“Hot” for Warm Water Cooling

Energy Efficient HPC Working Group
SC11 State of the Practice
November, 2011

Energy Efficient High Performance Computing Working Group

(EE HPC WG)

- Formed to drive energy efficient design and operation of HPC facilities and influence efficiency of High Performance Computers
- Demonstrate leadership in energy efficiency as well as computing performance
- Forum for sharing of information (peer-to-peer exchange) and collective action
- Collaboration with industry groups and HPC vendors

http://eehpcwg.lbl.gov

EE HPC WG

- Supported by the DOE Sustainability Performance Office
- Organized and led by Lawrence Berkeley National Laboratory
- Participants from DOE National Laboratories, Academia, various Federal Agencies, and International stakeholders
- HPC vendor participation
- Working Group selects energy related topics to develop

EE HPC WG Priorities

HPC Energy Efficiency:

- Metrics and benchmarking
- Best practices, tools, and resources
- Procurement guidelines
- Design guidelines
- Case studies
- Lessons learned and specifications
- Technical programs for key Conferences

BERKELEY LAB
Lawrence Berkeley National Laboratory

Liquid Cooling sub-committee

Goal: Encourage highly efficient liquid cooling through use of high temperature fluids delivered to the inlet of IT equipment

- Eliminate or dramatically reduce use of compressor cooling (chillers); secondarily – reduce water use
- Standardize temperature requirements – Common understanding between HPC mfgs and sites
- Ensure practicality of recommendations - Collaboration with HPC vendor community to develop attainable recommended limits
- Industry endorsement of recommended limits - Collaboration with ASHRAE to adopt recommendations in new thermal guidelines

“Hot” for Warm Water Cooling

paper presented at SC-11

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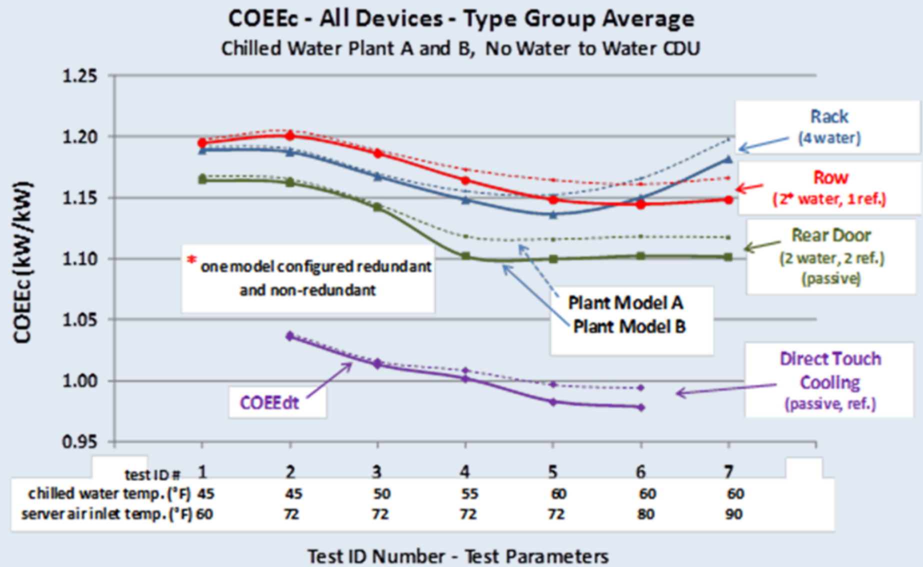
What is driving liquid cooling?

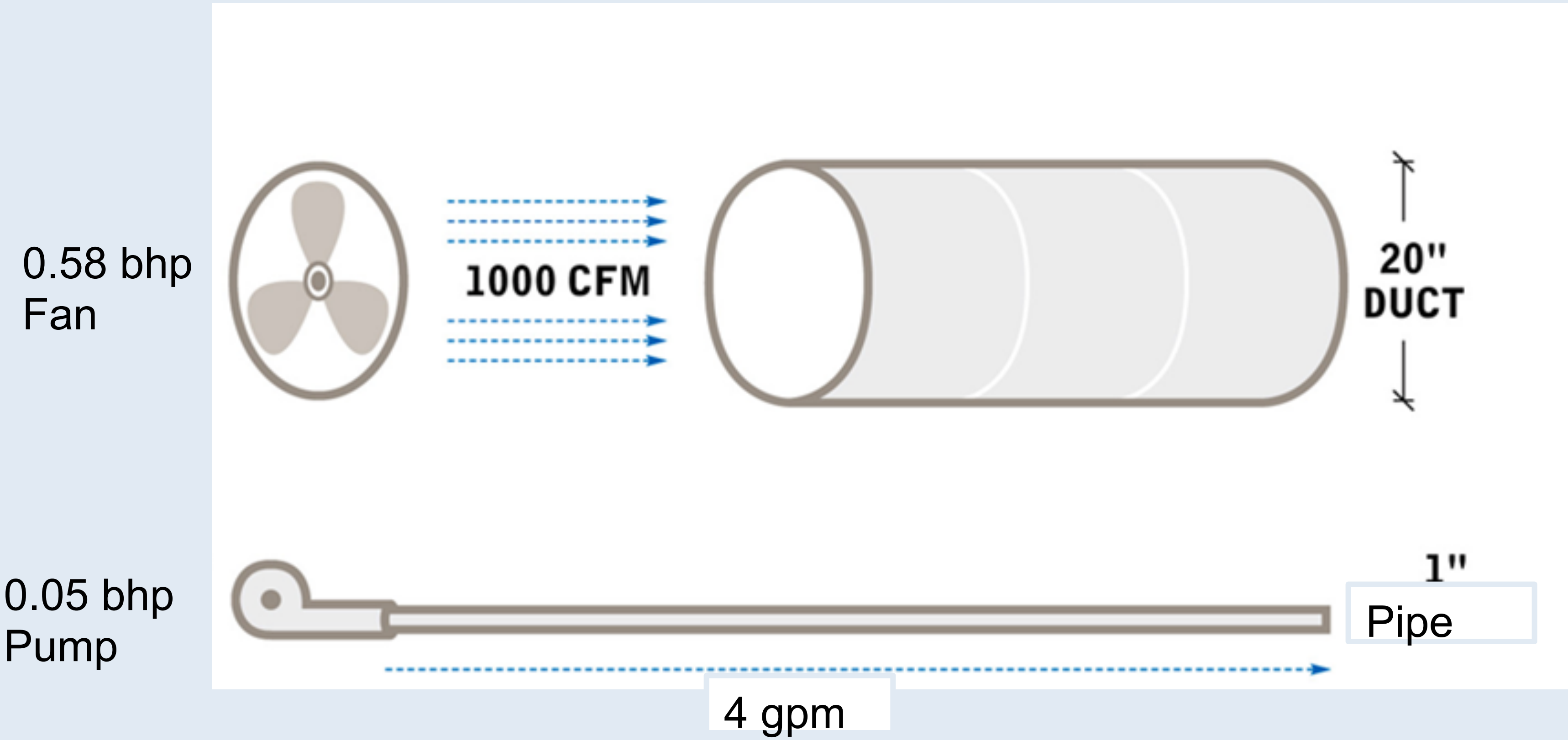
- HPC systems' power requirements and power density increasing
- PUE's are improving but high end is reaching limit of air cooling
- Liquid is a more efficient cooling medium
  - High specific heat, smaller volumes are needed
  - Gas to solid thermal resistances are high, large temperature differentials required
  - Liquid cooling eliminates "shadow" effects and produces higher delta T
- Higher temperature liquid leaving IT equipment can facilitate heat re-use
- Many flavors of liquid cooling –
  - Liquid at facility level (chilled water)
  - Modular in row, rack, and rear door cooling solutions becoming popular
  - Liquid inside the HPC equipment to the server or to the processor

Liquid cooled IT equipment

- Many configurations use liquid to cool air-cooled IT equipment
  - Rack level cooling - Through row cooling
  - Overhead cooling - Rear door heat exchangers
- Cooling effectiveness is better closer to the heat source
  - More heat is captured - less air mixing, conduction, etc.
  - Closer to the heat source, higher temperatures can be used
- "Chill-off" testing confirmed efficiency of modular cooling systems

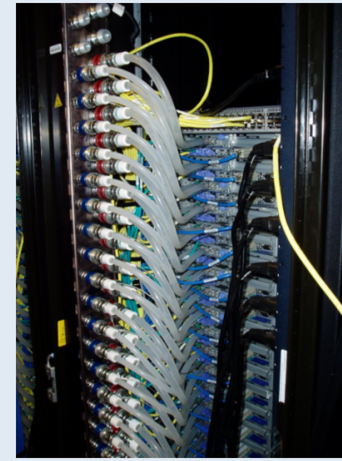


Liquids Move Energy More Efficiently

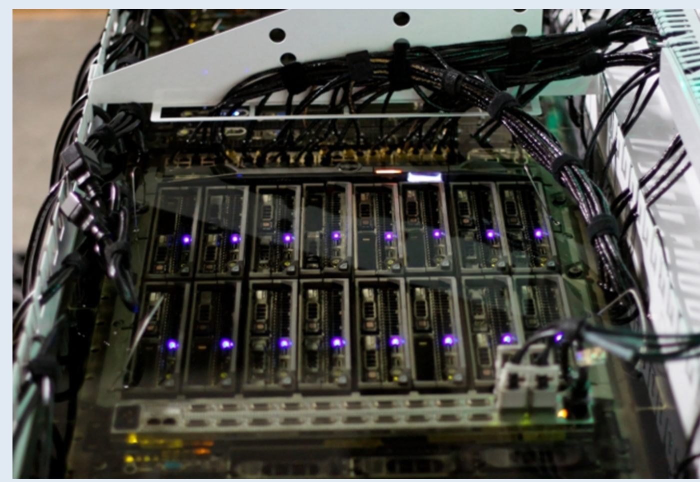


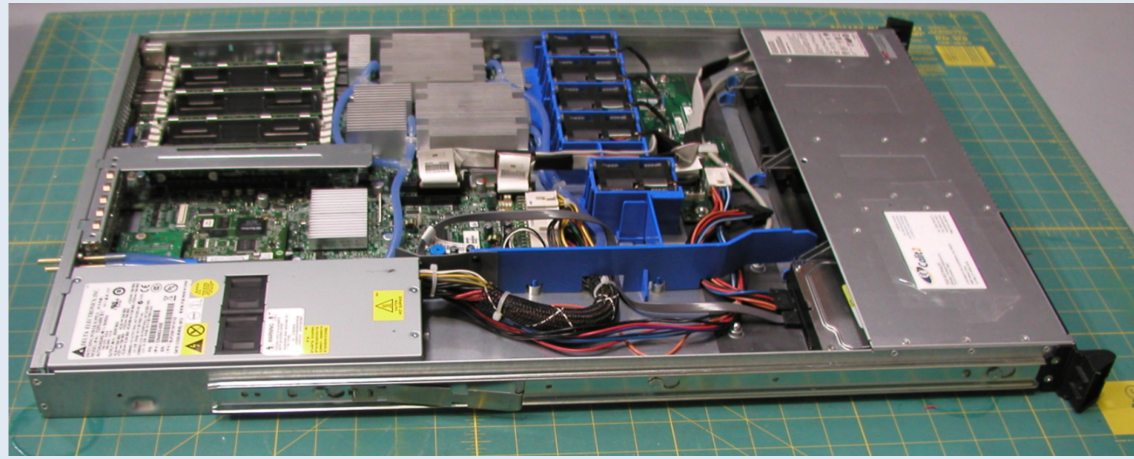
Flow		Formula	DT		BTUH	Eff	DP		Formula	BHP
1,000	cfm	BTUH=1.1*cfm*DT	21.8	°F	24,000	54%	2	in w.c.	bhp=cfm*DP/(6350*eff)	0.58
4	gpm	BTUH=500*gpm*DT	12.0	°F	24,000	80%	40	ft w.c.	bhp=gpm*DP/(3960*eff)	0.05

Types of liquid Solutions within IT equipment:



- Submersion in dielectric fluid (early Cray)
- Submersion in Oil (Green Revolution Cooling)
- Fluid to the server
- Fluid all the way to the CPU case (IBM)
- Fluid sprayed on CPU (Spraycool)
- Combination conduction and liquid cooled (Clustered Systems)





General Approach

Goal: Develop guidelines for liquid cooling temperatures at the inlet to IT equipment

- Determine climate conditions where National Laboratories are located
- Analyze systems that use evaporation (cooling towers) or dry coolers for ultimate heat rejection to atmosphere
- Model heat transfer from the processor to atmosphere
- Determine consensus of thermal margin to critical processor temperatures
- Obtain industry buy in for recommended temperatures

Methods

Determine National Laboratory locations and obtain ASHRAE Dry Bulb and Wet Bulb ASHRAE Design Data for 99.6% of conditions (all but a few hours per year)

Develop Cooling Architectures without compressors

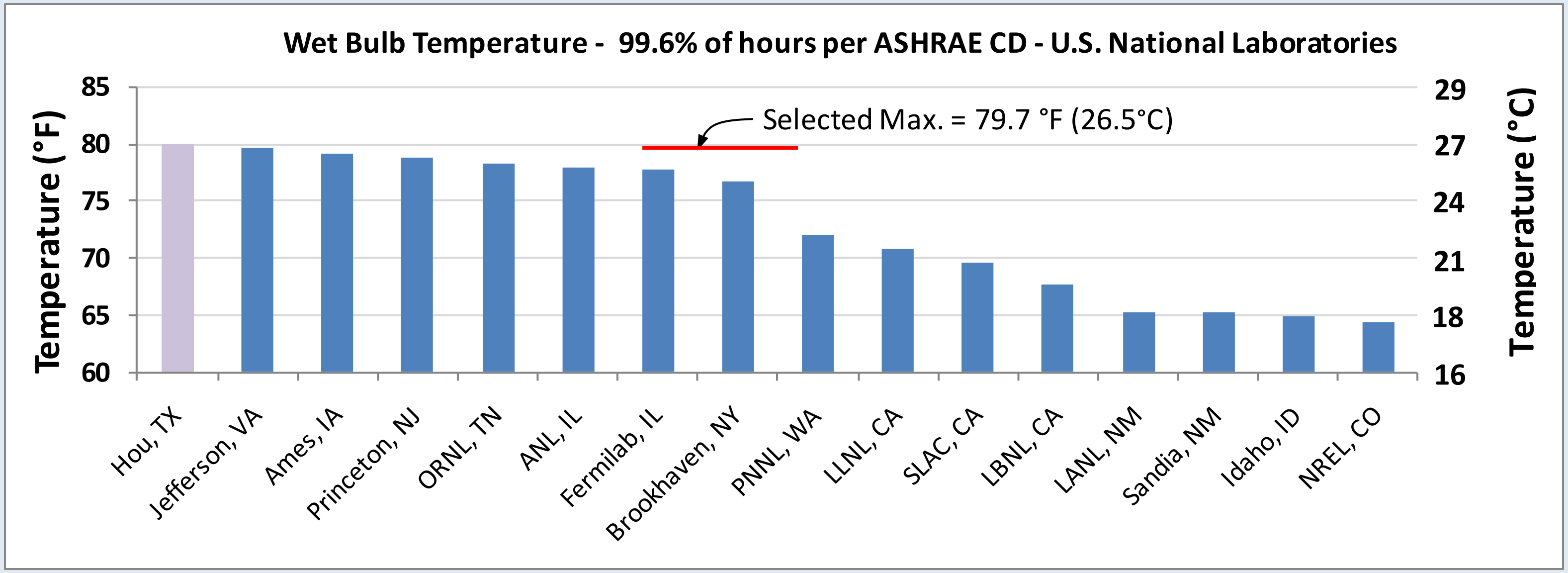
- Cooling towers – evaporative cooling limited by wet bulb temperature
- Dry coolers – air to air heat exchange limited by dry bulb temperature

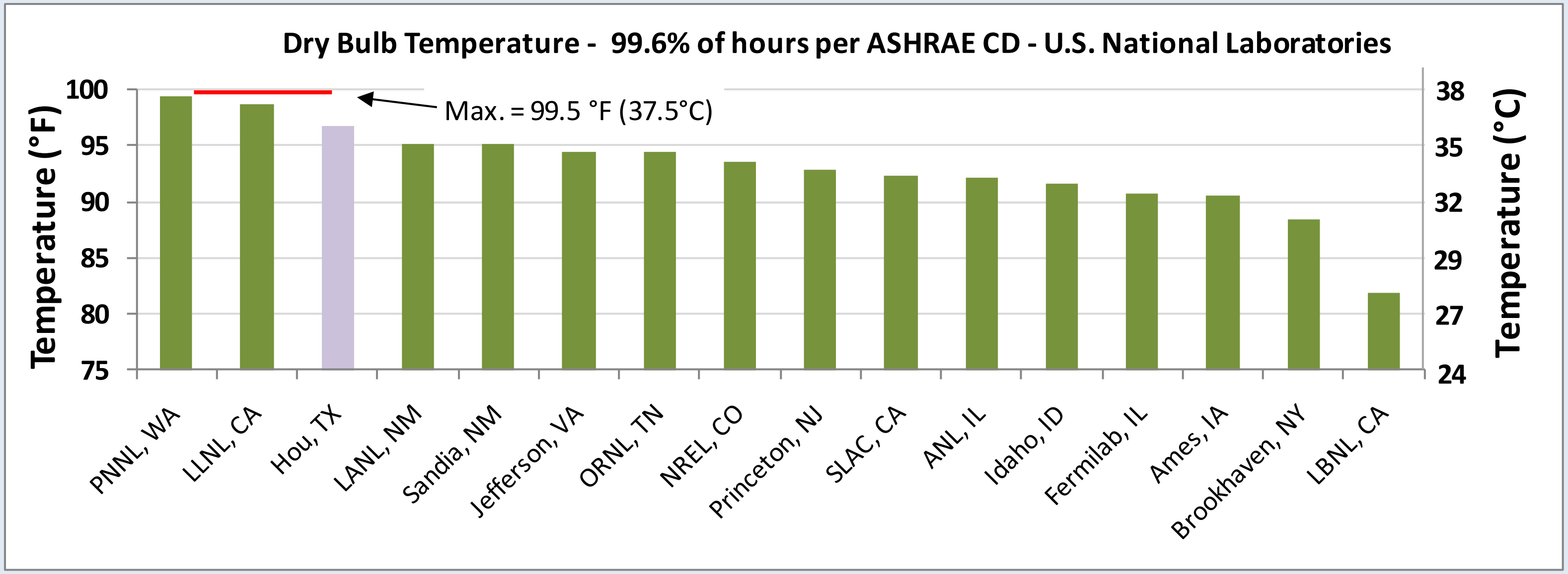
Select "typical" CPU – Intel 5545 @ 85 watts

Investigate Temperature changes throughout each system architecture (values from IT OEM's, other) to forecast cooling margins

Review results and agree on recommendation

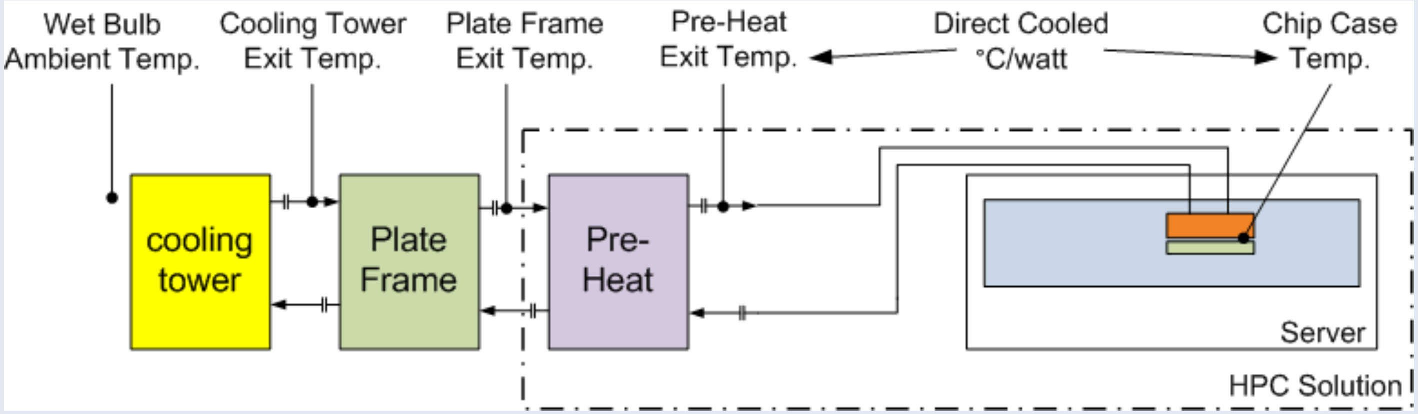
Wet and Dry Bulb Temperatures
ASHRAE CD, 99.6% of yearly hours, National Laboratory HPC Locations.



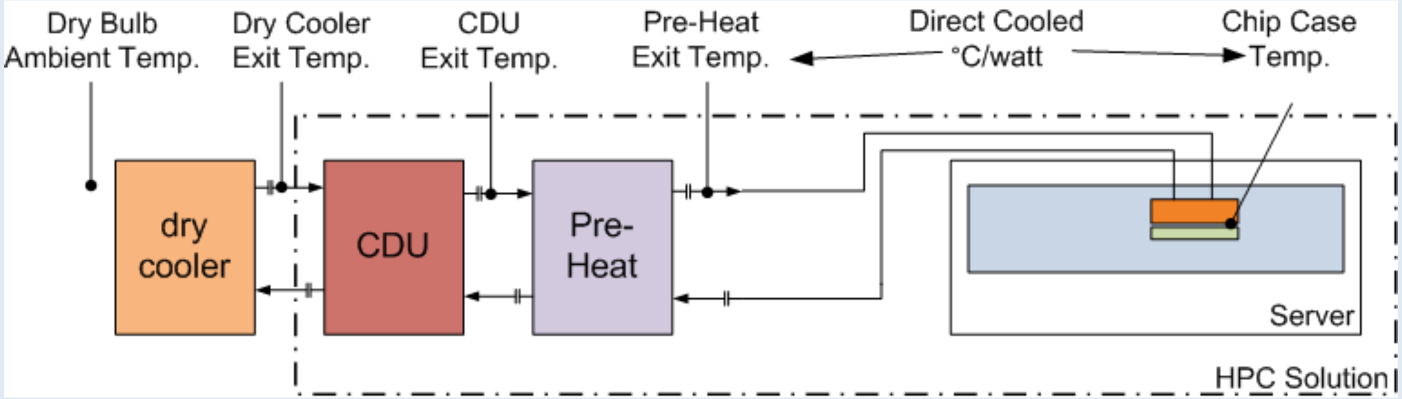


Direct Liquid Cooling Architectures

Cooling Tower

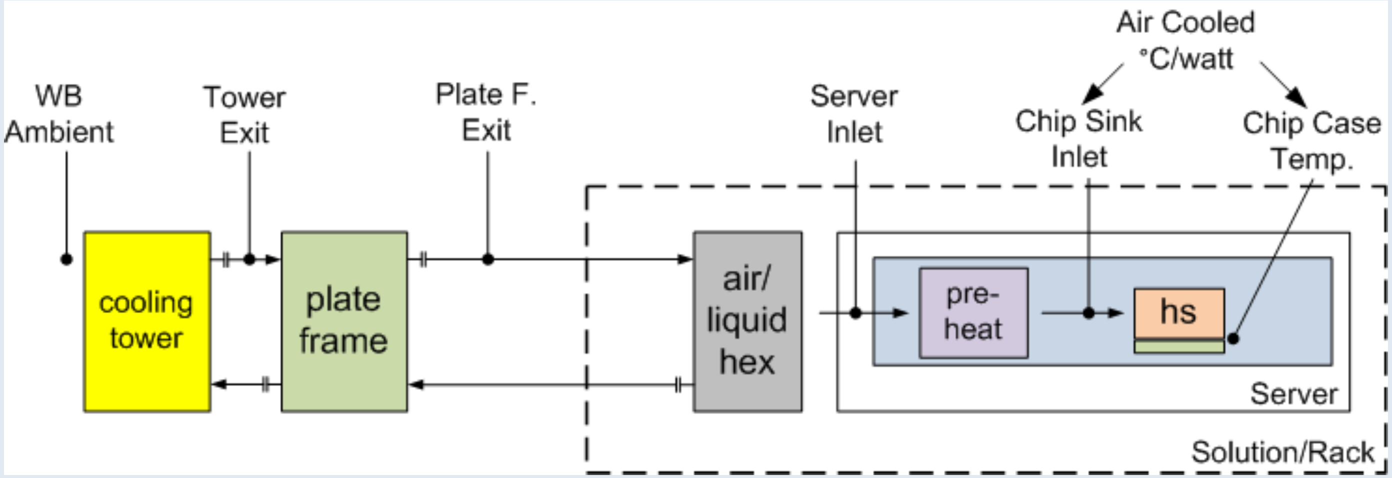


Dry Cooler

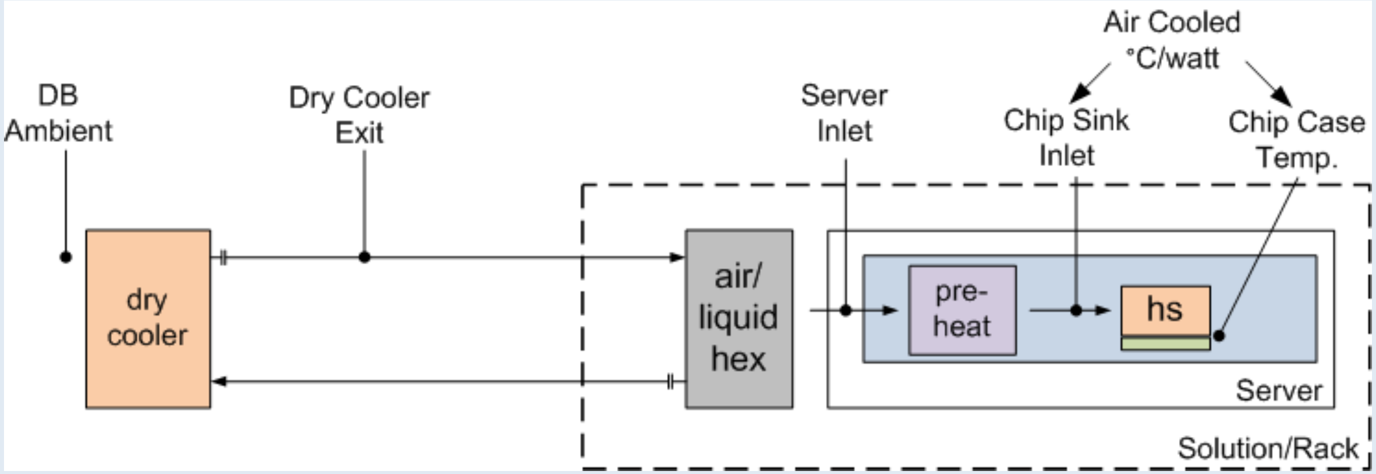


Air Cooling Architectures

Cooling Tower

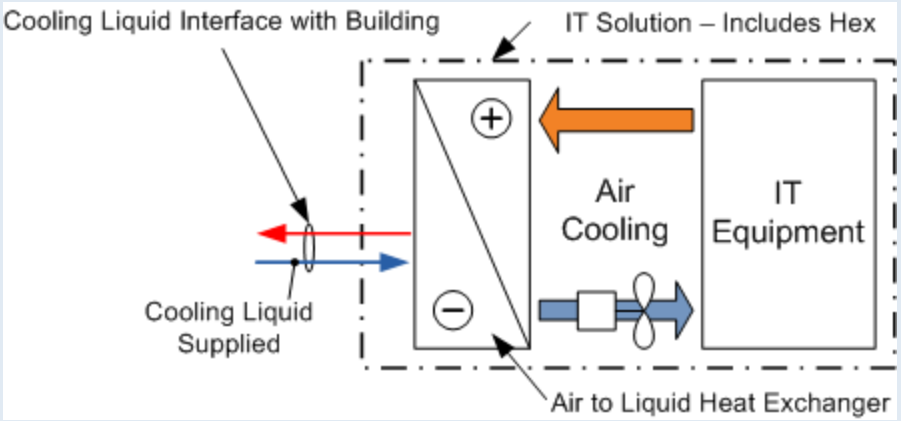


Dry Cooler

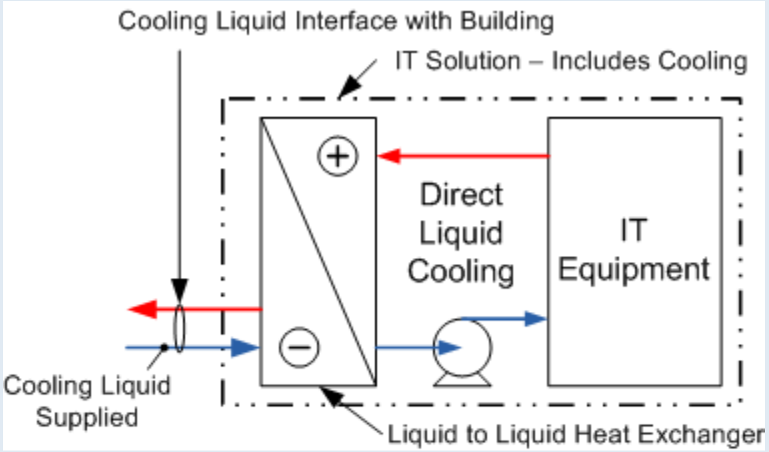


Examples : Air Cooling and Direct Liquid Cooling HPC Solution Architectures

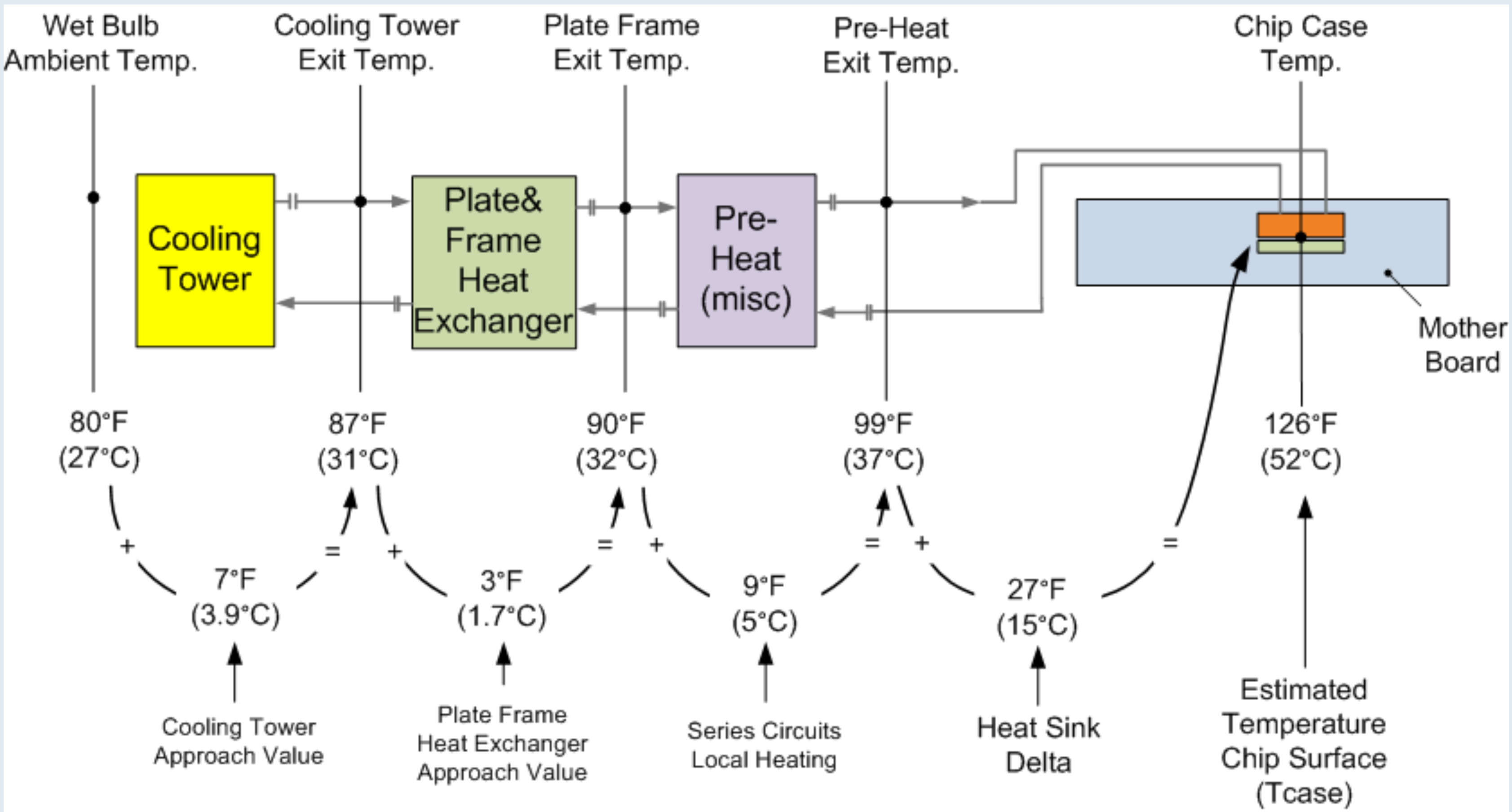
Air Cooling
with Air to Liquid
Heat Exchanger



Direct Liquid Cooling
with Liquid to Liquid
Heat Exchanger



Chip Temperature Estimate
Using Temperature Difference (Approach) Summation
Example: Direct Liquid Cooling with Cooling Tower



Direct Liquid Cooled Server

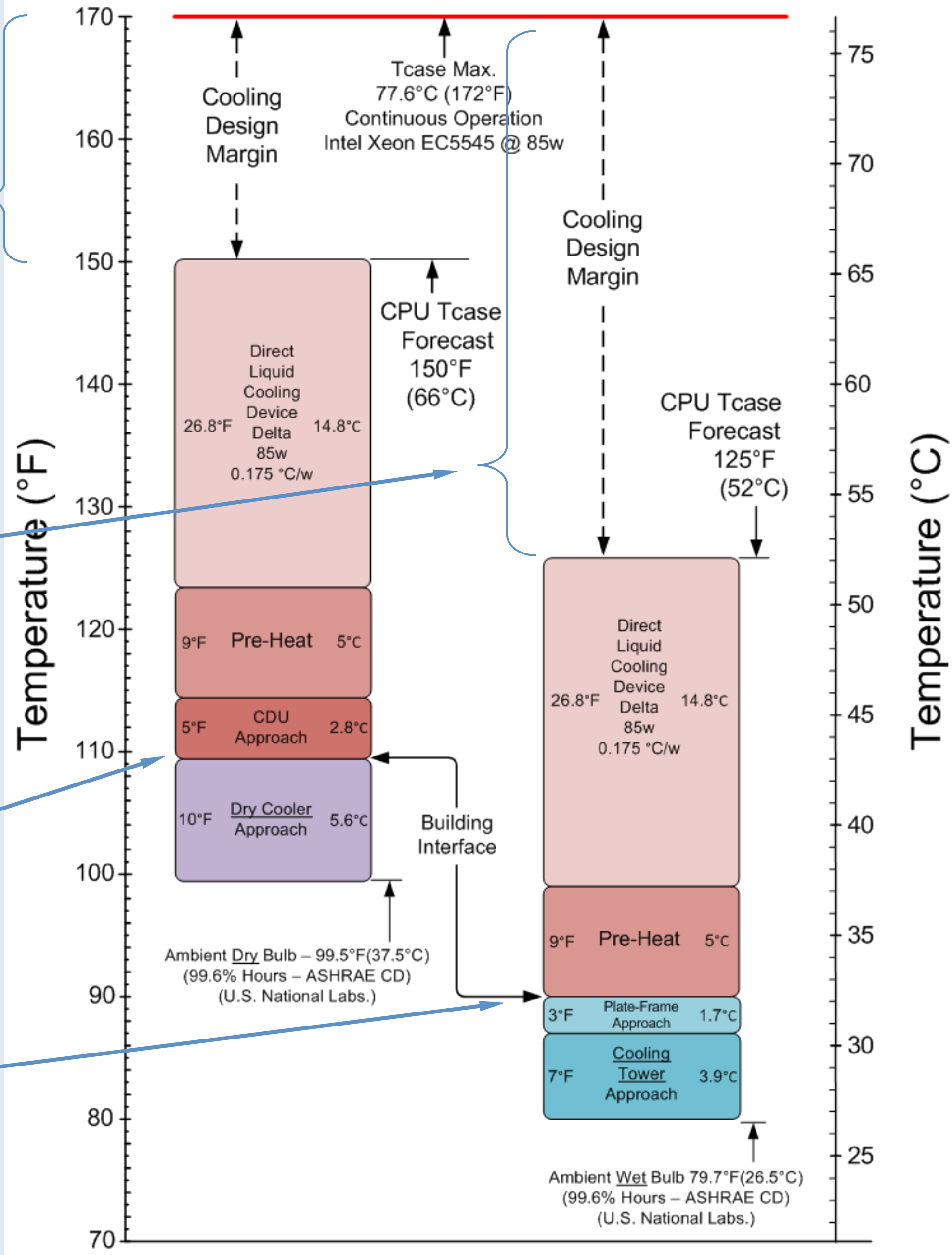
Dry Cooler and Cooling Tower

Chip Thermal Margin
22°F (12°C)
Using Dry Cooler Only

Chip Thermal Margin
47°F (26°C)
Using Cooling Tower Only

Using Dry Cooler Only
Water Temp. Supply from Building
109°F (43°C)

Using Cooling Tower Only
Water Temp. Supply from Building
89°F (32°C)



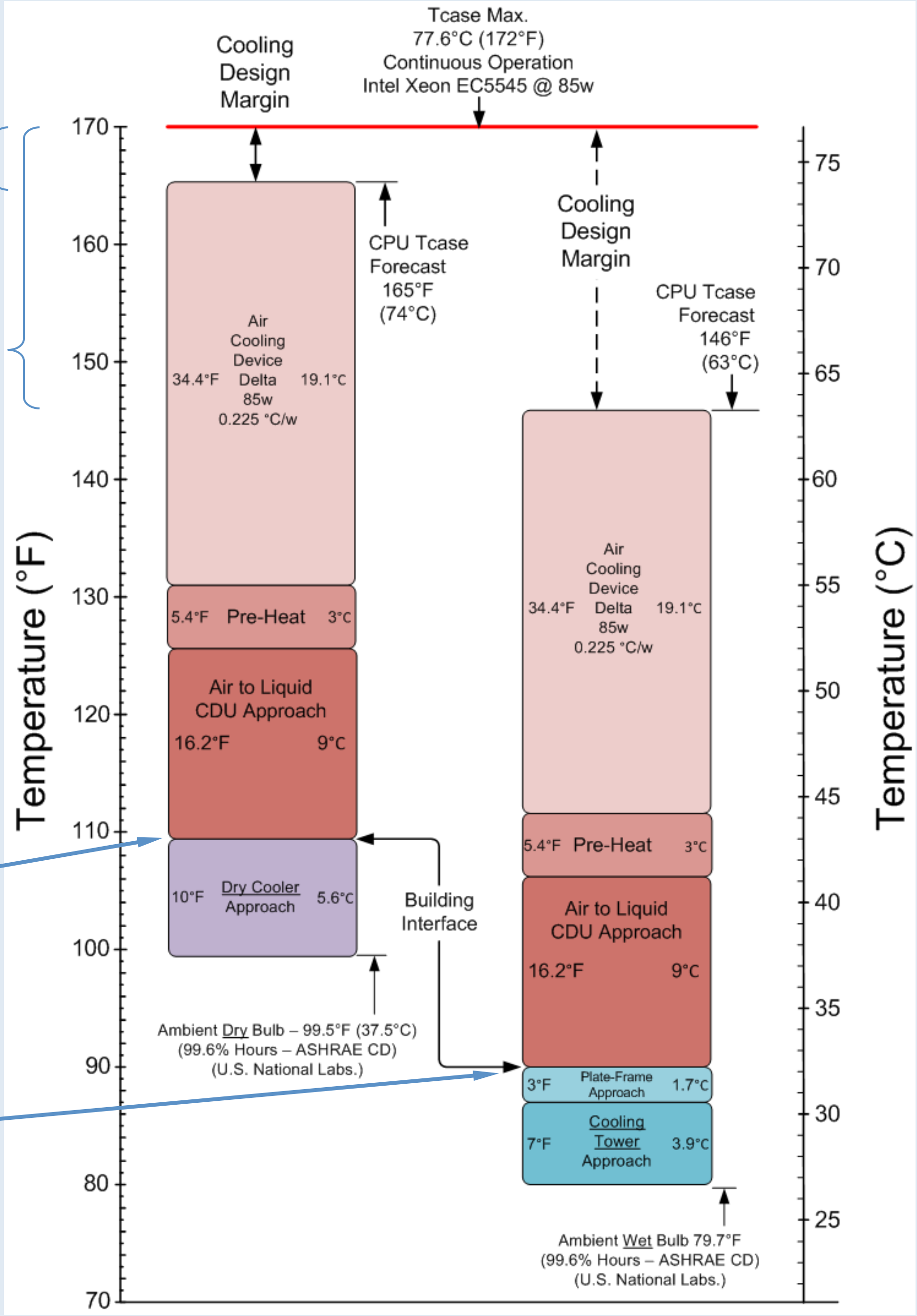
Air Cooled Server
Dry Cooler or Cooling Tower

Chip Thermal Margin
7°F (4°C)
Using Dry Cooler Only

Chip Thermal Margin
26°F (15°C)
Using Cooling Tower Only

Using Dry Cooler Only
Water Temp. Supply to Building
109°F (43°C)

Using Cooling Tower Only
Water Temp. Supply to Building
89°F (32°C)

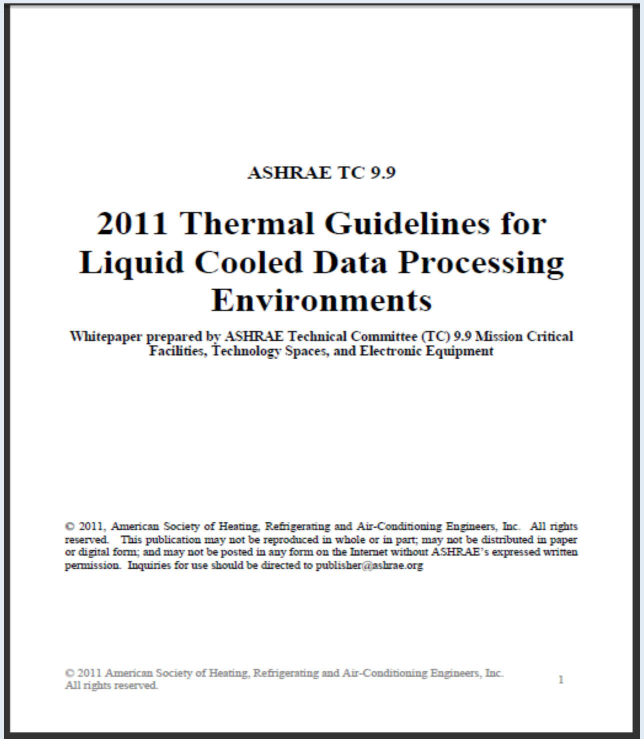


Summary Recommended Limits

Liquid Cooling Class	Main Cooling Equipment	Supplemental Cooling Equipment	Building Supplied Cooling Liquid Maximum Temperature
L1	Cooling Tower and Chiller	Not Needed	17°C (63°F)
L2	Cooling Tower	Chiller	32°C (89°F)
L3	Dry Cooler	Spray Dry Cooler, or Chiller	43°C (110°F)

Conclusions

- Direct liquid cooling is practical using only cooling towers producing water supplied at 89°F (32°C) with thermal margin of 47°F (27°C)
- Direct liquid cooling is practical using only dry coolers producing water supplied at 109°F (43°C) with thermal margin of 22°F (12°C)
- The EE HPC User Group collaborated with ASHRAE TC9.9 which included the recommended limits in its Liquid Cooling Thermal Guidelines white paper (2011)



ASHRAE TC 9.9

2011 Thermal Guidelines for Liquid Cooled Data Processing Environments

Whitepaper prepared by ASHRAE Technical Committee (TC) 9.9 Mission Critical Facilities, Technology Spaces, and Electronic Equipment

Next Steps

- Publicize the ability to cool with higher temperature liquids.
- ASHRAE will revise related Data Center Design and Operation book series
- Develop procurement specification guidance for HPC Users.
- HPC manufacturers develop high temperature liquid cooling solutions
- Inform Utility incentive programs

Questions