Recommendation to ASHRAE TC 9.9

Liquid Cooling Guidelines
HPC Compressorless Liquid Cooling
Building Supplied Cooling Water Guideline

HPC User Group
Liquid Cooling subcomittee
June 27, 2011

HPC User Group

- Initiated by LBNL, supported by the DOE-Federal Energy Management Program and now DOE – Sustainability Projects Office
- National laboratories, other Federal Agencies, Universities, Industry HPC operators, HPC manufacturers
- Over 160 members
- Large market presence

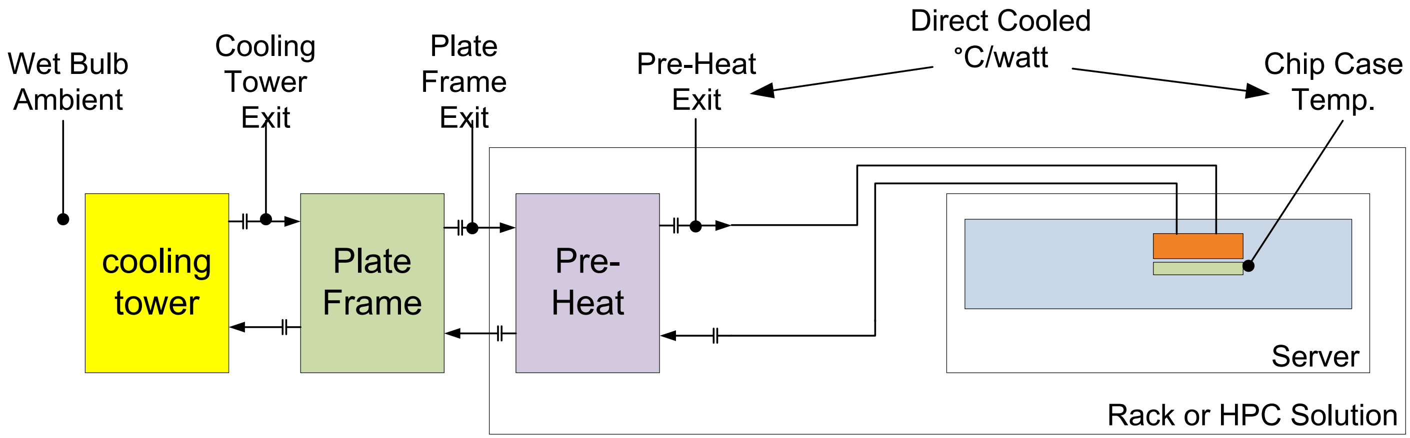
Motivation/Goals

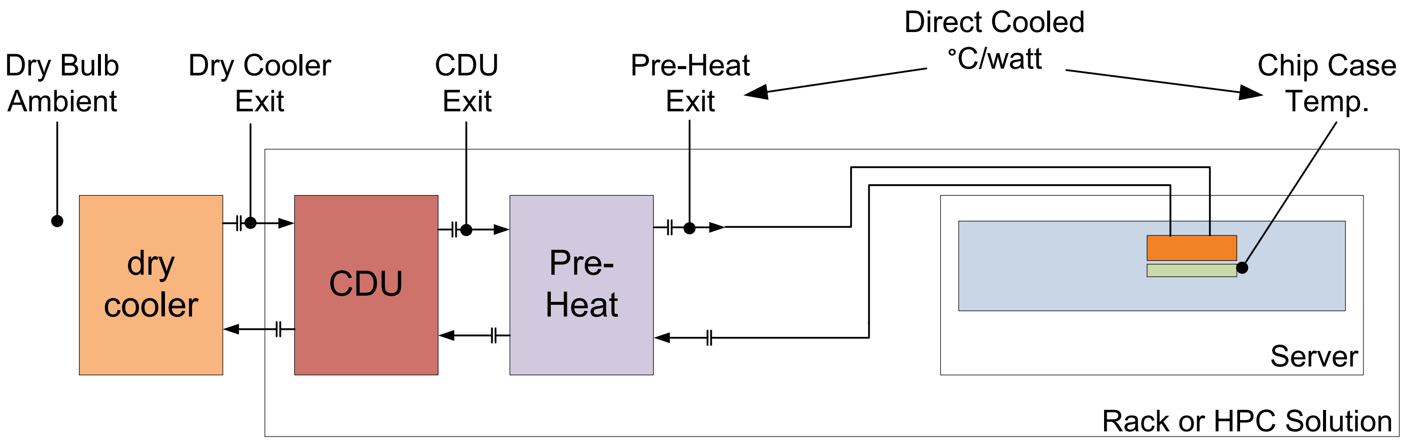
- Compressorless cooling can provide significant CAPX and OPEX (energy) savings for HPC facilities.
- Liquid cooling facilitates compressorless cooling.
- Minimize water use - Investigate the feasibility of dry cooling or cooling tower only infrastructure for HPC.
- Develop liquid cooling temperature guidelines to standardize HPC mfg designs and facility requirements.   Temperatures should be high enough to eliminate compressor cooling in at least 90% of the National Laboratory HPC locations.
- Liquid cooling guidelines could standardize broader data center cooling applications

Methods

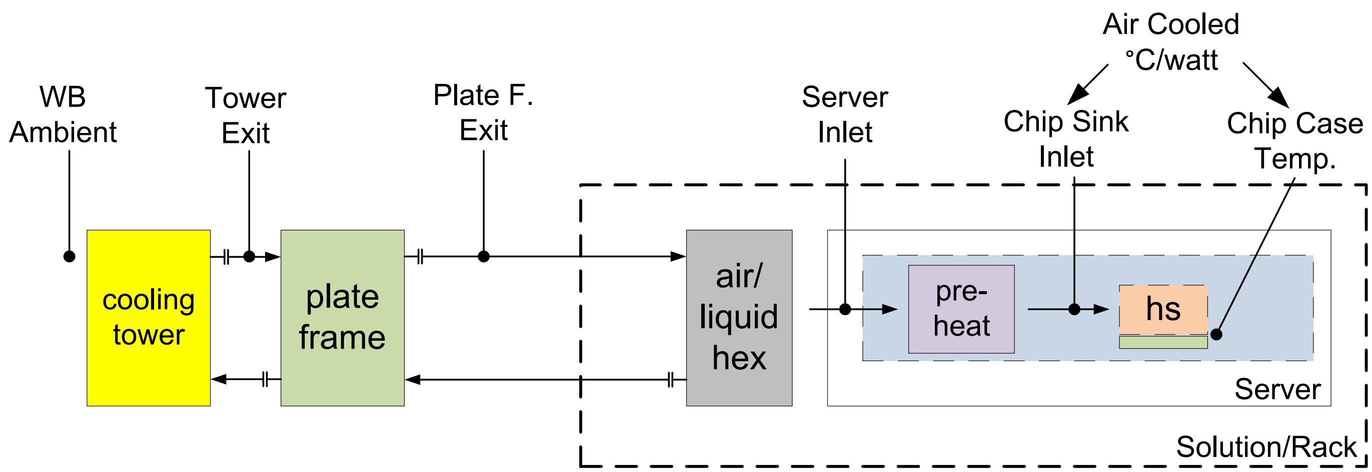
- building water supply guidelines: e.g. supply and return temperature, delta pressure, quality -
- for ~90% of National Labs. (15 sites), design point = 99.6% of hours per ASHRAE
- investigate dry cooler (dry bulb) and cooling tower (wet bulb) infrastructure types
- assume infrastructure design for feasibility study; assume plate frame and CDU components
- document component approach temperatures
- forecast processor case temperature compared to case temperature maximum for continuous operation (Intel Xeon 5500: Tcase=~76C)
- construct supply water temperature guideline table

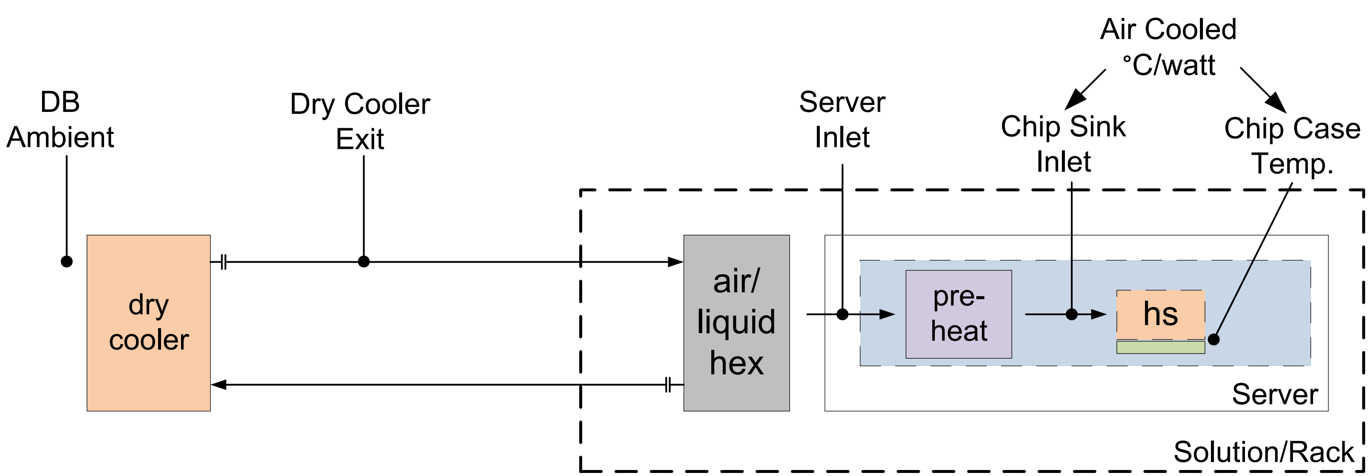
Liquid Direct Cooling Architectures using Cooling Towers or Dry Coolers





Air Cooled Solution Architectures using Cooling Towers or Dry Coolers





Sort by 0.4% dry bulb (exceeded on average of 3 hours/month)

HPC Data Center Owner	U.S. State	City Name	Lat	Long	Elevation (ft)	Closest ASHRAE Location	Lat	Long	Elevation (ft)	Dry Cooling 0.4% DB (F)	Evap. Cooling 0.4% WB (F)
Pacific Northwest National Laboratory	Washington	Richland	46.285	-119.283	384	Pasco	46.27	-119.12	404	99.5	72.1
Lawrence Livermore National Laboratory	California	Livermore	37.682	-121.767	480	Livermore Municipal Apt	37.69	-121.82	397	98.8	70.8
Houston Texas - Owner TBD	Texas	Houston				Bush Intl. Apt.	29.99	-95.36	105	96.8	80.1
Los Alamos National Laboratory	New Mexico	Los Alamos	35.888	-106.306	7320	Albuquerque Intl Apt	35.04	-106.62	5315	95.2	65.3
Sandia National Laboratory	New Mexico	Albuquerque	35.050	-106.540	5436	Albuquerque Intl Apt	35.04	-106.62	5315	95.2	65.3
Jefferson Laboratory	Virgina	Newport News	37.130	-76.490		New Port News	37.13	-76.49	52	94.5	79.7
Oak Ridge National Laboratory	Tennessee	Oak Ridge	36.010	-84.270	875	Nashville Intl Apt	36.12	-86.69	604	94.4	78.2
National Renewable Energy Laboratory	Colorado	Golden	39.755	-105.220	5675	Denver Stapleton Intl Apt	39.77	-104.87	5285	93.5	64.4
Princeton Plasma Phisics Laboratory	Princeton	New Jersey	40.348	-74.659		Mcguire AFB	40.02	-74.6	148	92.9	78.8
SLAC	California	Palo Alto	37.416	-122.202	262	San Jose Intl Apt	37.36	-121.93	49	92.3	69.5
Argonne National Laboratory	Illinois	Argonne	41.711	-87.983	685	Chicago Midway Apt	41.79	-87.75	617	92.1	78.0
Idaho National Laboratory	Idaho Falls	Idaho	43.466	-112.030		Fanning Field Apt	43.52	-112.07	4744	91.7	64.9
Fermilab	Illinois	Batavia	41.850	-88.313	771	Aurora Municipal Apt	41.77	-88.47	705	90.8	77.7
Ames National Laboratory	Iowa	Ames	42.020	-93.640		Ames Muni Apt	42	-93.62	955	90.5	79.2
Brookhaven National Laboratory	New York	Upton	40.883	-72.870	81	Long Island Macarthur Apt	40.79	-73.1	108	88.4	76.7
Lawrence Berkeley National Laboratory	California	Berkeley	37.870	-122.250	1000	Oakland	37.76	-122.22	89	81.8	67.6

Natural Break Points

Sort by 0.4% wet bulb (exceeded on average of 3 hours/month)

HPC Data Center Owner	U.S. State	City Name	Lat	Long	Elevation (ft)	Closest ASHRAE Location	Lat	Long	Elevation (ft)	Dry Cooling 0.4% DB (F)	Evap. Cooling 0.4% WB (F)
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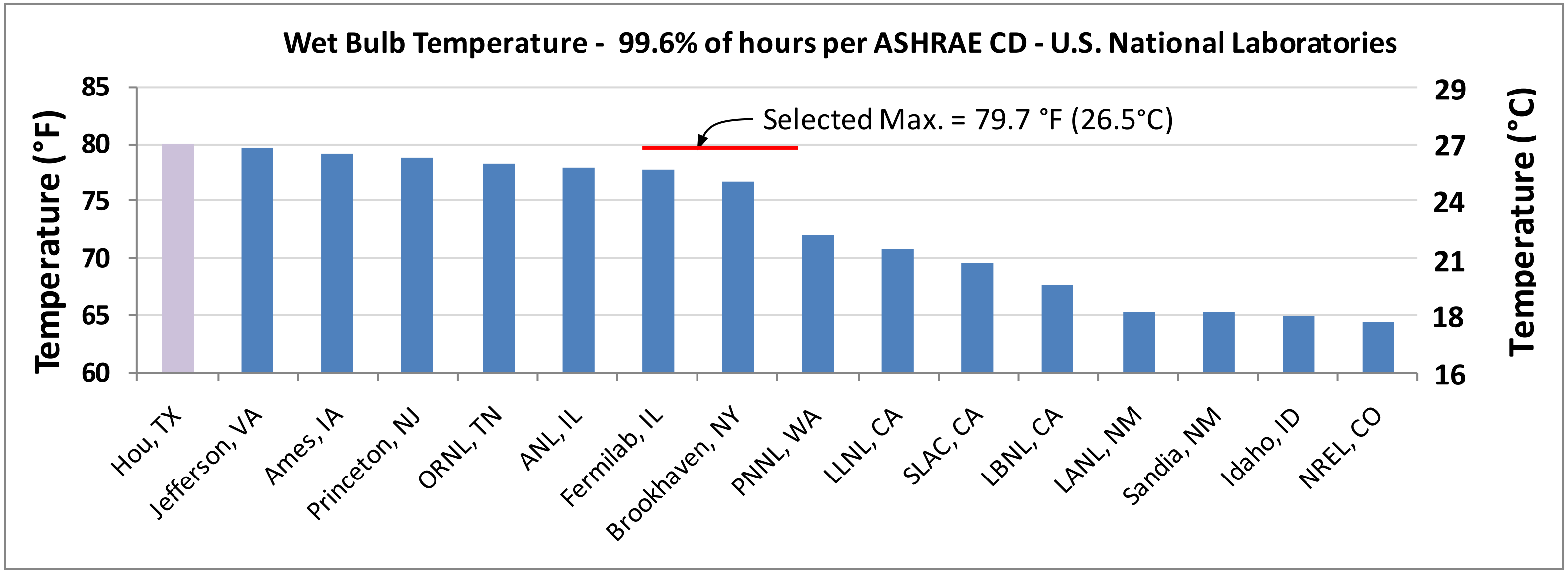
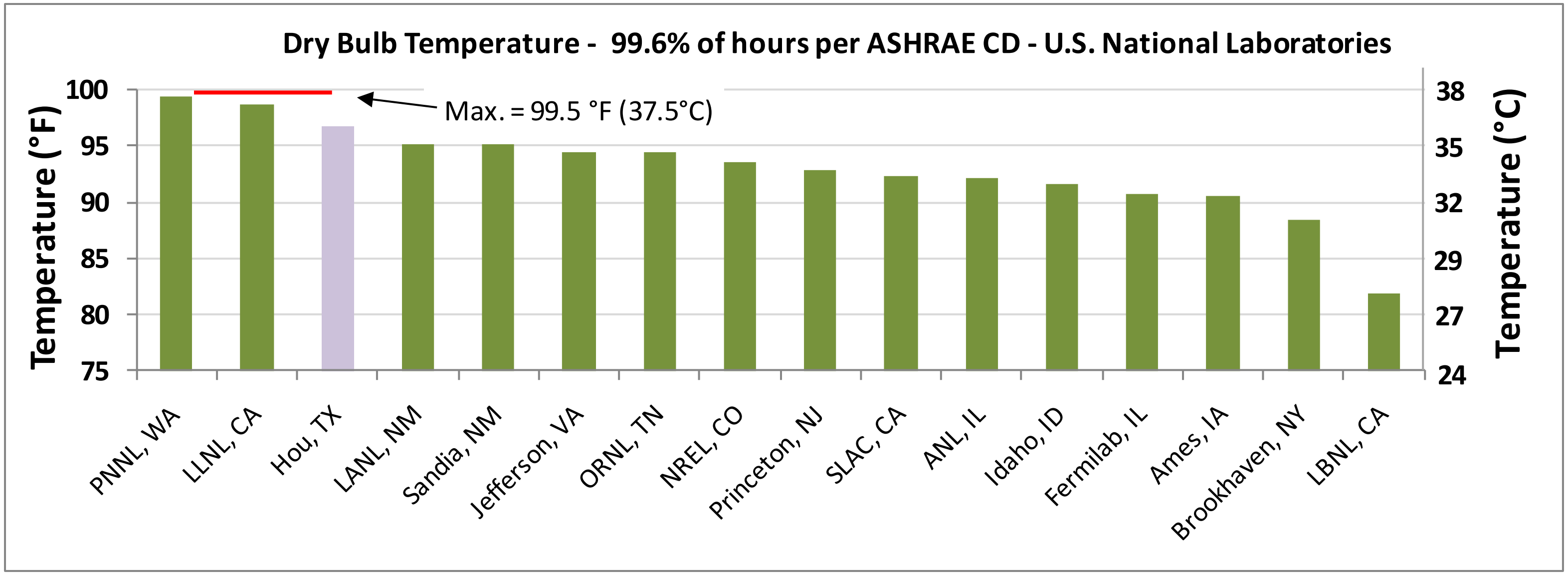
Wet and Dry Bulb Temperatures

ASHRAE CD, 99.6% of yearly hours, National Laboratory HPC Locations.





Thermal Assumptions

Heat Transfer Component	Delta Description	Approach/Delta	
		°F	°C
Open Cooling Tower	WB Ambient to Water Leaving	7[1]	3.8
Dry Fin Cooler	DB Ambient to Water Leaving	10[7]	5.5
Plate and Frame Heat Exchanger	Cooling Water Entering To Cooled Water Leaving	3[5]	1.67
Cooling Distribution Unit (CDU) e.g. Water to Water or Refrigerant to Water	Cooling Water Entering To Cooled Water Leaving	5[9]	2.77
Air to Water Heat Exchanger	Cooling Water Entering To Cooled Air Leaving (server entering)	16.2	9[3]
Server Bezel Pre-Heating	Server Air Entering To Chip Air Cooler Entering	5.4	3[4]
Water Rack Pre-Heating	Rack Water Increase Due to Serial Circuits	9	5[8]
Chip Air Cooler (heat sink)	Cooling Air Entering To Chip Tcase Max.	0.405 °F/watt	0.225[2] °C/watt
Chip Liquid Cooler (plate?)	Cooling Liquid Entering To Chip Tcase Max.	0.315 °F/watt	0.175[6] °C/watt

Thermal Architecture Approach References

(1) Open Cooling Tower water cooled from 95°F to 85°F using a WB temperature of 78°F – 1996 ASHRAE Systems and Equipment Handbook – page 36.2 – reference to description of nominal cooling tower tons. Approach in this case is 7°F. Colorado Springs Utilities – White Paper #14 3/11/2005 – Smart Use of Your HVAC Cooling Towers – "Approach temperatures lower than 7 degrees encounter diminishing returns and require larger investment in fan horsepower for each additional degree."

(2) Air Cooling Heat Sink Performance SGI – Larry Seibold – Xeon 5500 processor 1U form factor – Nehalem 95W – 0.18 to 0.22 C/W – Tcase 75C and 76 using a high performance heat sink, email May 29, 2011 IBM – M. Ellsworth – June 2, 2011, air cooling = 0.25C/W, question watts 80? or 100? Range : 0.18 to 0.27 C/W, averaging = 0.225 C/W? (group discussion needed plus watt level) Cray Inc. – G. Pautsch – Xeon processor 2U server – 0.27C /W – email May 24, 2011.

(3) Air Cooling Heat Exchanger Air to Liquid Approach – Vette passive door data

(4) Server Bezel Air Pre-Heating server bezel entry to cpu heat sink entry – 3C conservative number assuming only misc components in path not storage or memory modules and well controlled internal recirculation. – B. Maltz Electronic Cooling Solutions – June 2, 2011

(5) Plate Frame Heat Exchanger Approach Plate Frame – BG P47-90-TMTL4 – 200gpm cold, 220gpm hot – cold side 62F entering – 72F leaving, warm side 74F entering, 65F leaving – Taylor 8/23/2010 LBNL ALS USB Server Room, Drawing M0.2

(6) Liquid Direct Cooling Approach - M. Ellsworth June 2, 2011 – 0.2C/W – Greg Pautsch (Cray) 0.15C/W possible, 0.175C/W average used

(7) Dry Fin Cooler Dry Cooler Info. – www.drycoolers.com – 10F approach typical , 5F possible with 2x # of units using pure water.

(8) Server Liquid Pre-Heating 5C per M. Ellsworth

(9) CDU Approach TBD

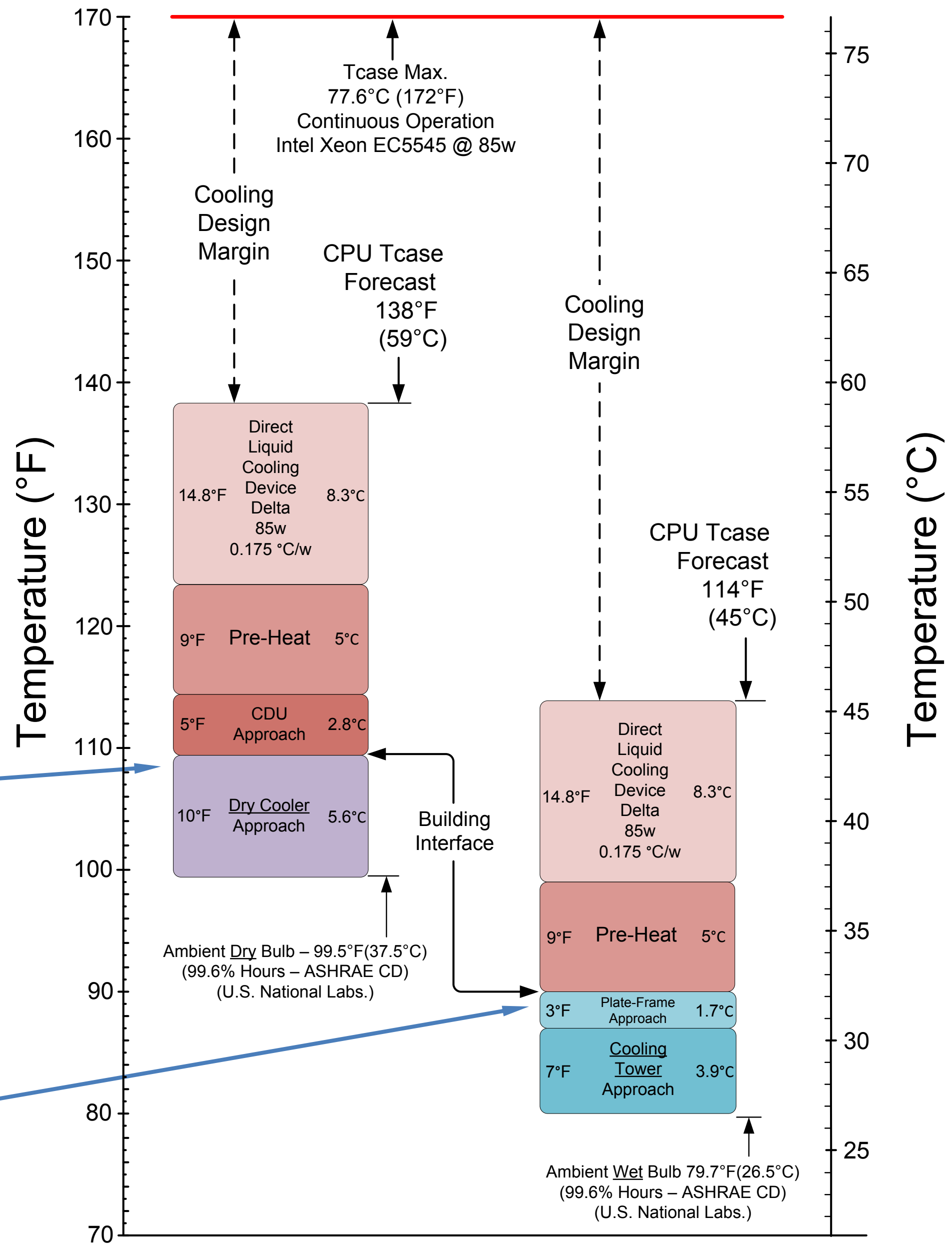
Liquid Cooled Server

Dry Cooler and Cooling Tower Direct Cooling Infrastructure CPU Case Temperature Forecast Compared to Intel Xeon 5500 Tcase maximum.

Pre-Heat: allowance for inside server routing (components in series) and local pipe heating

cooling water using a dry cooler at 109°F (43°C)

cooling water using a cooling tower and plate frame heat exchanger at 90°F (32°C)



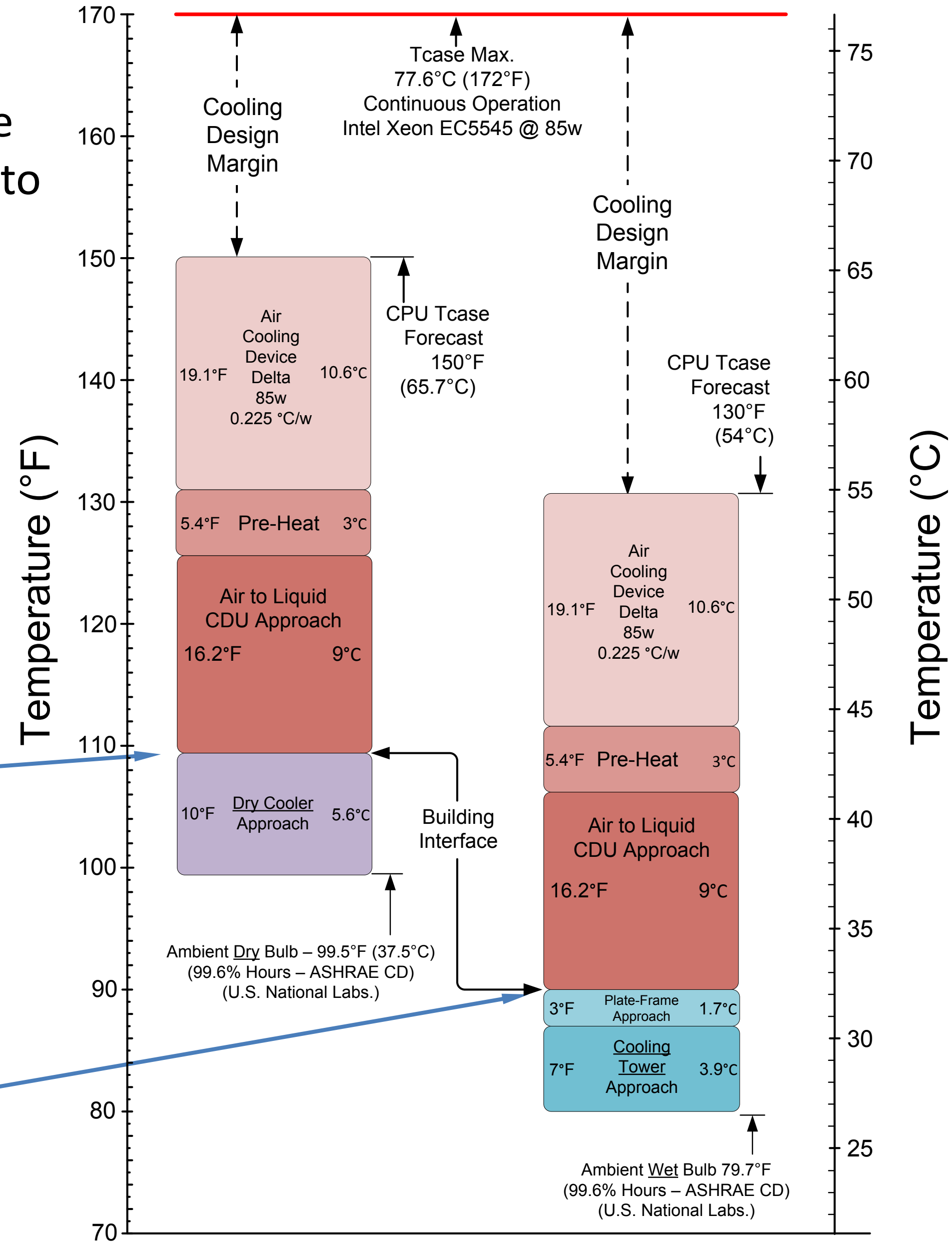
Air Cooled Server

Dry Cooler and Cooling Tower Infrastructure CPU Case Temperature Forecast Compared to Intel Xeon 5500 Tcase maximum.

Pre-Heat: allowance for heating from sever inlet to cpu heat sink

cooling water using a dry cooler at 109°F (43°C)

cooling water using a cooling tower and plate frame hex at 90°F (32°C)



HPC Liquid Cooling Guideline

rev. June 27, 2011

(building supplied cooling water to HPC solution)

Range Name	Building Supplied Water Temperature Range	Notes
W3	43°C (109°F) to 17.2°C (63°F)	Top of range: Use with dry cooler Bottom of range: Highest of value listed or 4°F above dew point
W2	32°C (90°F) to 17.2°C (63°F)	Top of range: Use with cooling tower Bottom of range: Highest of value listed or 4°F above dew point
W1	65F	legacy chilled water plant sites

HPC Survey

- What climatic data do we use?
- Two options:
  - 0.4% (3 hours/month) average exceeded
  - 1.0% (14 hours/month) average exceeded
- Results
  - 13 respondents
  - 69% of the respondents chose 0.4%