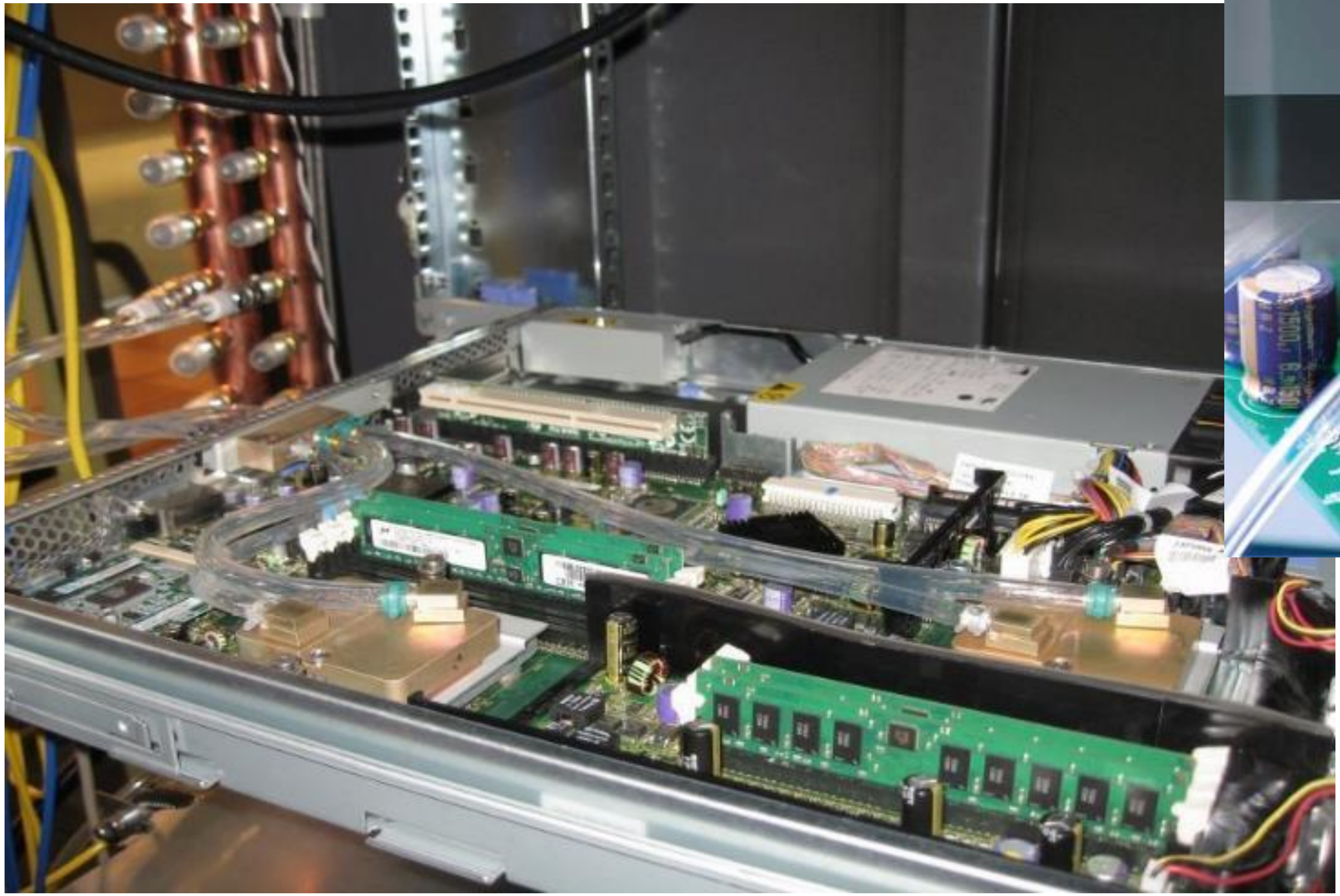
Rear-Door Heat Exchanger

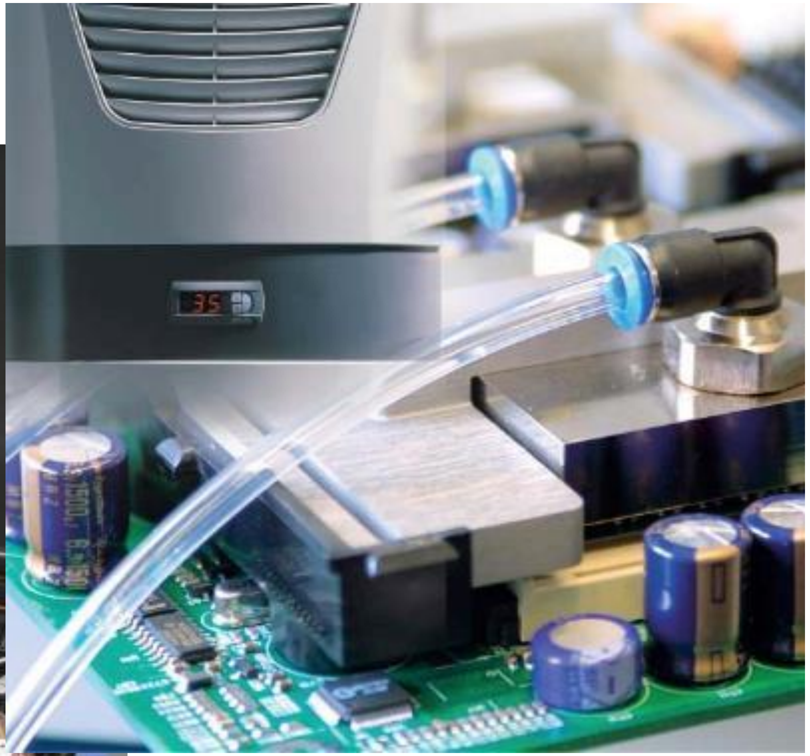
- Passive technology:
  relies on server fans for airflow
- Active technology:
  supplements server fans with external fans in door
- Can use chilled or higher temperature water for cooling

https://datacenters.lbl.gov/sites/default/files/rdhx-doe-femp.pdf

Photo courtesy of Vette

Liquid On-Board Cooling





Example: Maui DOD HPC Center Warm Water Cooling

Liquid cooled rack

- 90% water cooled
- 10% air cooled
- Cooling water temperature as high as 44°C

Water inside

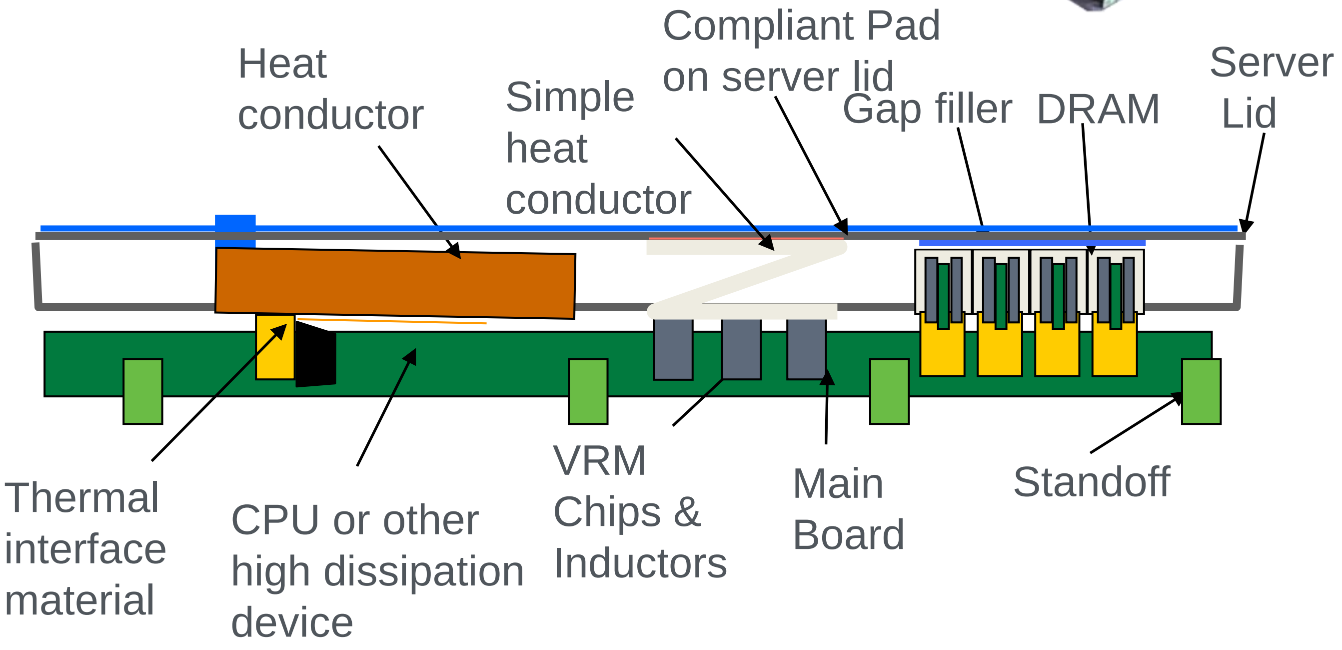
Dry Coolers, 10 kW each compared to 100 kW Chillers

https://datacenters.lbl.gov/sites/default/files/MHPCC%20White%20Paper%20_Mahdavi-July%202014.pdf

Cold Plate Variation 1

- Heat exchanger plate covers top of server and heat risers connect to hot components
- Test at NREL and SNL
- Server fans removed, 90+% liquid cooled
- Nodes never throttled back while testing between 24C – 35C entering

www.nrel.gov/docs/fy19osti/73356.pdf



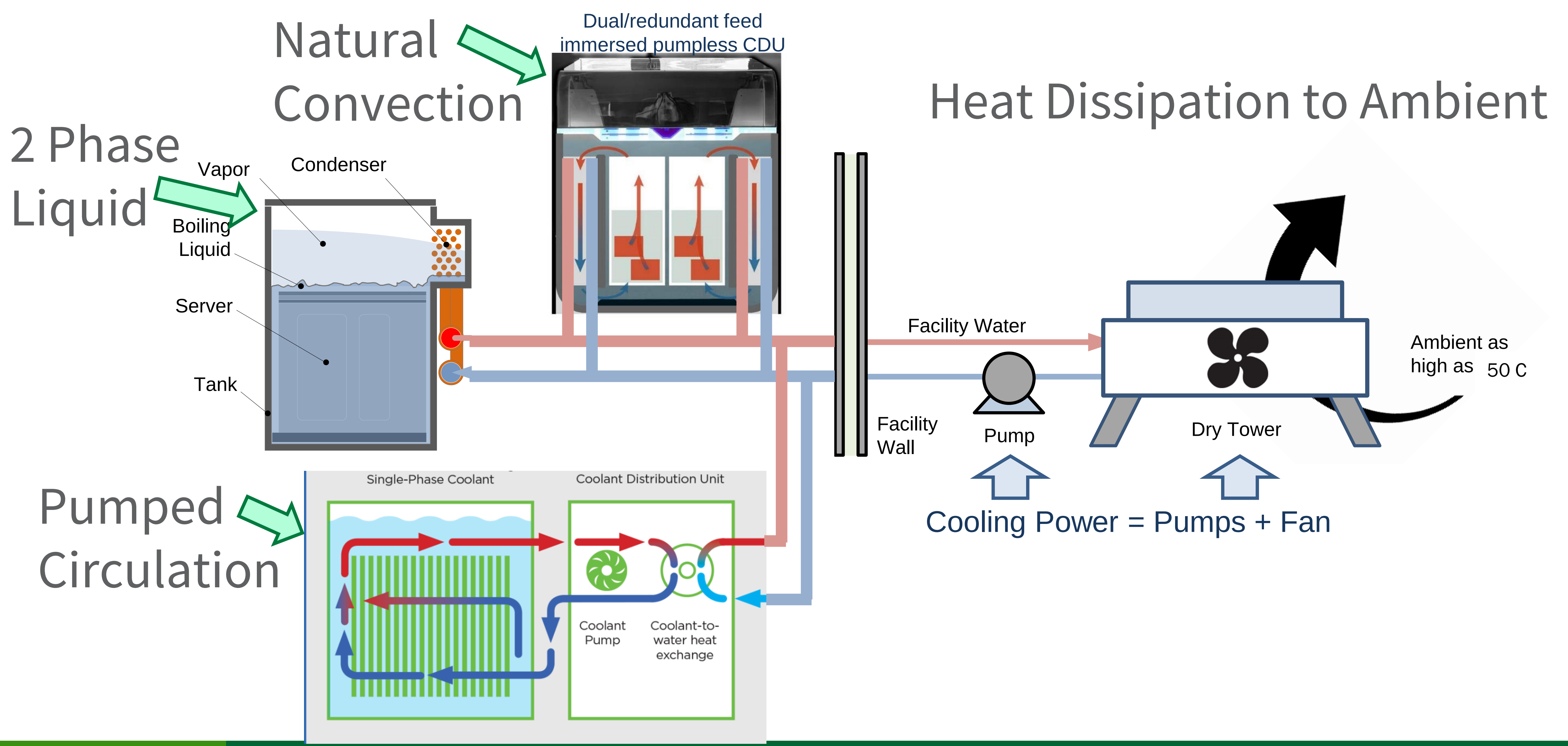
Cold Plate Variation 2

- Cold plates under negative pressure: Sandia National Lab Test
- ~30 kW per rack 12 volt DC (OCP Bus Bar)
- 70% liquid cooled, medium temp supply water 21 C, return water ~32 C, entering air temp 26 C
- Note partial cooling common with cold plates requires secondary cooling system

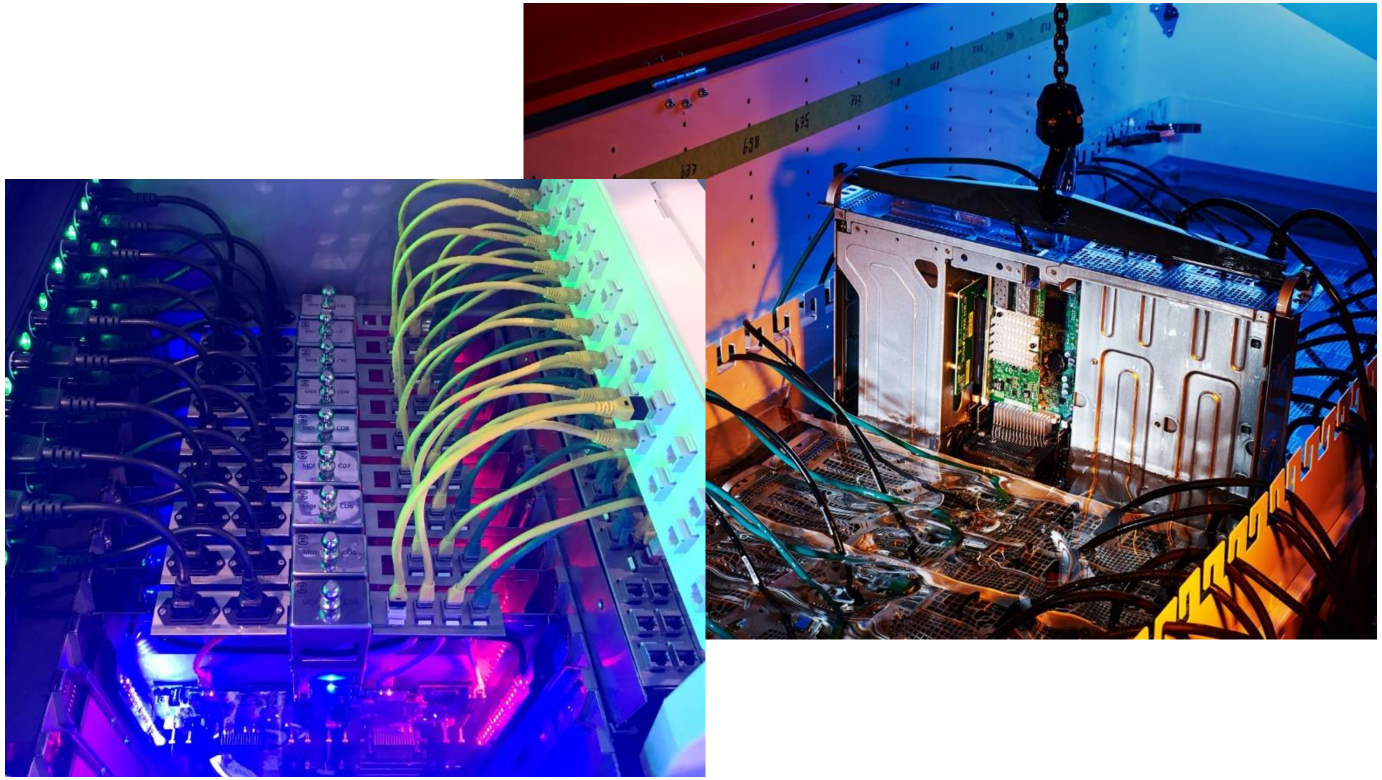
https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2020/206888r.pdf

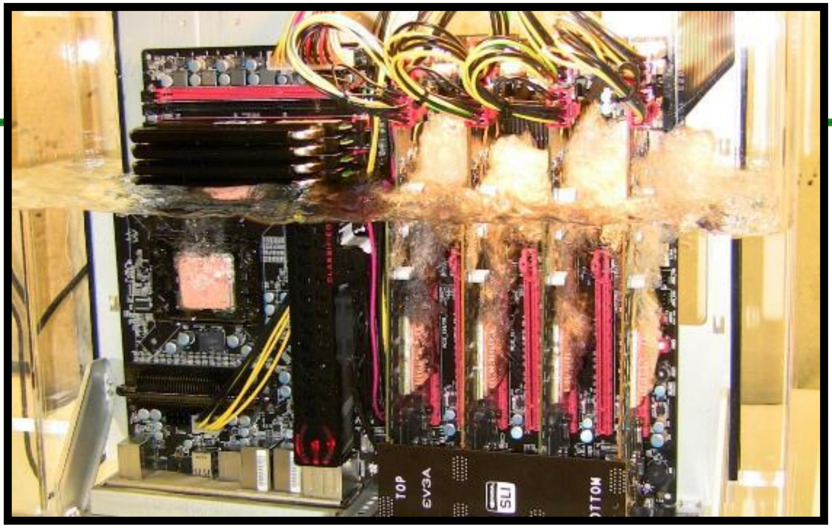
Negative pressure CDU

Liquid Immersion Cooling

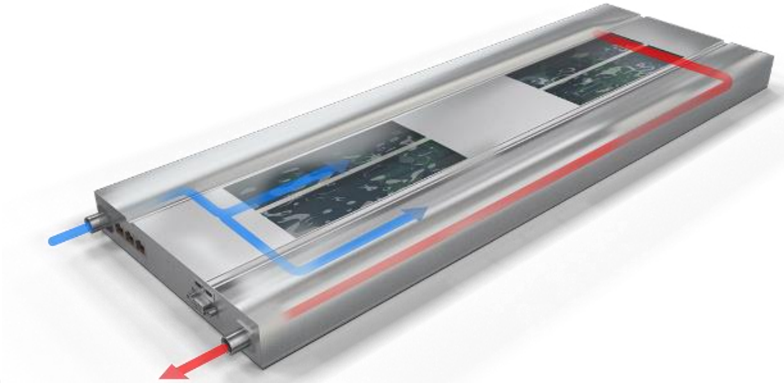


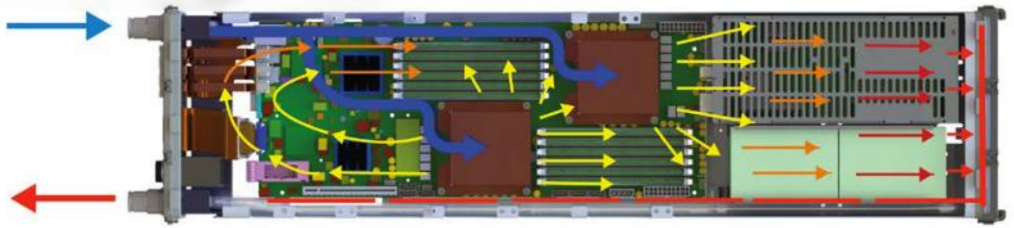
Liquid Immersion Cooling





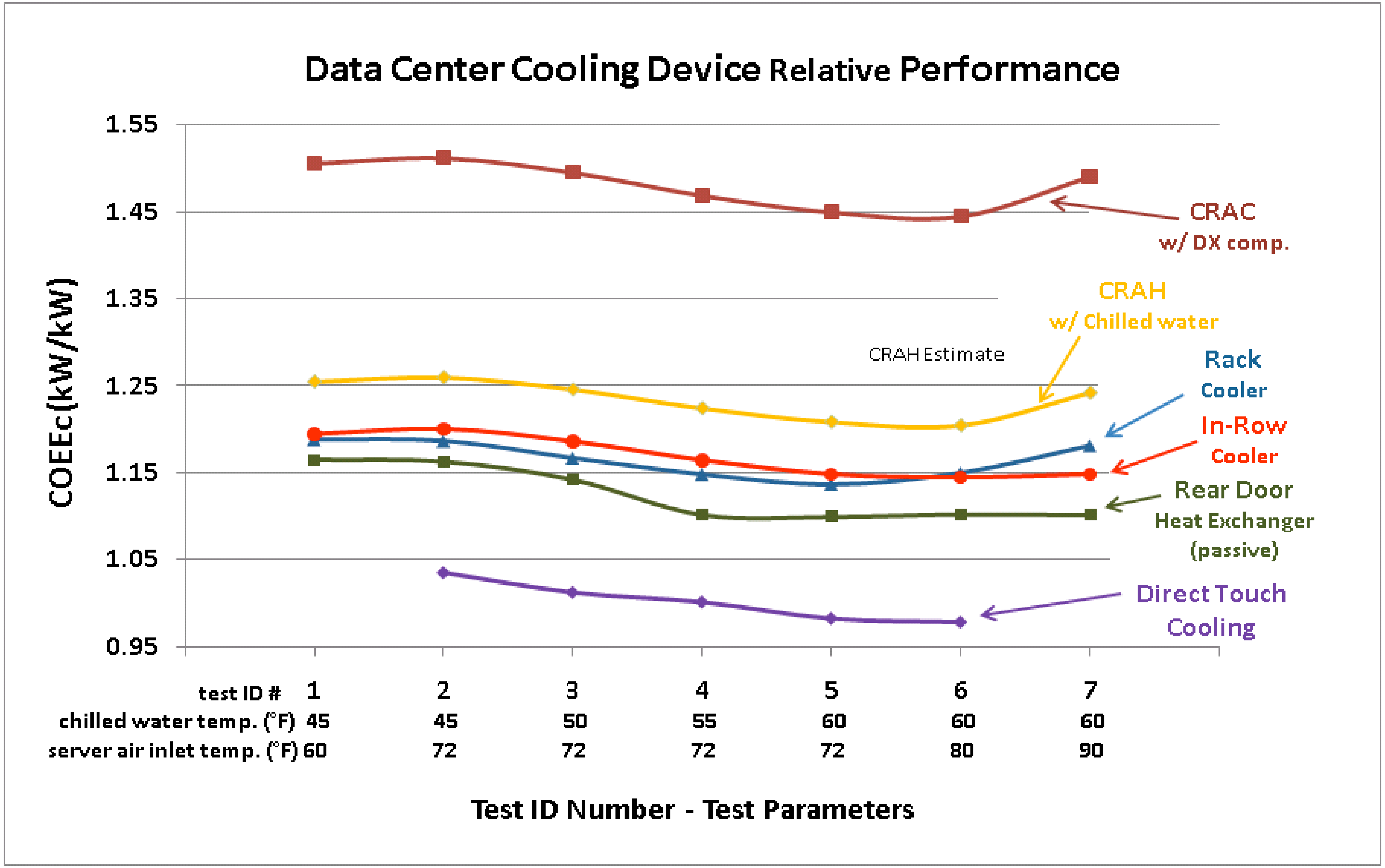
2-phase, fluorocarbon



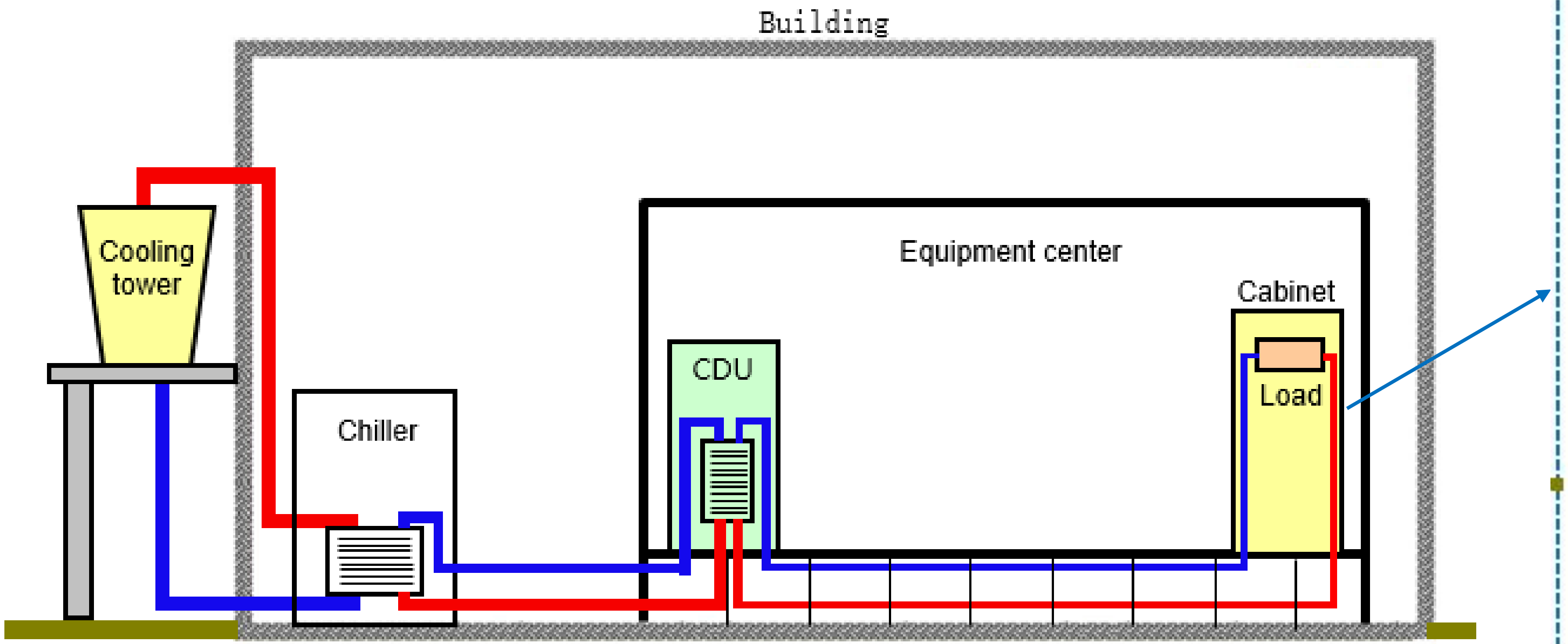


Single phase, hydrocarbon or fluorocarbon in tank (above) or in "Clamshell" (to right)

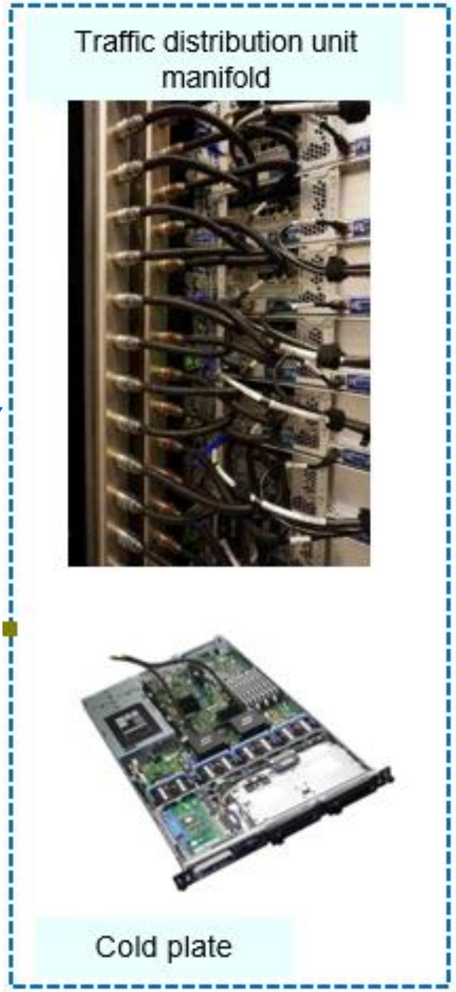
"Chill-Off 2" Evaluation of Liquid Cooling Solutions



Typical Liquid Cooling Solution



Typical liquid cooled equipment room, with external coolant distribution units (CDUs)



- For most locations data centers may be operated without chillers with a water-side economizer

"Free Cooling" w/ Water-Side Economizers

- Cooling without Compressors
- Less space/easier retrofit
- Added reliability (backup in case of chiller failure)
- No contamination issues
- Put in series with chiller
- Uses tower or dry cooler

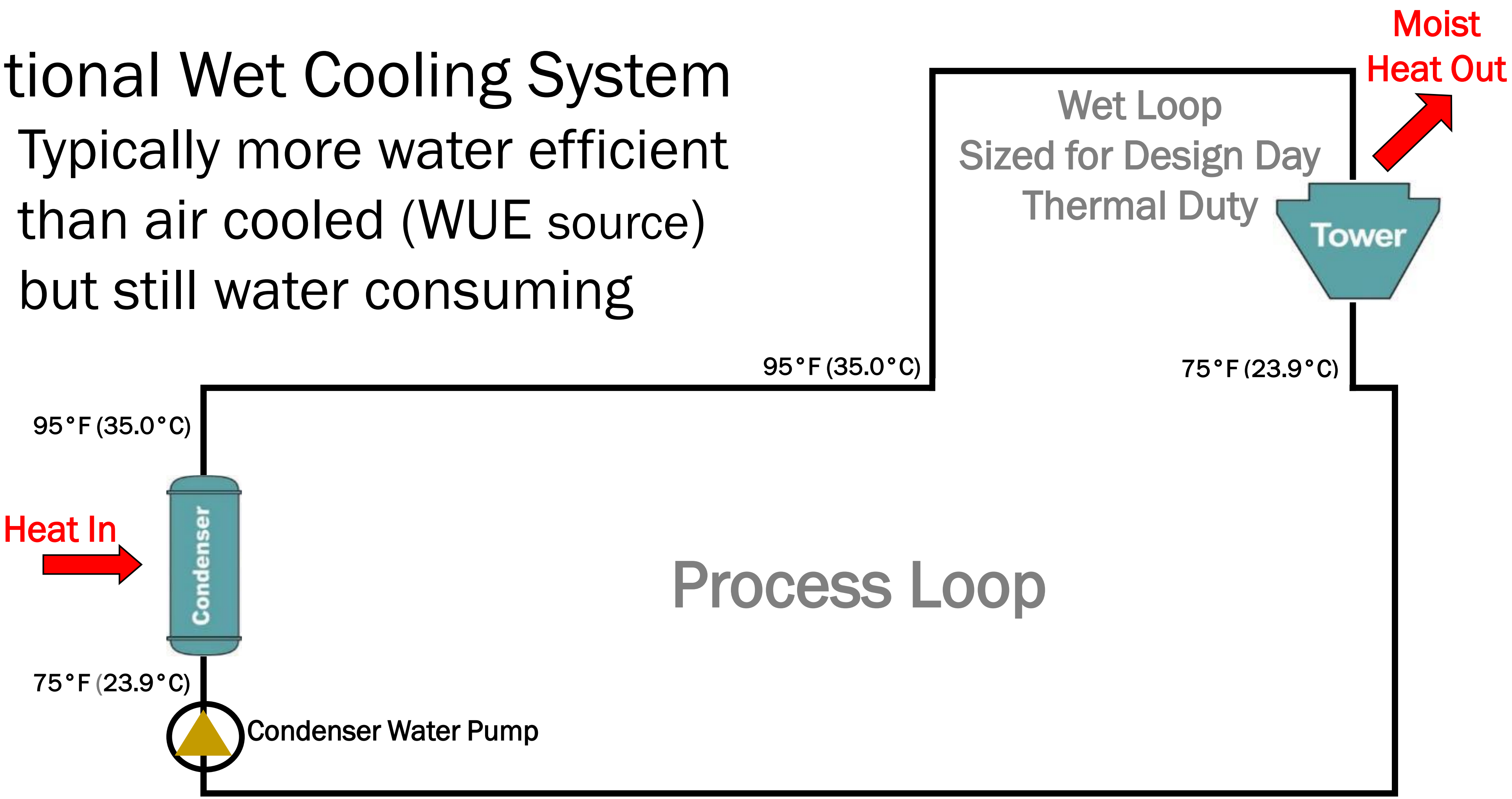
No or minimum compressor cooling

Cooling tower and HX = Water-side Economizer

What About Water Use?

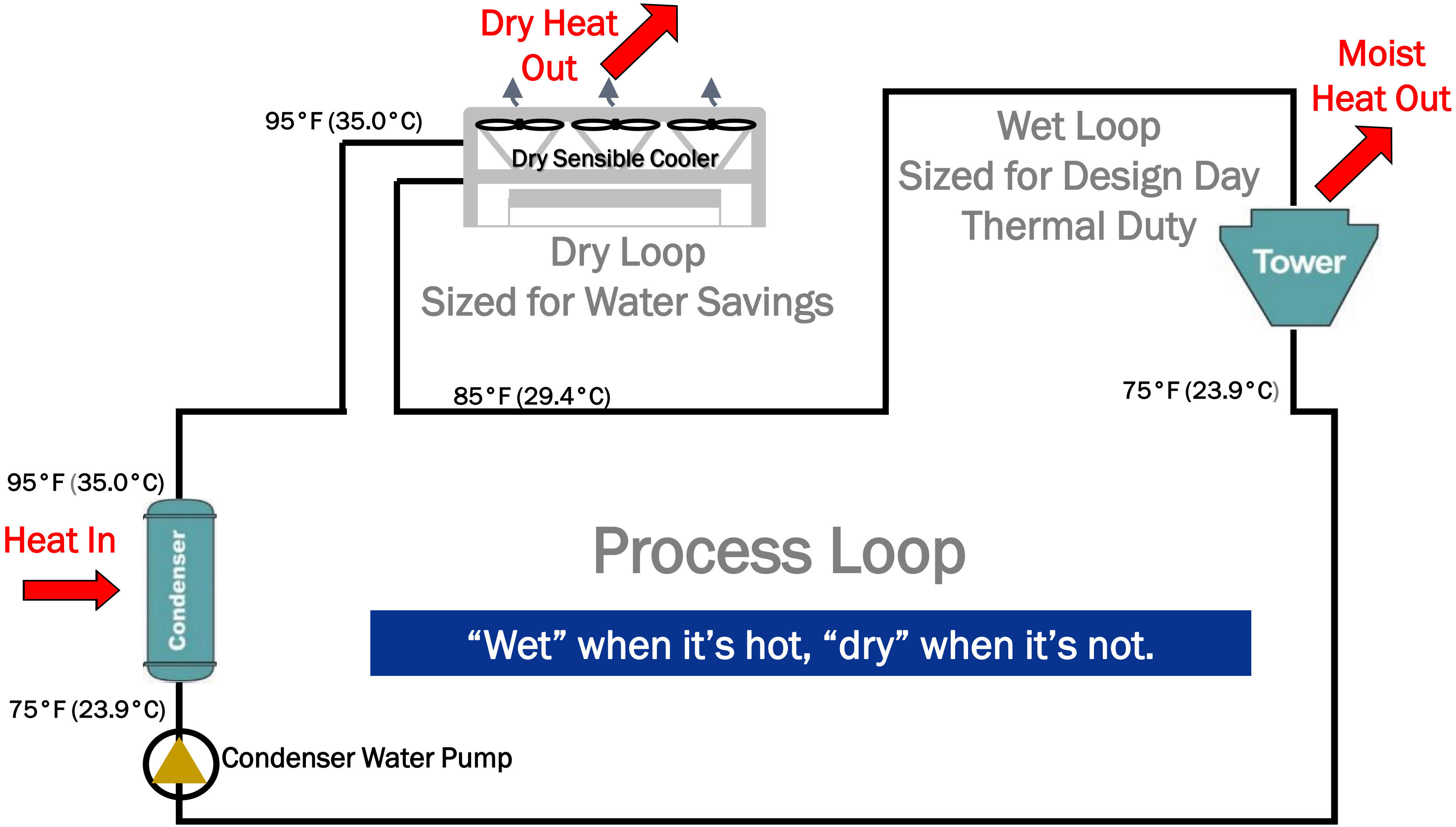
Traditional Wet Cooling System

- Typically more water efficient than air cooled (WUE source) but still water consuming



Courtesy of NREL

Hybrid System Concept



Courtesy of NREL

Water (vs. Air) Heat Sinks

- **Large bodies of water are great heat sinks**
  - Lakes/rivers
  - Aquifers (no depletion – water is returned)
  - Mine water
- **We are looking for partners to explore reuse of coal assets (mines and power plants) for data centers**
  - Mine water for energy (& water) efficient cooling
  - Use of other reusable infrastructure (e.g. power)
  - Renewable energy and storage options
  - See Iron Mountain’s use of mines and mine water

Re-Use of Waste Heat

- **Heat from a data center can be used for:**
  - Heating adjacent buildings directly
  - Preheating make-up air (e.g., “run around coil” for adjacent laboratories)
- **Use a heat pump to elevate temperature if needed**
  - Waste heat from an LBL data center captured with rear doors feeds a heat pump that provides hot water for reheat coils
- **Warm-water cooled computers are used to heat:**
  - Greenhouses, swimming pools, DHW, and district heating systems

Open Specifications for Liquid Cooling

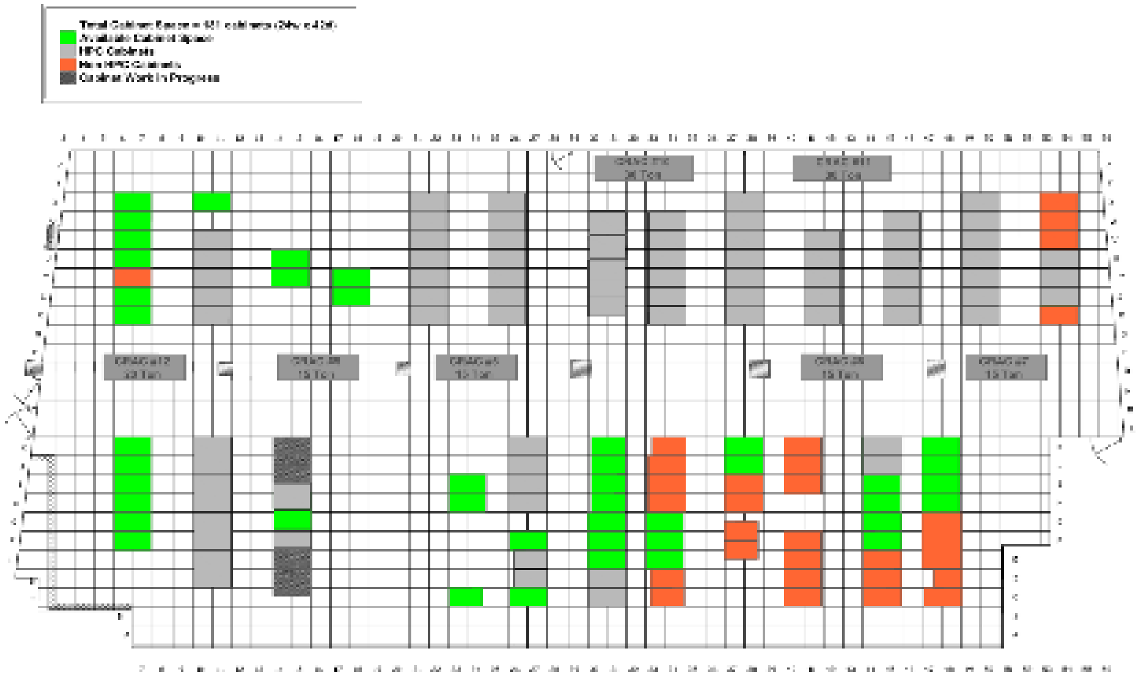
- **While liquid cooling potential is understood, uptake is slow**
- **Most solutions are unique and proprietary**
- **Needed:**
  - Standards
  - Multi-source solutions
  - Reusable rack infrastructure
- **Users can drive faster technology development and adoption**

ASHRAE Design Reference Conditions - 2021

Liquid Cooling Classes	Typical Infrastructure Design		Facility Supply Water Temperatures (°C)
	Main Heat Rejection Equipment	Supplemental Cooling Equipment	
W17	Chiller/Cooling Tower	Water-side Economizer (With Dry Cooler or Cooling Tower)	2 – 17
W27			2 – 27
W32	Cooling Tower	Chiller	2 – 32
W45	Water-side Economizer (With Dry Cooler or Cooling Tower)		2 – 45
W+	Building/District Heating System	Dry Cooler or Cooling Tower	> 45

LBNL Case Study – Future Proofing Plan

- **Super computers are already liquid cooled (each uniquely) but growing need in smaller HPC clusters that use more conventional components (e.g. server racks)**
- **10 Year Master Plan for legacy data center**
- **A transition back to liquid cooling**
  - Legacy and inherited systems
  - New(er) air cooled equipment
    - Multi-rack clusters
  - Future high density racks
    - 30kW+ per rack



LBNL Building 50B Room 1275 Data Center

Master Plan Drivers and Targets

Drivers:

- Increase density
- Need for energy efficiency
- Water consumption concern

Targets:

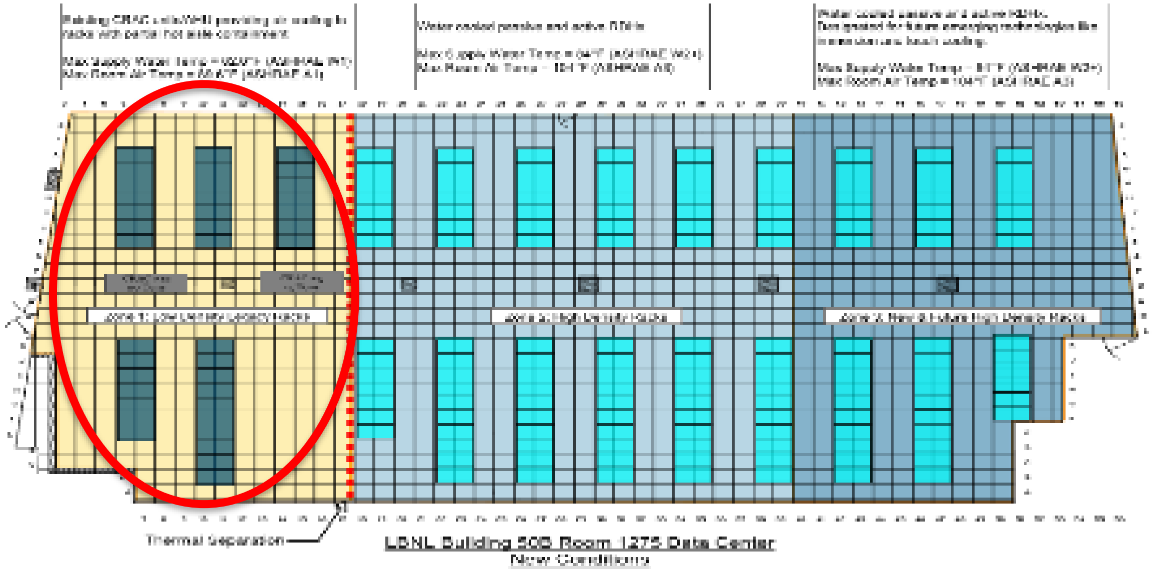
- IT MW: 0.5 growing to 1.2
- Space: Same or less
- PUE: 1.65 reduce to 1.2 (1.1 stretch)

➢ Conceptual 10 year plan with 3 zones:

1. Legacy air cooled
2. High density air cooled IT
3. High density direct liquid cooled

Zone 1 Legacy Air Cooled

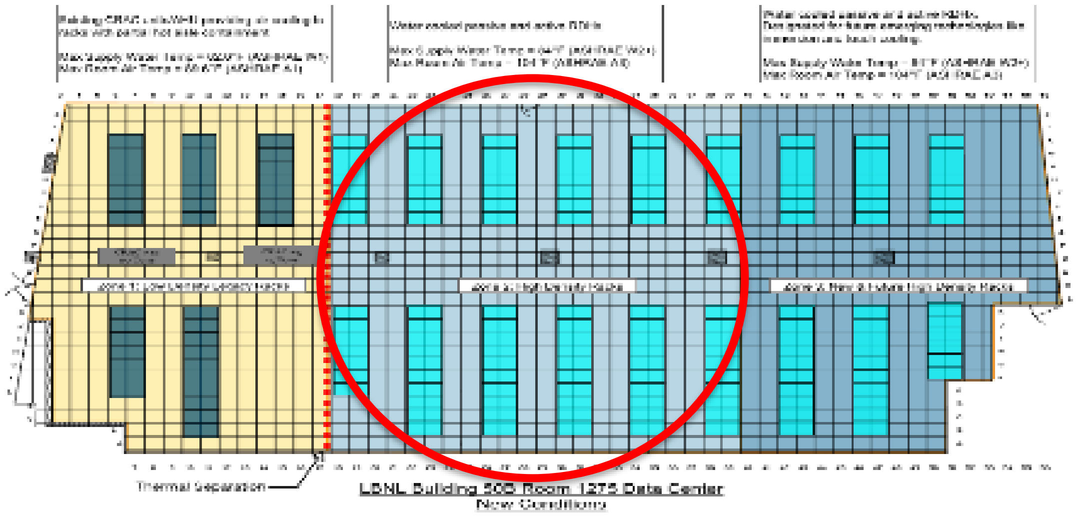
- ASHRAE A1: 27 C (80.6 F) operating, 32 C (89.6 F) maximum
- Raised floor
- Partial hot aisle containment
- Existing AHU and CRAC units



Upsite Technologies, Inc

Zone 2 High Density Air Cooled IT

- ASHRAE A3: 27 C (80.6 F) operating, 40 C (104 F) maximum
- Passive and active rear door heat exchangers
  - ➢ Selection based on rack load
- Rear doors supplied with 19 C (66 F) operating, 29 C (84 F) maximum water temp

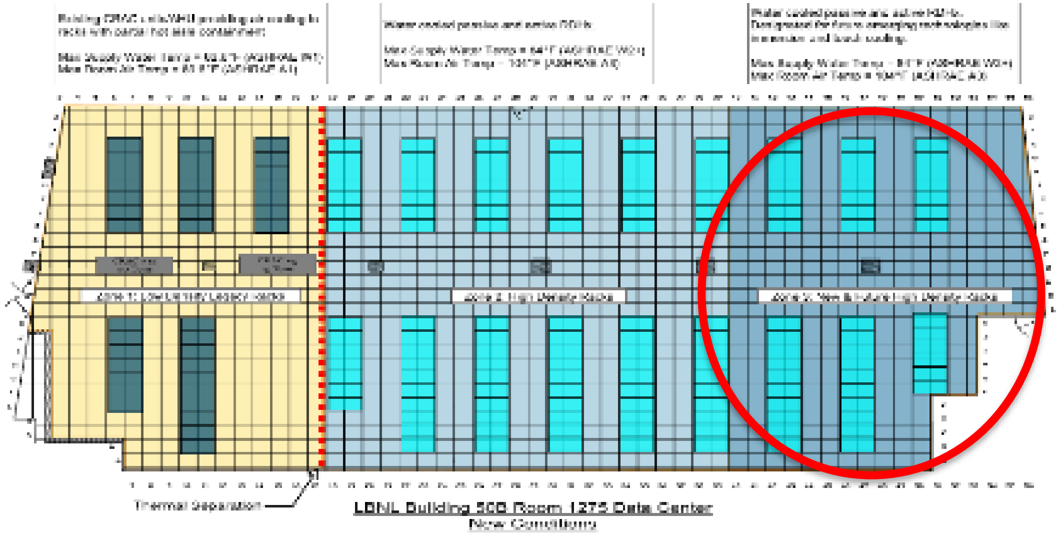


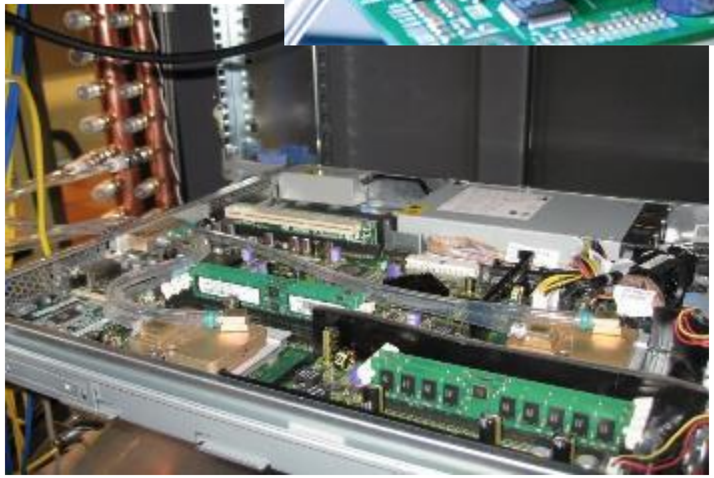
Passive Rear Door Heat Exchanger

Rear Door Heat Exchanger w/ Fan Assist

Zone 3 Super High Density Liquid to Chip Cooled

- ASHRAE W3(32)+ warm water cooling
- Airspace temperature = Zone 2
- Warmer water can be used, e.g. using effluent from Zone 2 or water cooled by outside air
- Need for liquid cooling rack standards

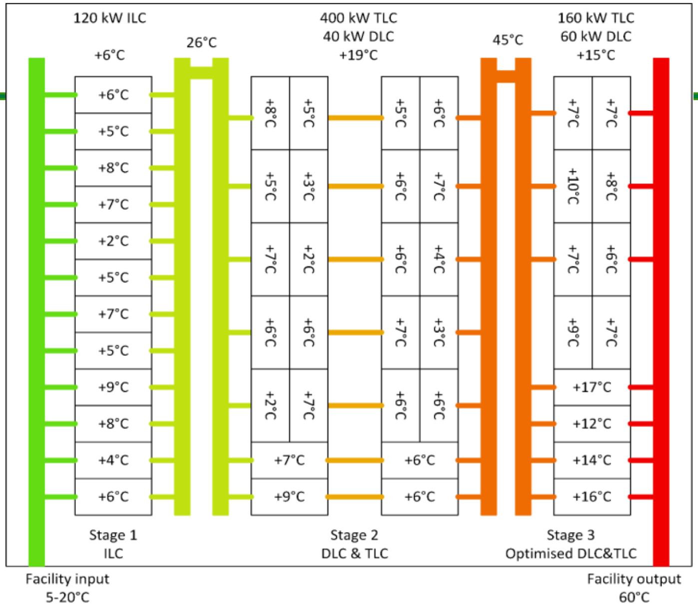




Cascading Temperatures

TECHNOLOGY	TYPICAL INLET RANGE		"W" CLASS	LBNL ZONE
	NORMAL	EXTREME		
CRAH	6-18°C	21°C	1	1
Rear Door	18-23°C	29°C	2 & 3	2
Cold Plate	18-40°C	45°C	3 & 4	3
Immersion	18-40°C	55°C	4 & 5	3

"Extreme" is the maximum inlet temperature for specific systems and may not represent all available options



https://www.asperitas.com/wp-content/uploads/2019/03/Asperitas-The-Datacentre-of-the-Future.pdf

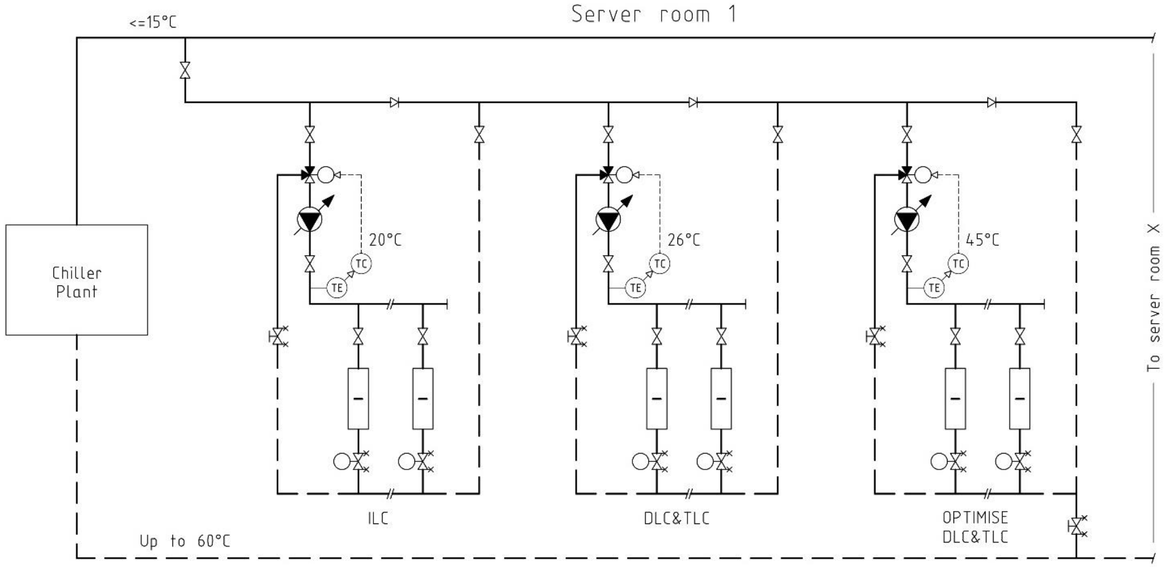


Image 11 Chiller based Temperature Chaining by Tebodin Bilfinger

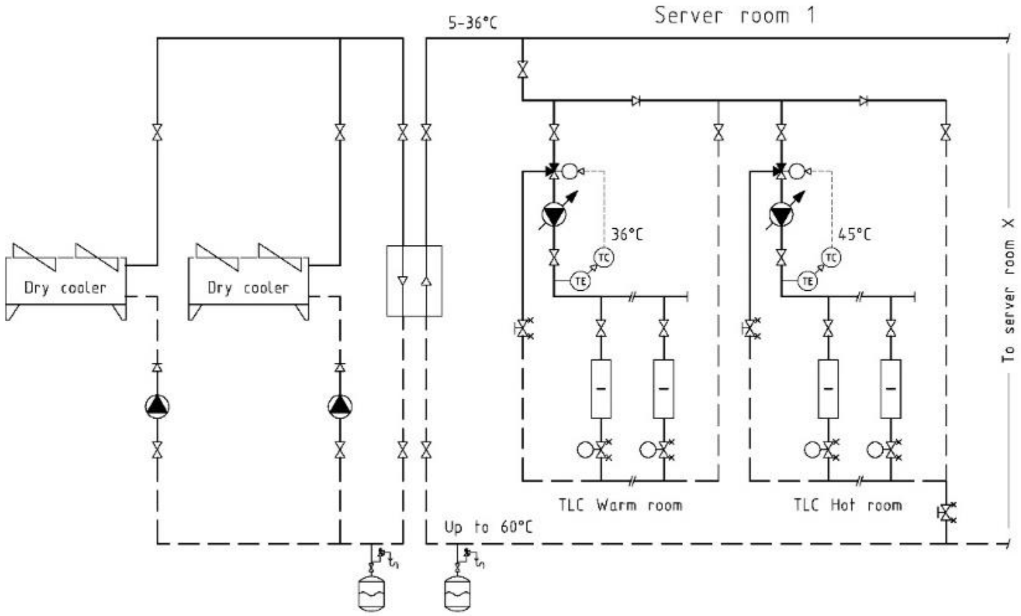


Image 12 Free Cooling based Temperature Chaining by Tebodin Bilfinger

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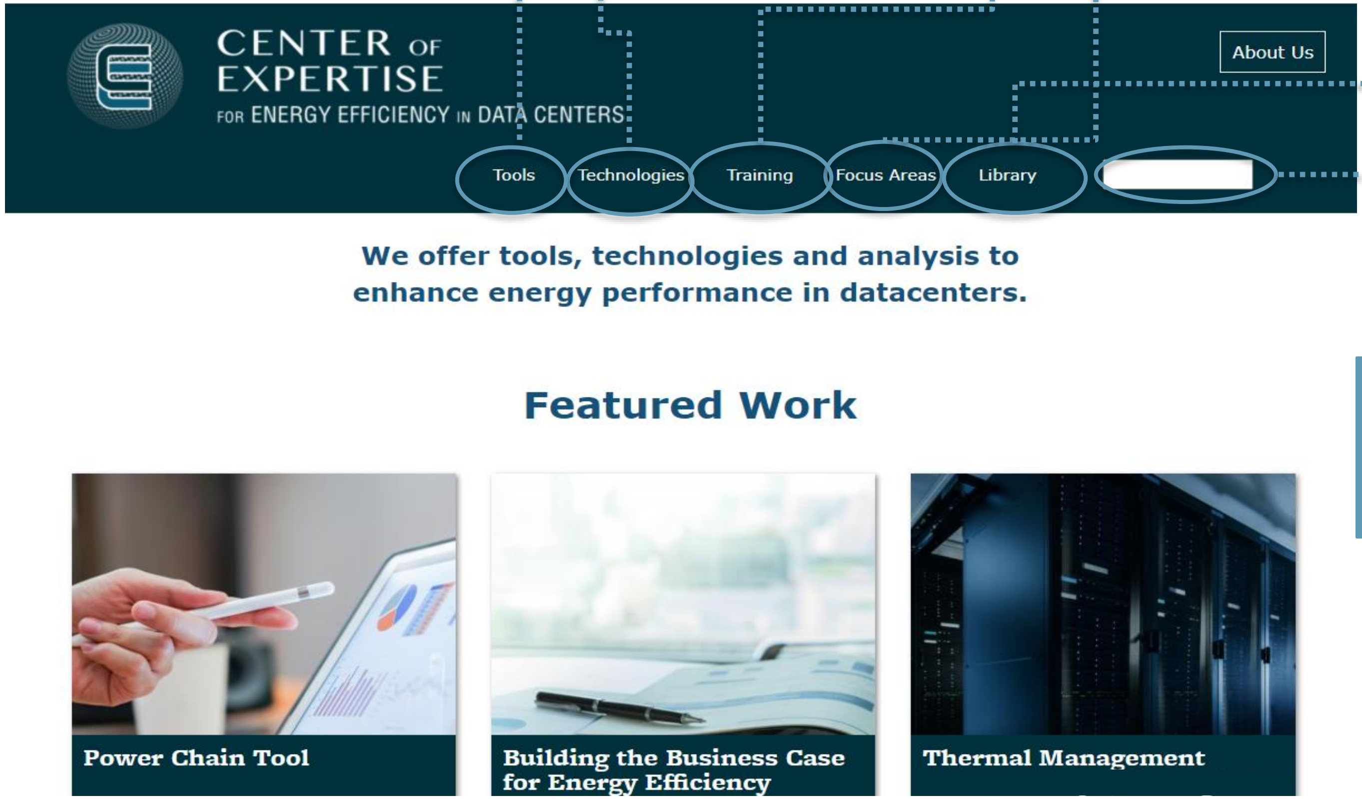

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Conclusion

- Liquid cooling can move us to compressorless cooling
- Water savings and heat recovery are further goals
- Facility needs a "warm" water loop
  - ✓ Using chilled water doesn't capture many of the benefits (efficiency, reliability, simplicity, first cost)
  - ✓ Can start with water fed CRAC units, move to rear doors (good transitional technology), and ultimately to cold plates and/or immersion
  - ✓ CoLo's should offer it, customers should demand it

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