Agenda

- **Introduction**
  - Natalie Bates, Energy Efficient HPC Working Group
- **Goals and Motivation**
  - Marriann Silveira, LLNL
- **Case Studies**
  - Thomas Durbin, NCSA
  - David Martinez, SNL
  - Greg Rottman and Charles Rush, ERDC
  - Torsten Wilde, LRZ
- **Next Steps and Closing Statements**
  - David Grant, ORNL

System Integrator Webinar: Liquid Cooling Controls

Thank you for presenting!

HP, Cray, IBM, Lenovo and RSC

Presentations and audio recording posted on EE HPC WG website https://eehpcwg.llnl.gov/pages/webinar.htm

System Integrator Webinar: Liquid Cooling Controls

- Today's Roadmap
  - CDUs manage delivery of liquid to the HPC system.
  - Most CDUs are constant flow-rate and temperature.
  - Some customers re-set these points on a seasonal basis and could re-set them as dew point changes.
  - There are CDUs deployed at different levels of the system with the lowest level being the rack, but not the node level.
  - CDUs range in their intelligence, with some claims for integrated controls.
- Tomorrow's Possibilities
  - Tomorrow's products could allow for inlet flow-rate and temperature to vary based on actual, not maximum specified heat removal.
  - There would have to be more and finer grained telemetry and controls.

EE HPC Working Group
Liquid Cooling Controls Webinar

Goals and Motivations

October 7, 2015

Marriann Silveira, PE

Lawrence Livermore National Laboratory

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Goals

- **Encourage communication between vendors (especially system integrators) and HPC centers**
- **Stress the importance of liquid cooling controls for energy efficiency and cost savings**

Motivation

- Improve energy efficiency and reduce operational expenditures by optimizing liquid cooling controls. What are the liquid cooling energy costs? How much power is being utilized?
- We want to better understand how the HPC system load dynamics or volatility plays into how to control cooling and therefore impacts efficiency. HPC loads can vary by MWs. What are the sites experiences with this?
- Environmental conditions are also variable which leads to varying temperatures and energy use to cool the water. What are the sites experiences with this?
- What other factors might drive for more dynamic controls – e.g. water conservation?
- Where are liquid cooling controls best implemented – in the HPC system or in the building or both? Interoperability: components and subsystem level(s)
- What other strategies could be implemented such as power managed job scheduling?
- Can we develop recommendations for implementation to reduce control system complexity for sites with multiple HPC systems?

BLUE WATERS

SUSTAINED PETASCALE COMPUTING

October 8, 2015

National Petascale Computing Facility

Chilled Water Pump Control

THOMAS DURBIN, P.E., LEED AP

GREAT LAKES CONSORTIUM FOR PETASCALE COMPUTATION

BLUE WATERS

- 288 CRAY CABINETS
- 26,864 COMPUTE NODES
- >49,000 AMD CPUS
- 405,248 CPU CORES
- 4,224 NVIDIA KEPLER GPUS
- 1.5 PETABYTES RAM
- 13.34 PETAFLOPS
- 72 XDP COOLING UNITS
- >95% LIQUID COOLING
- PEAK >3,500 TONS

NPCF

- LEED GOLD CERTIFIED

Basic System Description

- Separate chilled water loops for building climate controls and chilled water for computing systems
- Separate control of Blue Waters from BAS
- Examples of gpm at 43 F and 50 F, effect of temp change on flow rate.
  - For 43 F water, gpm = 2,700
  - For 50 F water, gpm = 5,400

Basic System Description

- The facility has 4 chilled water pumps serving the HPC equipment, pump capacity is 2,325 gpm each
- Total CHW pump capacity is 9,300 gpm
- Historical pump operation would be on-off usage and flow increments were one pump's capacity
- Flow adjustment historically with 3-way valves
- Default operation to avoid disruption of HPC system cooling would leave all 4 pumps running simultaneously regardless of load

Chilled Water Pumps Energy Case Study

- Problem: Running 4 pumps at all times is inefficient and expensive. It also results in low return water temperature when load is low.
- Due to fluctuations in the heat load of Blue Waters and other computing equipment, the amount of chilled water needed varies.

- Primary cooling system concerns are differential pressure, flow rate of chilled water, and return temperature.

- Running 4 pumps (each with a 100 Hp motor) continuously costs $429.70 daily when electricity costs $0.06/kWh.
- Fixed flow rate and varying load don’t match

- Solution: Install variable frequency drives and utilize the VFDs to control the chilled water pumps based on system differential pressure and flow data.
- The controls system varies the speed of each pump and the number of pumps operating to provide the required differential pressure and flow rate.
- The total cost of this project was about $51,000, including VFDs, wiring, and controls integration.

- Running only the pumps needed (about 56% long-term average of total pump capacity) costs $240.63 daily when electricity costs $0.06/kWh.
- Result: Electricity cost savings of $189.07 daily and monthly (30 days) savings of $5,671.99.
- Simple payback: $51,000/$5,671.99 yields return of investment in less than 9 months.

QUESTIONS

THOMAS DURBIN, P.E., LEED AP
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Power & Cooling Design

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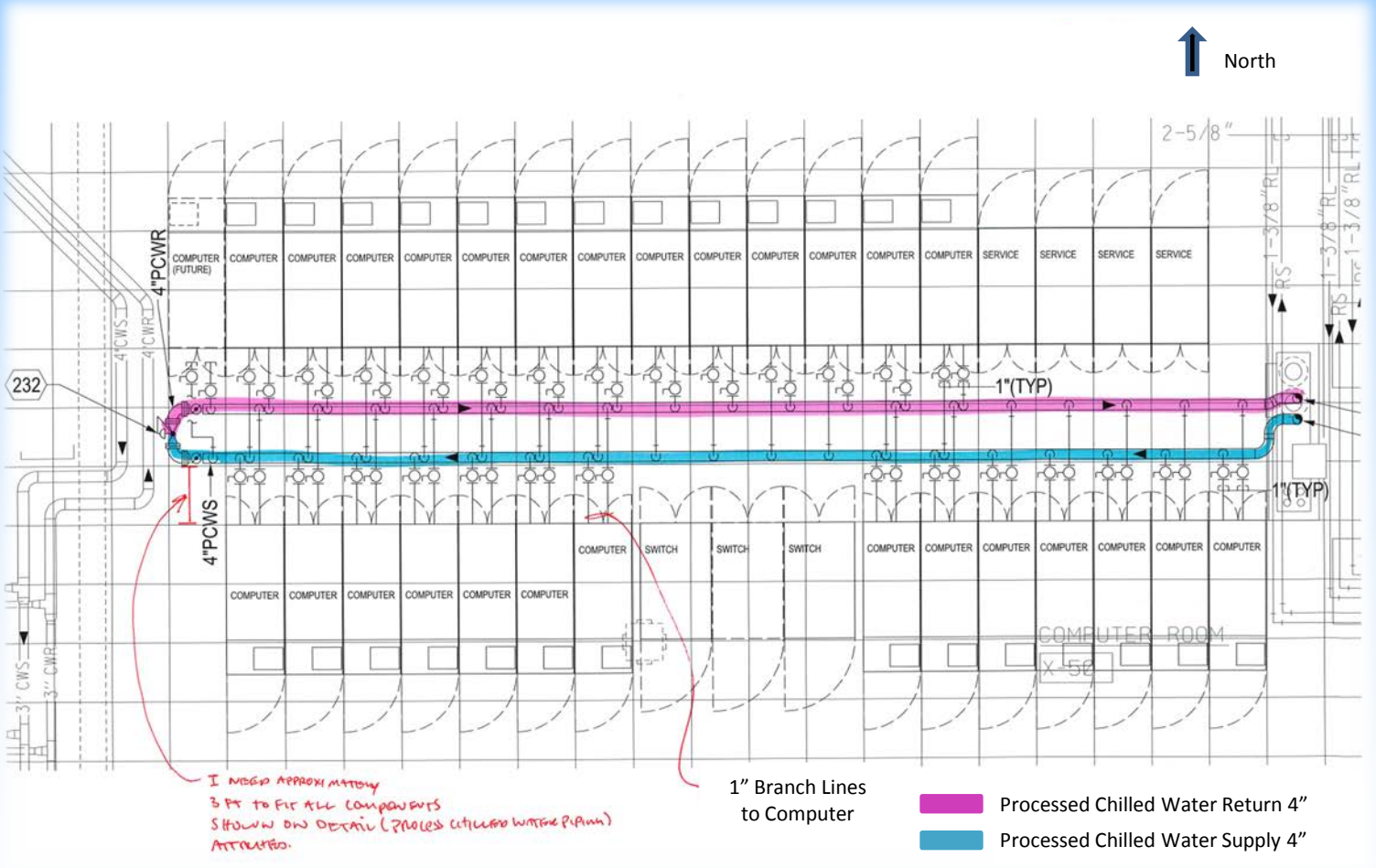
Piping Diagram



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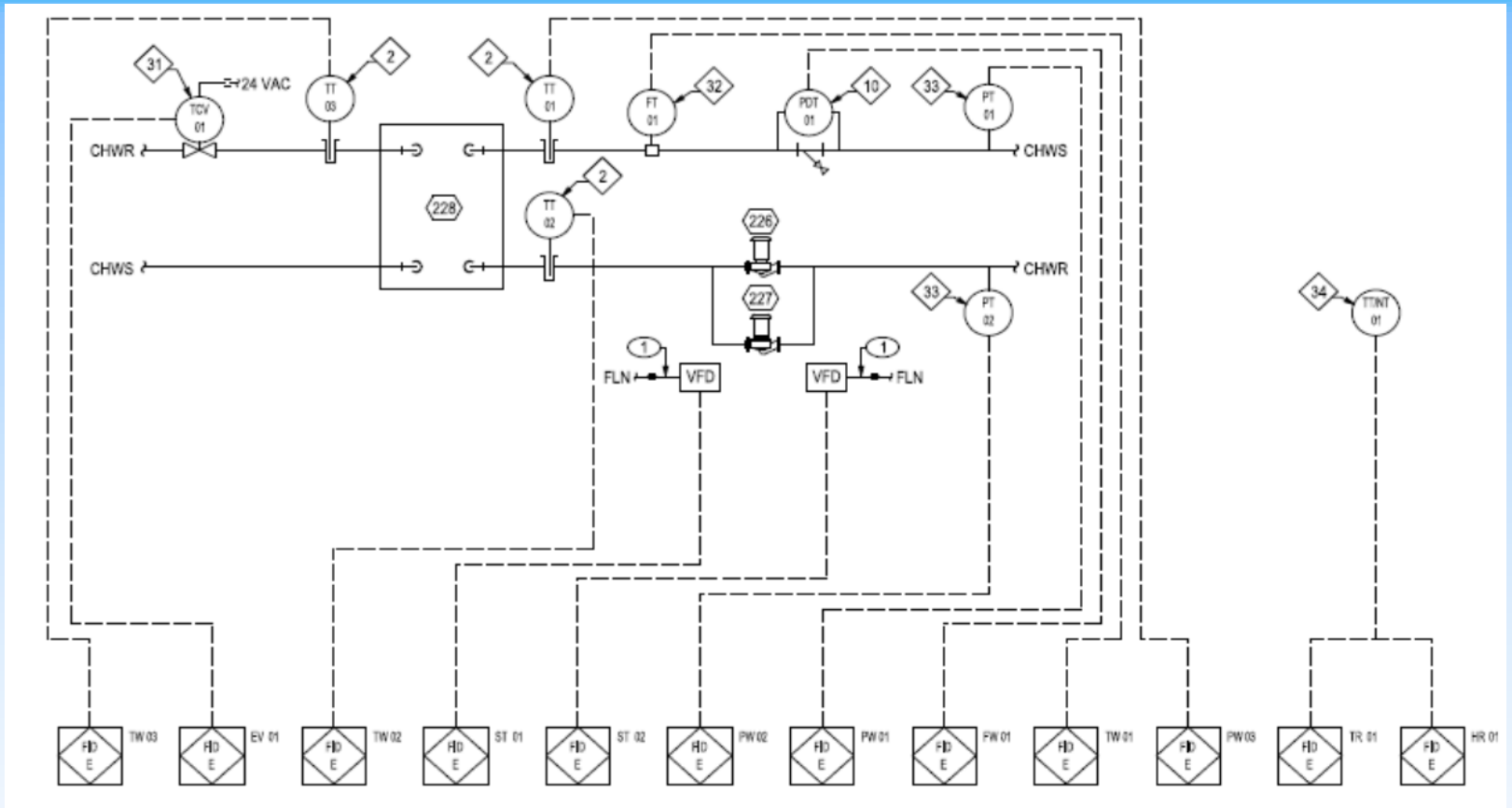

Cooling Sequence

PROCESS CHILLED WATER SYSTEM CH09

GENERAL
THE PRIMARY PROCESS CHILLED WATER SYSTEM SHALL CONSIST OF A FLAT PLATE HEAT EXCHANGER AND TWO PROCESS DISTRIBUTION PUMPS WITH VFC'S. THE PROCESS CHILLED WATER SYSTEM SHALL OPERATE CONTINUOUSLY.

CHILLED WATER LOOP PUMP CONTROL
THE PUMPS SHALL OPERATE IN A LEAD/STANDBY CONFIGURATION. THE LEAD PUMP SHALL OPERATE ANYTIME THE SYSTEM IS ENABLED. THE FCS SHALL MODULATE THE SPEED OF THE PUMP TO MAINTAIN THE SYSTEM DIFFERENTIAL PRESSURE AT SETPOINT. THE FCS SHALL MONITOR THE STATUS OF EACH PUMP THROUGH A SET OF CONTACTS IN THE VFC AS WELL AS THROUGH THE FLN NETWORK CONNECTION. IF A FAILURE IS DETECTED IN THE LEAD PUMP, THE STANDBY PUMP SHALL AUTOMATICALLY START AND AN ALARM SHALL BE INITIATED BY THE FCS. THE PUMPS SHALL BE ROTATED MONTHLY. THE DIFFERENTIAL PRESSURE SETPOINTS SHALL BE SET BY THE TEST AND BALANCE CONTRACTOR.

HEAT EXCHANGER TEMPERATURE CONTROL
THE FCS SHALL MODULATE THE HEAT EXCHANGER VALVE TO MAINTAIN THE PROCESS CHILLED WATER SUPPLY TEMPERATURE AT A SETPOINT OF 60 DEGREES F (ADJUSTABLE). THE FCS SHALL MONITOR THE DEWPOINT TEMPERATURE OF THE SPACE. THE FCS SHALL RESET THE PROCESS CHILLED WATER SUPPLY TEMPERATURE AT 2 DEGREES F ABOVE DEWPOINT IF THE DEWPOINT TEMPERATURE RISES ABOVE 60 DEGREES F. THE FCS SHALL INITIATE AN ALARM IF THE PROCESS CHILLED WATER SUPPLY TEMPERATURE EXCEEDS 5 DEGREES F (ADJUSTABLE) ABOVE SETPOINT.

STRAINER DIFFERENTIAL PRESSURE
THE FCS SHALL MONITOR THE DIFFERENTIAL PRESSURE ACROSS THE STRAINER. IF THE STRAINER DIFFERENTIAL PRESSURE EXCEEDS THE ALARM SETPOINT, THE FCS SHALL INITIATE AN ALARM.

CHILLED WATER SYSTEM CH09 CONTROL DIAGRAM

SCALE: NONE

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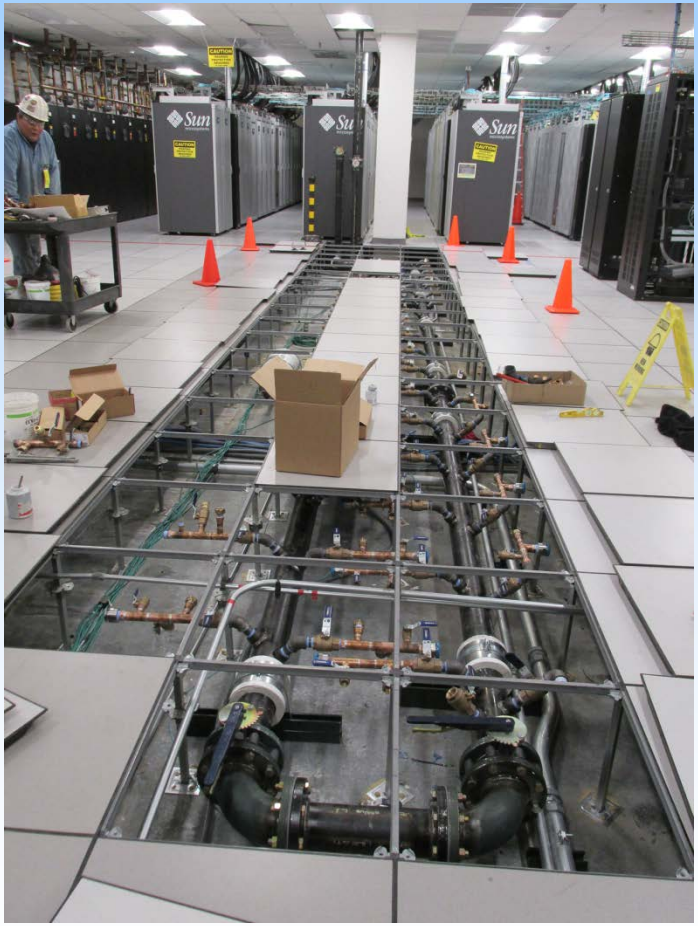
Sky Bridge



Process Loop Supply and Return piping

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Sky Bridge

Balancing valve between supply and return on the process loop

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Sky Bridge

Heat exchanger Chilled Water/Tower Water 55 F to 60 F to Process Cooling Loop 60 F to 70 F depending on calculated dew point

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Sky Bridge

StarLine Buss system 480 volt 600 amp main 60 amp per cabinet

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Sky Bridge

- The power is 480V 60 AMP
- StarLine track buss system
- 65% liquid cooled right to the chip
- Liquid temperature range 60F to 90F
- Controls off differential pressure

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What is RackCDU?

Direct-to-Chip, Hot Water Liquid Cooling for Servers

Three Key Elements in the System:

- Outdoor Dry Cooler / Cooling Tower
- Rack Extension containing CDU and L2L HEXs
- Server Cooler

Sever Cooler is a drop in replacement for CPU & GPU air coolers

- Air cools components that are not liquid cooled

RackCDU Separates Facilities Liquid and Server Cooling Liquid at the Rack.

- The two liquids never mix.

Facilities Liquid Cooled with ”Free” Ambient Outdoor Air, No Chilling Required

- Dry Coolers, Cooling Towers, or Waste Heat Recycling used to take heat from facilities liquid

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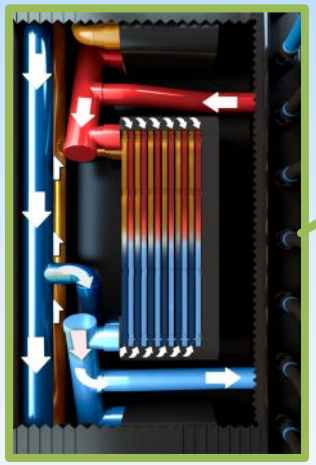
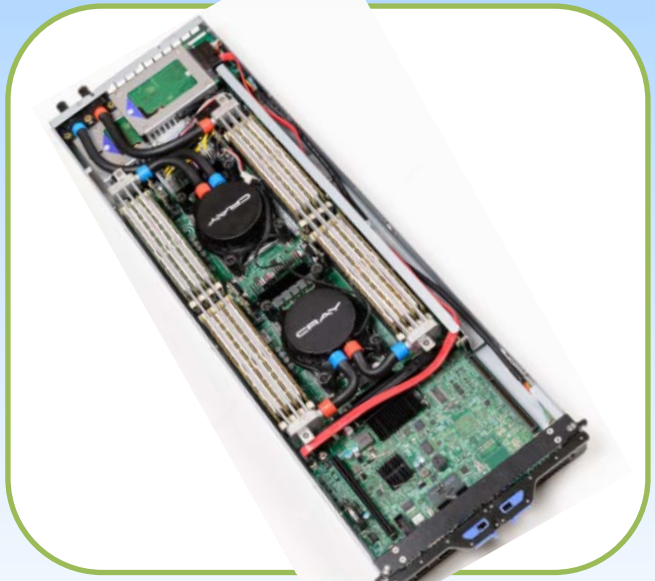
How RackCDU Works

Hot water from Facilities dry cooler or cooling tower enters RackCDU, hotter water returns.



Liquid-to-liquid HEXs exchange heat between facilities liquid loop and server liquid loops. Facilities and server liquids are kept separate and never mix.

Tubes move cooling liquid to and from RackCDU to servers.



Pump/cold plate units atop CPUs (or GPUs) circulate liquid through blades and RackCDU, collecting heat and returning to RackCDU for exchange with facilities liquid.

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Sky Bridge

- CAPEX cost for water cooled system install ~35% lower vs air cooled system
- OPEX ~ cost for water cooled system ~ 50% lower vs air cooled system
- Total footprint for install inside the white space for water cooled / system ~30 sq.ft. vs air cooled system~ 400 sq.ft.

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Present

- Tracking both facilities & compute systems
- Looking at jobs in the que
- Gathering data
- Validating information
- Understanding risk and impact

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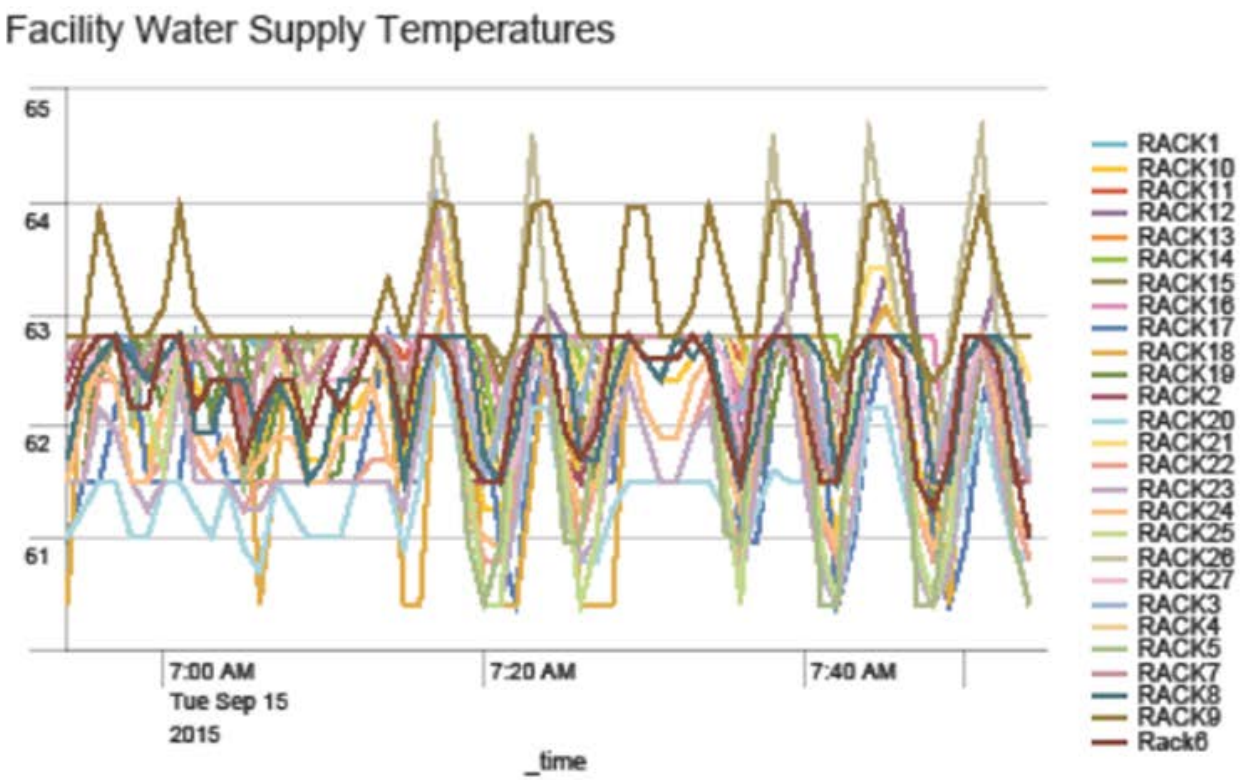
Sky Bridge – H2O Supply Temperatures



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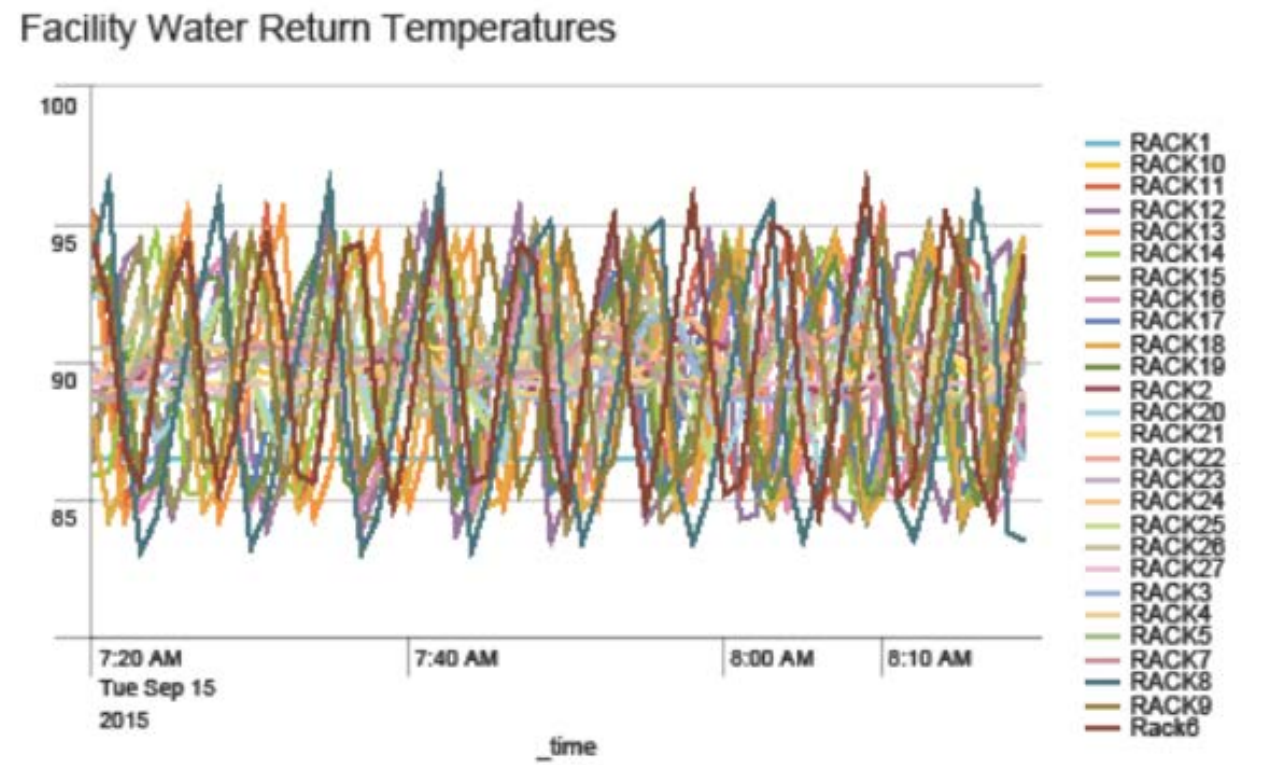
Sky Bridge – H2O Return Temperatures



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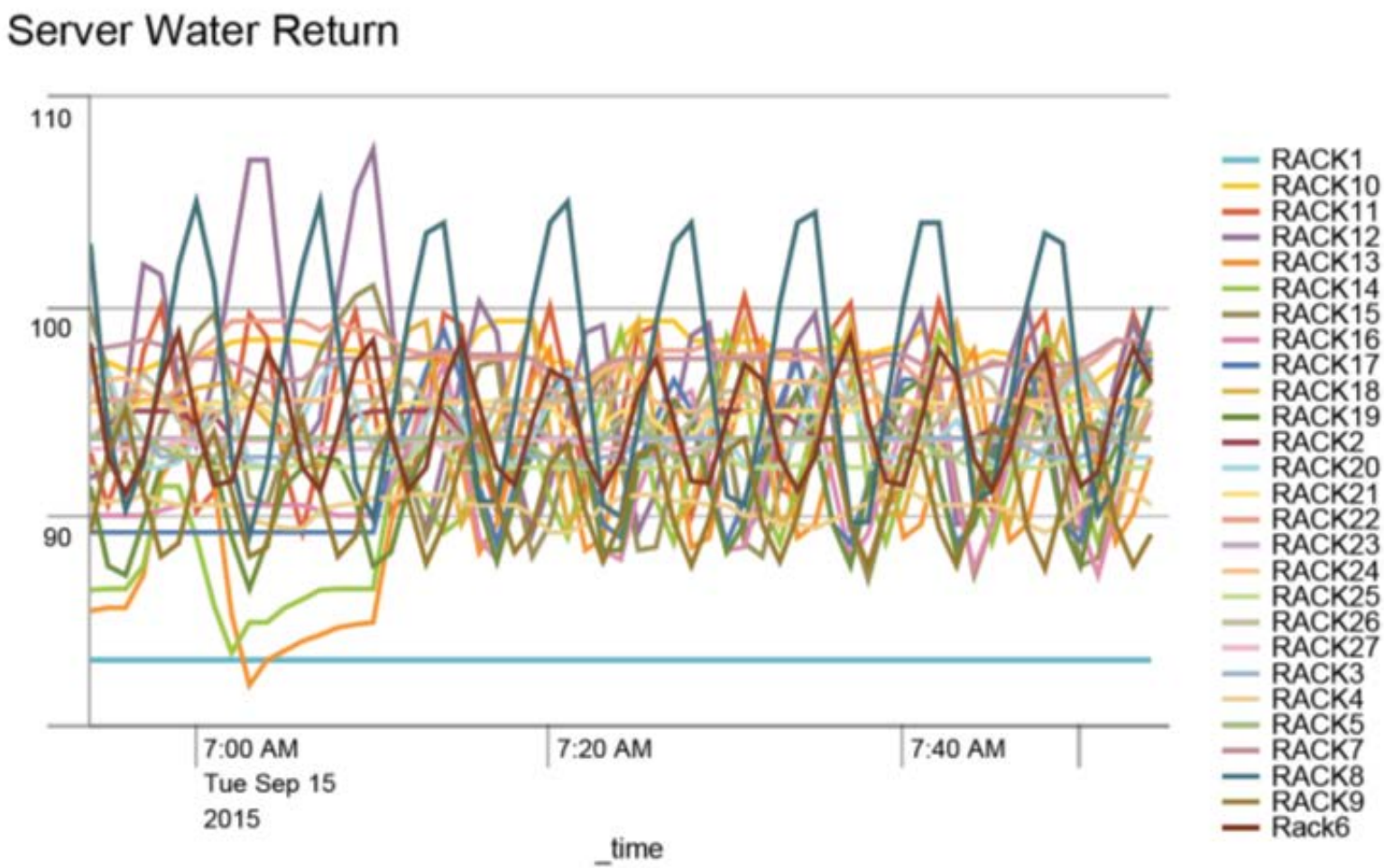
Sky Bridge – Server H2O Return



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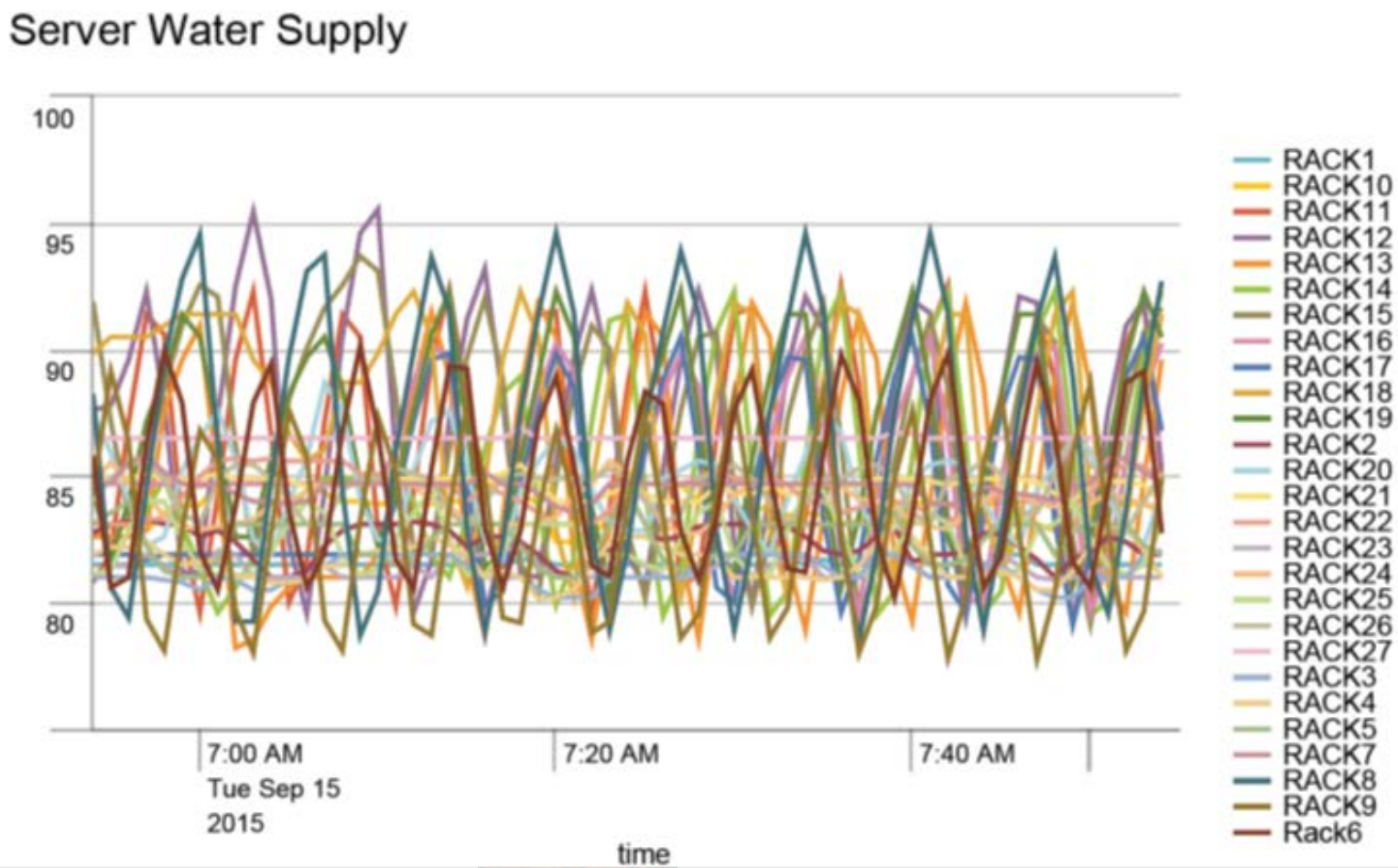
Sky Bridge – Server H2O Supply



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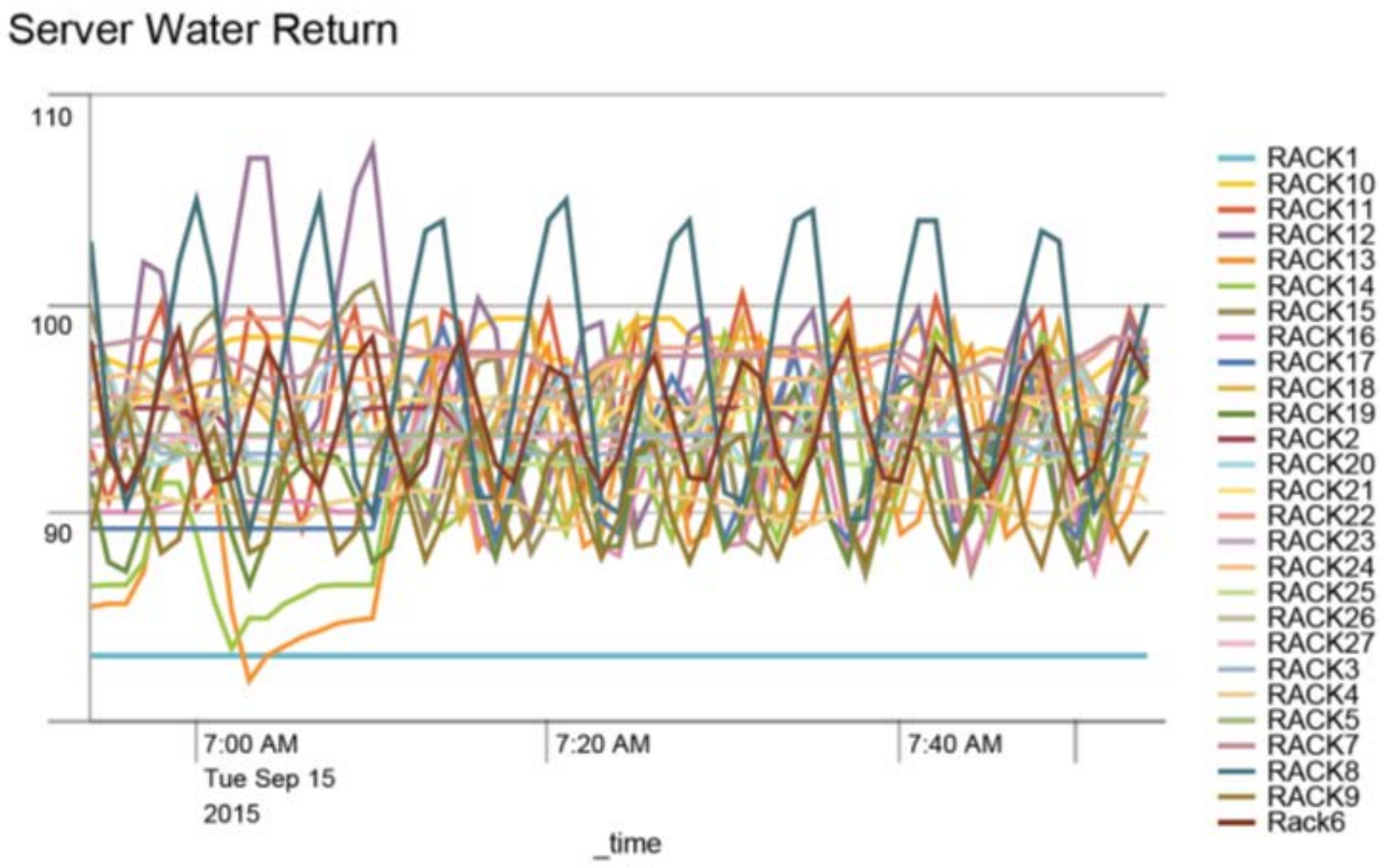
Sky Bridge – Server H2O Return



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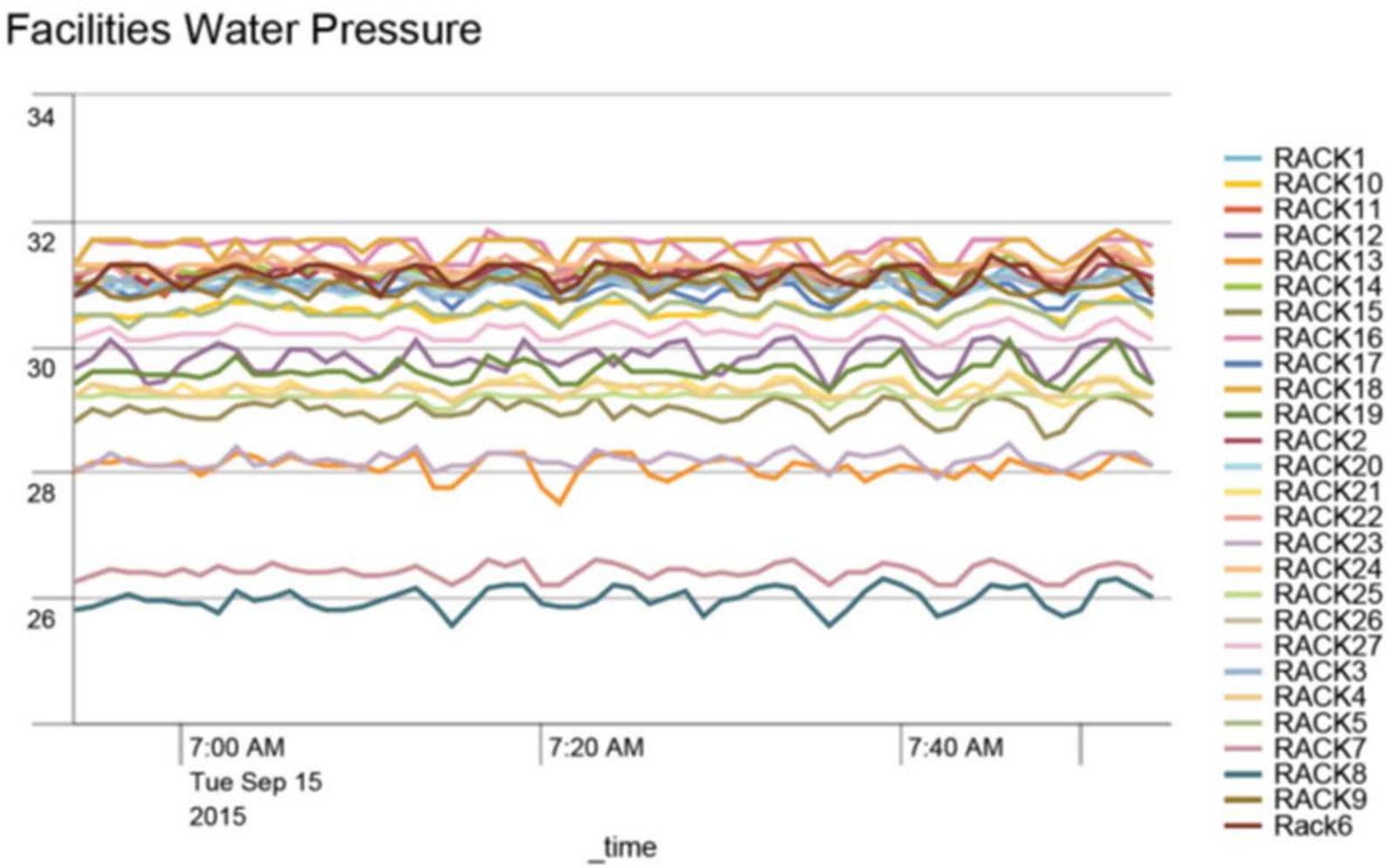
Sky Bridge – Facilities H2O Pressure



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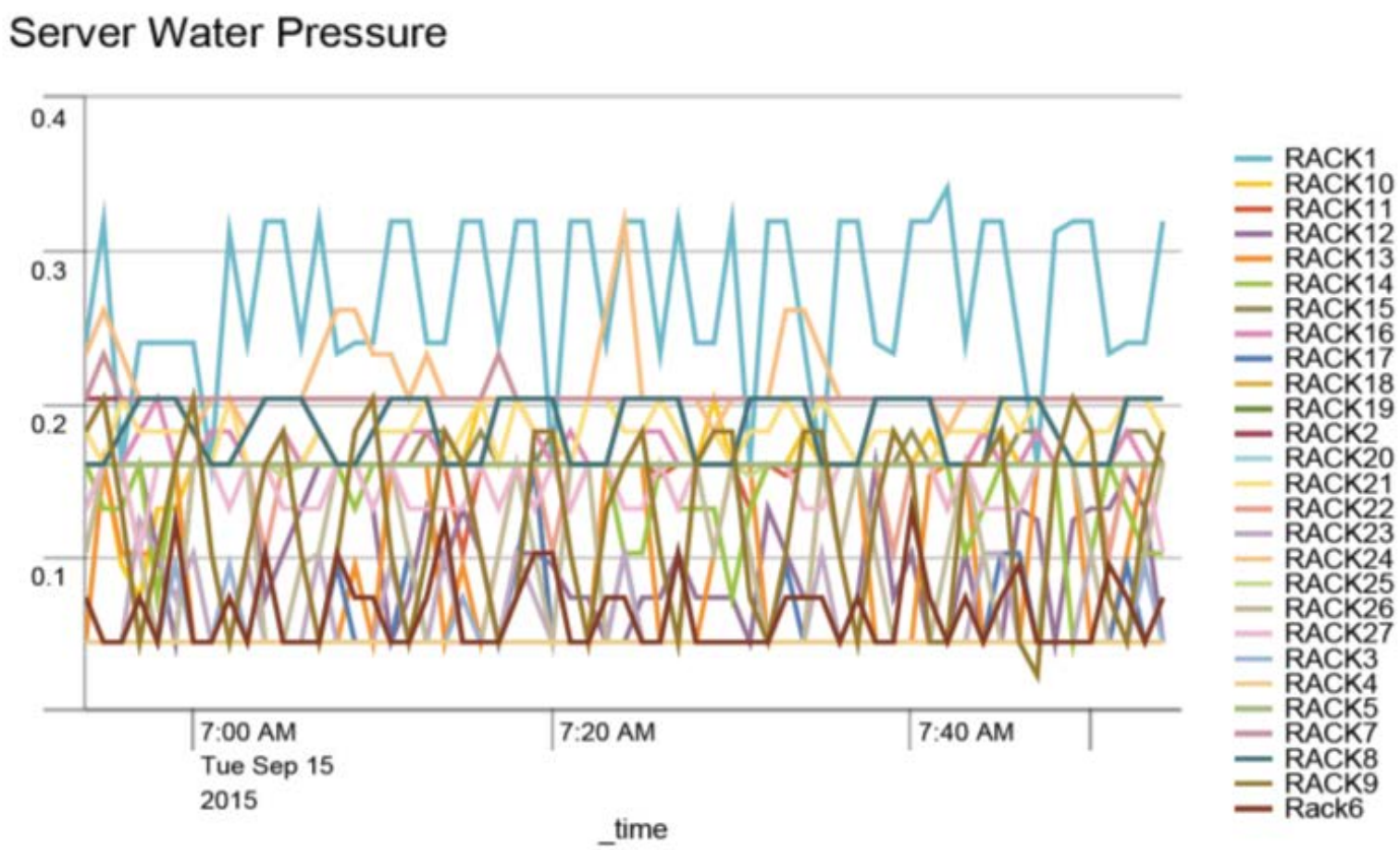
Sky Bridge – Server H2O Pressure



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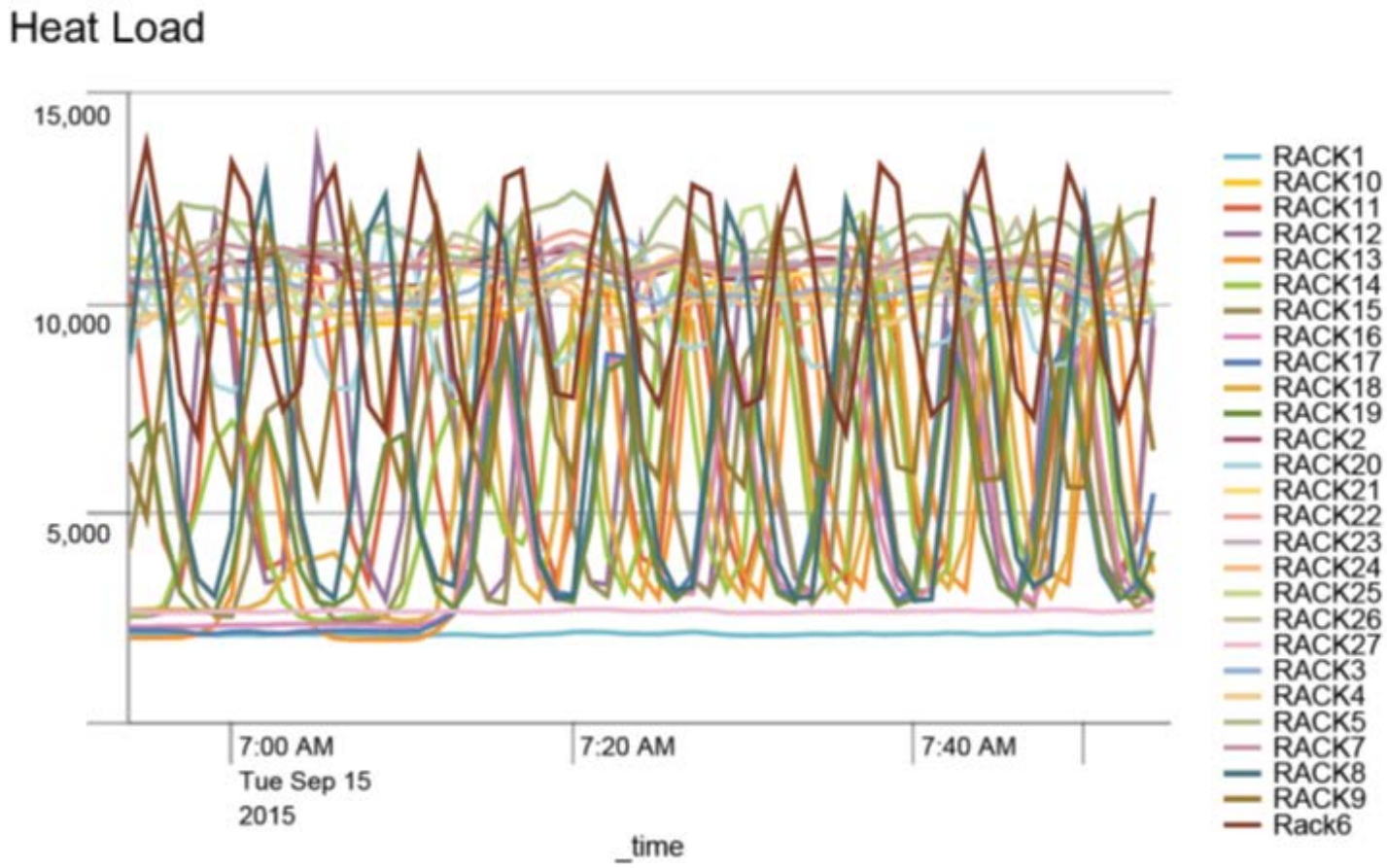
Sky Bridge – Heat Load



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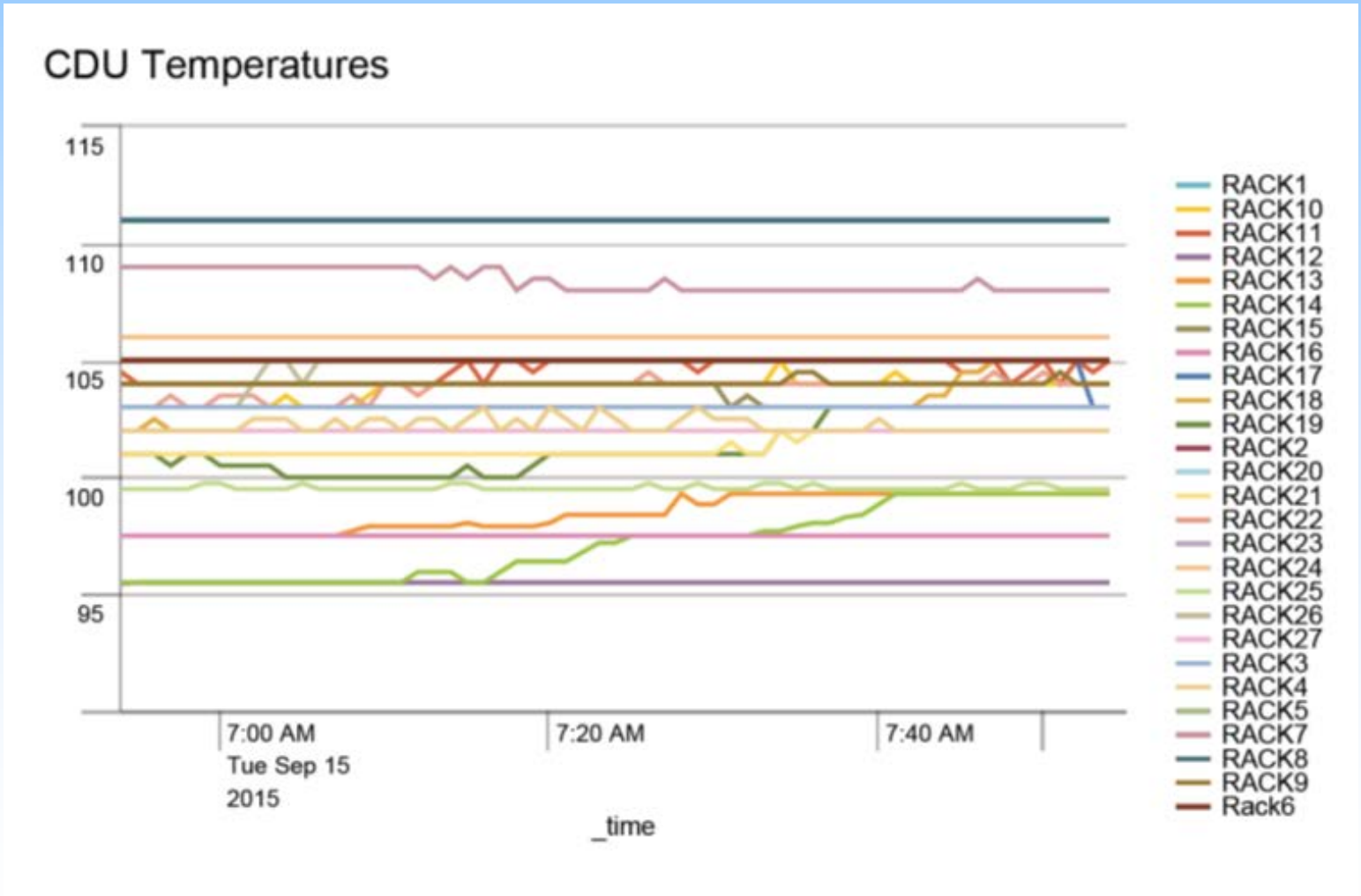
Sky Bridge – CDU Temps



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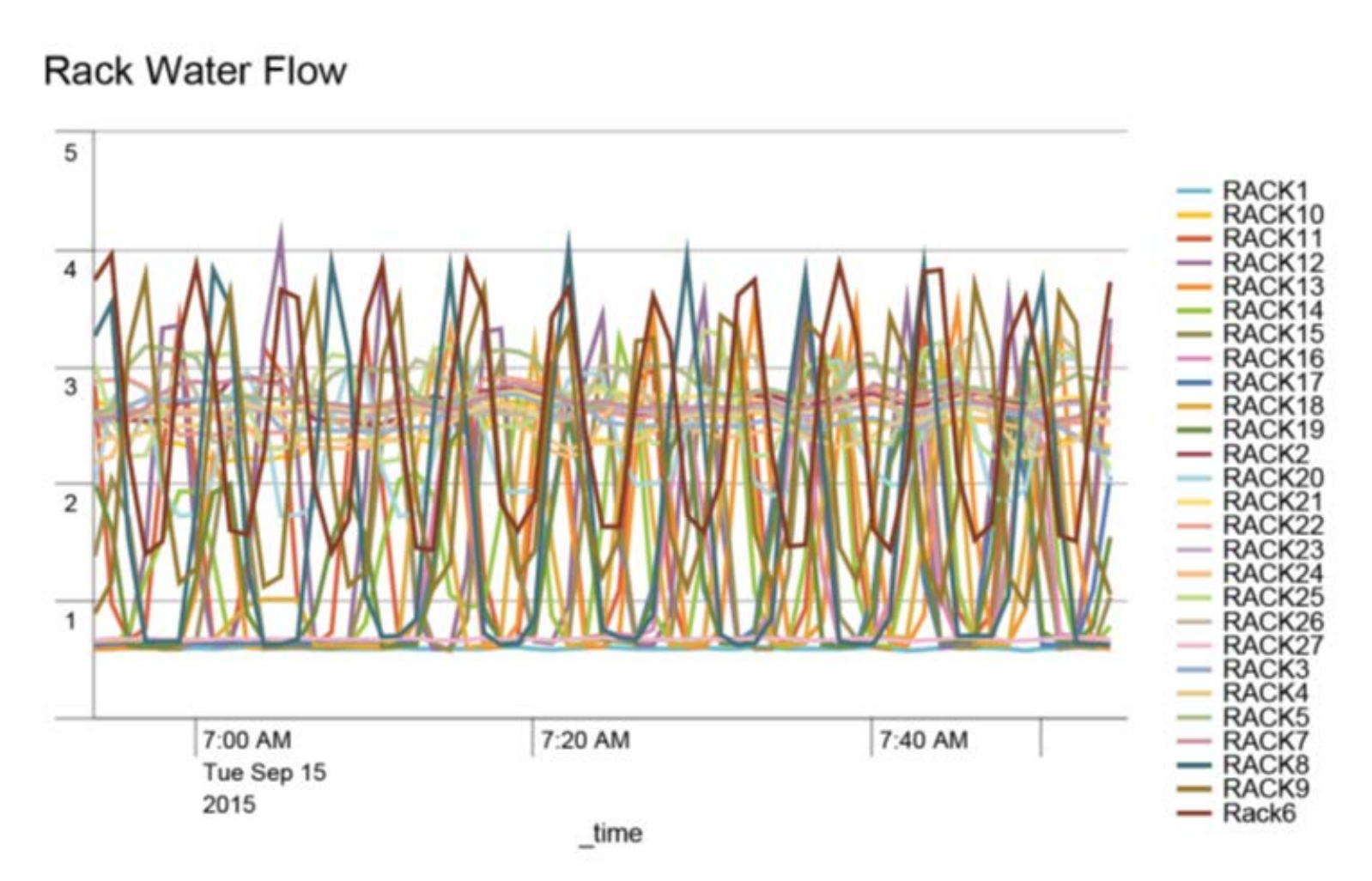
Sky Bridge – Rack Water Flow



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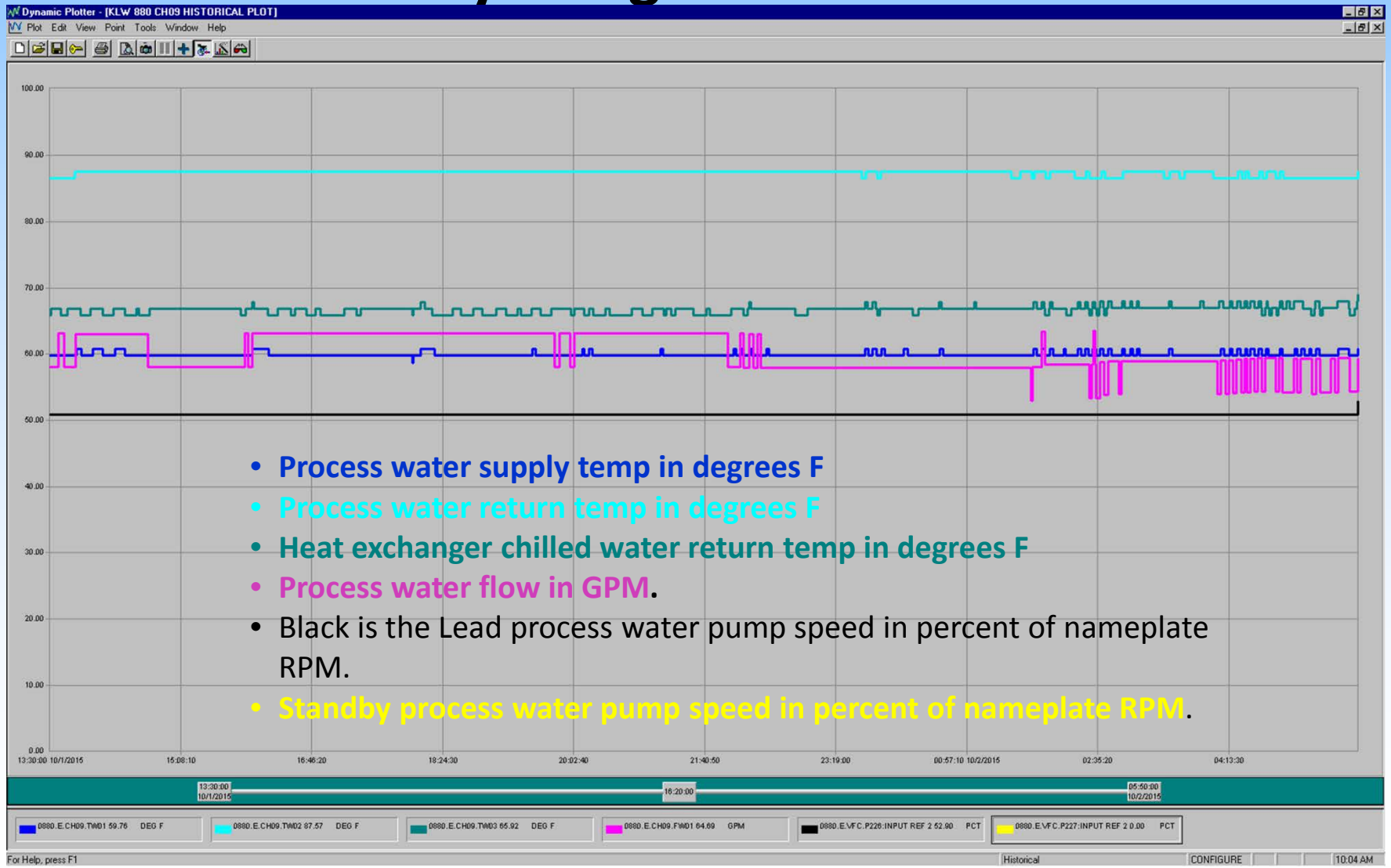
Sky Bridge – Chiller Plant



- **Process water supply temp in degrees F**
- **Process water return temp in degrees F**
- **Heat exchanger chilled water return temp in degrees F**
- **Process water flow in GPM**.
- Black is the Lead process water pump speed in percent of nameplate RPM.
- **Standby process water pump speed in percent of nameplate RPM**.

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Future

- Increase usage of Plate Frame HX year round
- Trend points with both systems
- Integrated Controls systems
- Trend points with both systems
- Predictive solutions

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Case Study at Stennis Space Center, MS.

Energy Savings Solutions

Started July 2014-July 2015

Case Study at Stennis Space Center, MS

What makes the Chiller Plant

- **Chiller(s) at SSC 2-WME 700 ton Magnetic Chillers 1-WMC300 magnetic Chiller**
- **Baltimore Air Coil FXV Closed Circuit Cooling Towers 500 tons each**
- **Chill water pumps are 60 HP 480v/3ph 1775 RPM 1400 GPM 75FTHD**
- **Condenser water pumps 60 HP 480v/3ph 1800 RPM 2100 GPM 40 FTHD**
- **All pumps have VFD's CHW/CW**

Case Study Stennis Space Center, MS

Criteria Requirements

- **Upgrade an existing Data Center Water Cooled Centrifugal Chiller Plant with better Energy Efficient systems and strategies**
- **Provide Energy Reduction in a Hot, Humid Climate Zone**
- **Reduce the energy usage to improve the yearly PUE**
- **Maintain uptime and reliability**
- **Incorporate control system to meet the criteria 24/7/365**
- **Cooling required is 500 tons with expansion plans**

Case Study Stennis Space Center, MS

Products Selected

- **Daikin Magnetic Bearing (WME700) oil free chillers**
- **BAC Closed Circuit Cooling Towers**
- **Controlled Water Results Process Control Design**
- **Honeywell Webs AX Niagara Platform**

Case Study Stennis Space Center, MS

Types of Computer Systems

- **IBM, with rear door heat exchangers**
- **Cray XE30 and XE40 internal cooling coils systems**

Case Study Stennis Space Center, MS

Energy Measures

- **Entering Water Temps 63F (This was done in steps)**
- **CWR controls system was installed**
- **Controls were programmed to optimize the site environmental dynamics (During start up and commissioning seasonally)**
- **Monitoring and trend data to record the plant KW/t**
- **Monitoring and trend data for the rack performance**

Case Study Stennis Space Center, MS

Results

Typical water cooled chiller plant kW/t averages 1.5 or higher

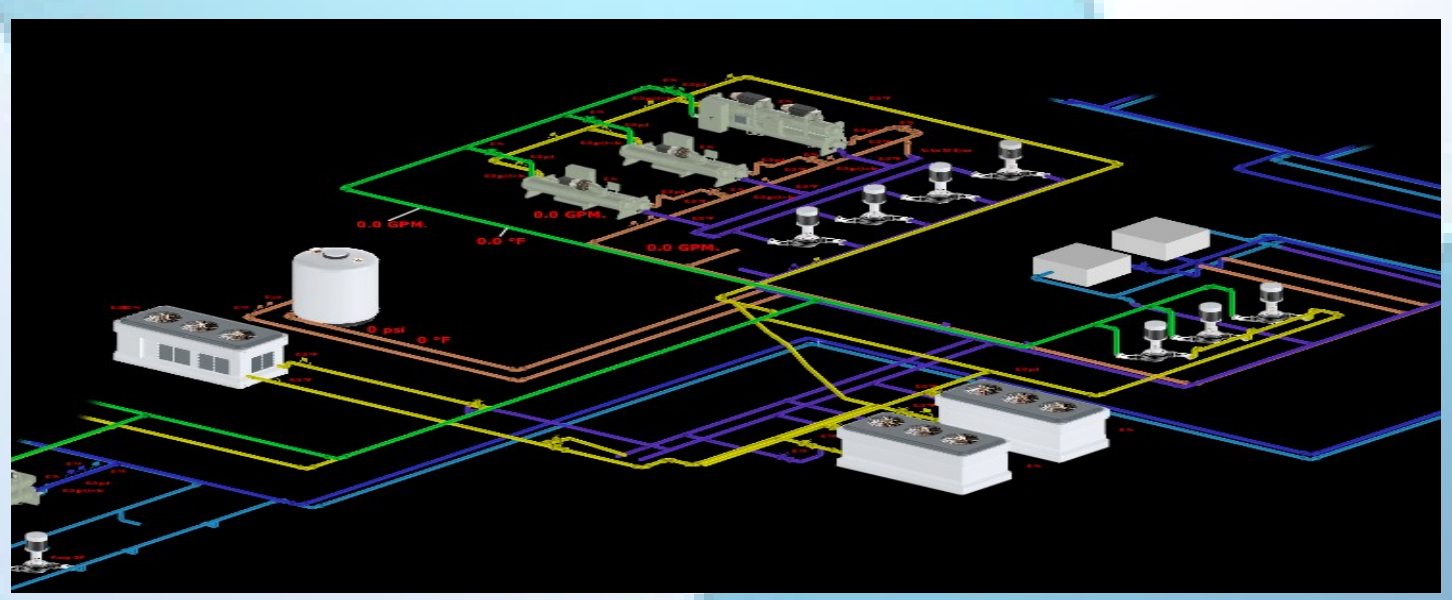
While newly designed efficient plants approach kW/t of 1.2

Our Results for the entire Chiller Plant:

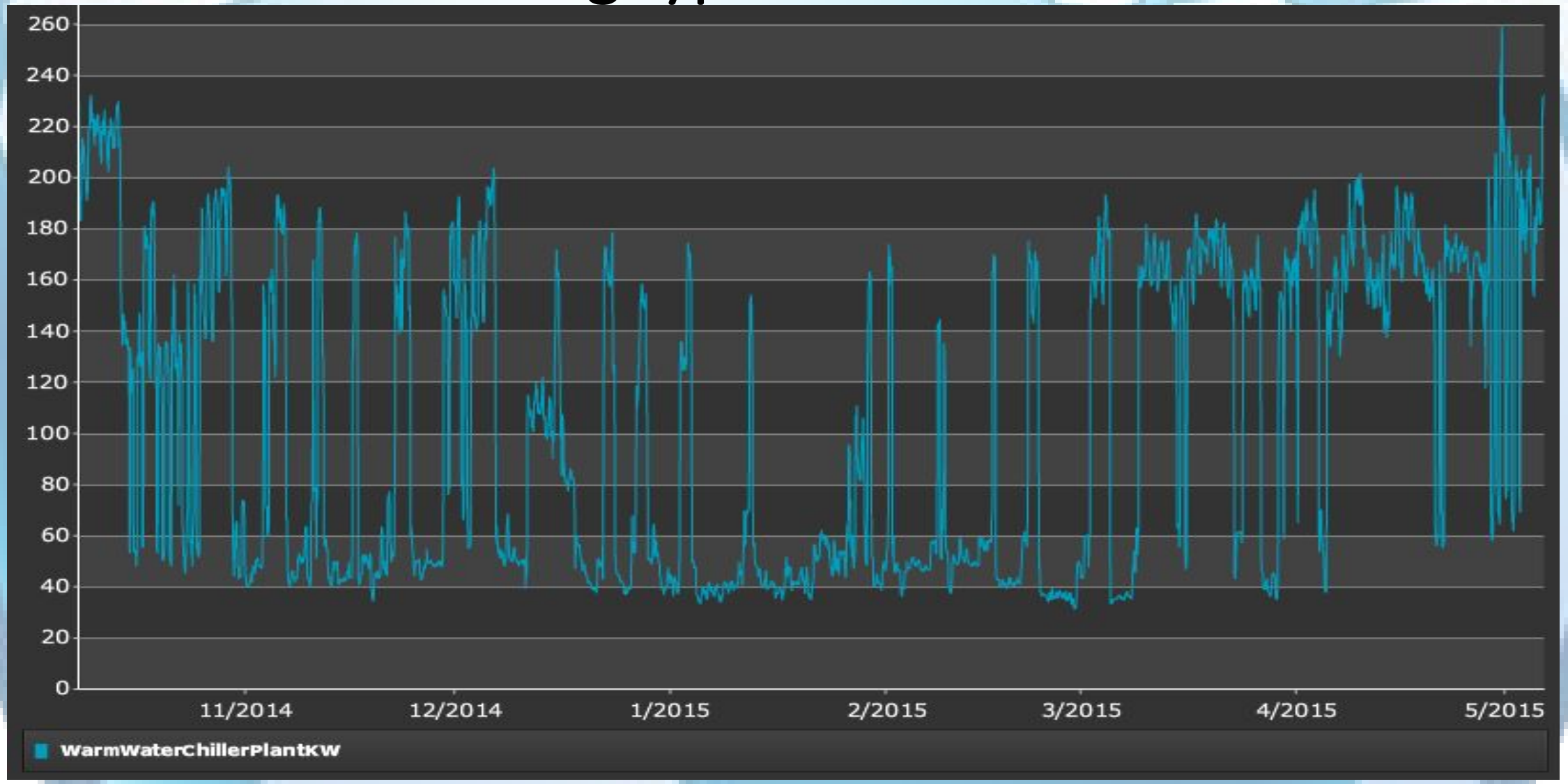
- **Peak Hot weather conditions August 31 Total plant kW/t 1.222 at 89.1F ambient, 78Fwet bulb (cool summer for MS)**
- **Lowest kW/t was March 6, 2015 kW/t of .181**
- **Over 1450 hours from July ‘14 – July ‘15 cooling kW/t at high of .999 to the low of .181 Under 1.000 kW/t was accomplished**

Case Study Stennis Space Center, MS

- **Plant KW/t using High Efficient Chillers and CWR Control System reduced the Hot/Warm weather ~25%**
- **In Comprehensive Cooling Mode Cooler Weather conditions the Reduction was from Mid to Upper 300/250+KW range Reduced to 51-31KW Same Load Same Amount of Work**



Case Study Actual Graph showing the reduction of KW during typical run conditions



Case Study Stennis Space Center, MS

Energy Savings Availability in "Better Climate Zones"

- **Operating kw/h 24/7/365 8760 hours/year**
- **Operating kw/h Comprehensive Cooling Mode**
- **Different regions what are the savings**
- **Examples for better weather states**
- **Oak Ridge, TN using the CWR process EWT 60F 4495 hrs. 51%/year EWT of 45F 2329 hrs. 26%/year 2014**
- **Dayton, OH using the CWR process EWT 60F 5331 hrs. 60%/year**

  EWT 45F 3159 hrs. 36%/year 2014

Case Study Stennis Space Center, MS

Questions???

SIMOPEK

sponsored by

Federal Ministry of Education and Research

Increasing Data Center Energy Efficiency via Simulation and Optimization of Cooling Circuits

-

A Practical Approach

Torsten Wilde (LRZ), Tanja Clees, Hayk Shoukourian, Nils Hornung, Michael Schnell,

Inna Torgovitskaia, Eric Lluch Alvarez, Detlef Labrenz, and Horst Schwichtenberg

EEHPCWG Webinar, 7.Oct. 2015

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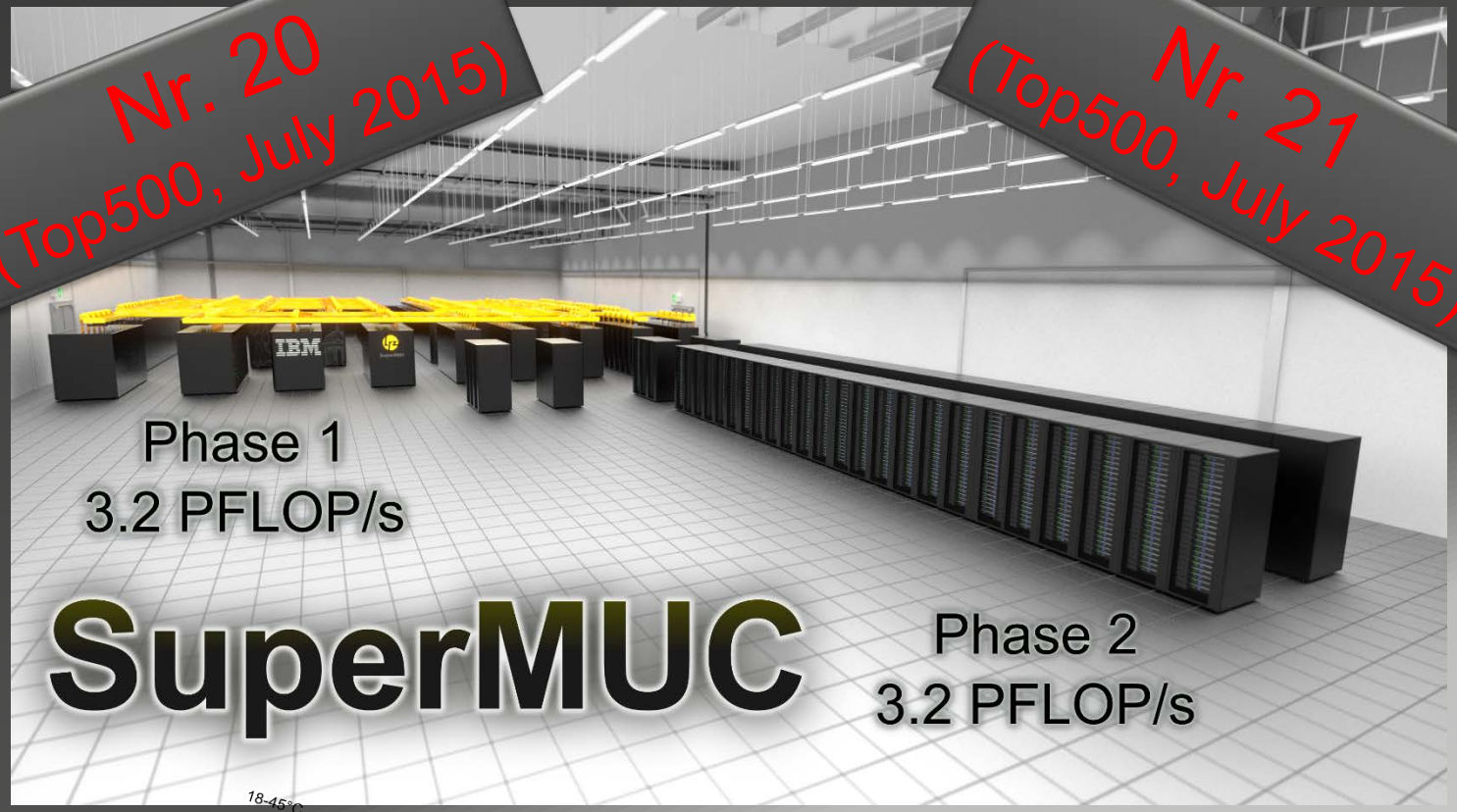
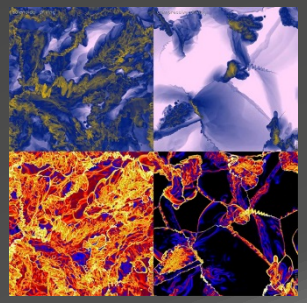
Some more Facts

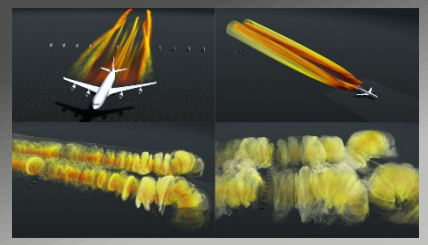
- **3160.5 m²** (34 019 ft²) IT Equipment Floor Space (6 rooms on 3 floors)
- **6393.5 m²** (68 819 ft²) Infrastructure Floor Space
- **2 x 10 MW** 20kV Power Supply
- **Powered Entirely by Renewable Energy**
- **> 5M €** (> 6M US$) Annual Power Bill

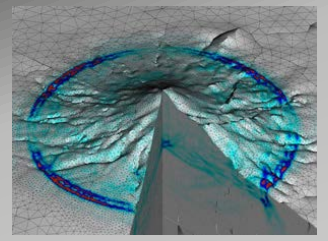
The Leibniz Supercomputing Centre

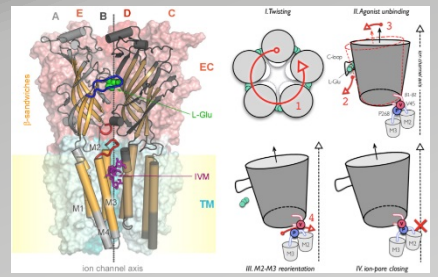
Scientific Computing at LRZ

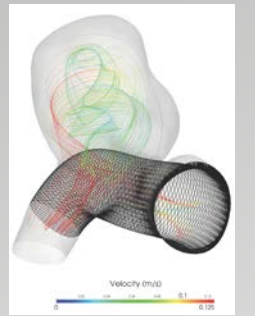


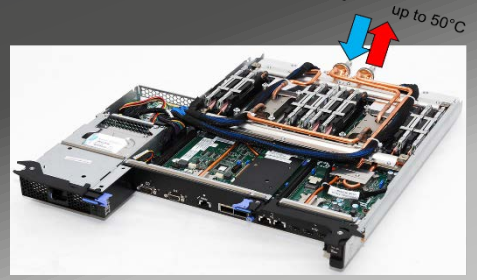


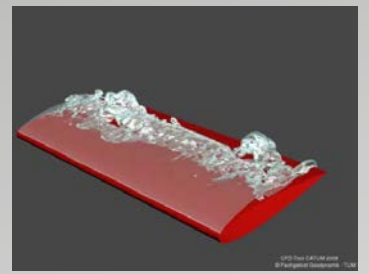


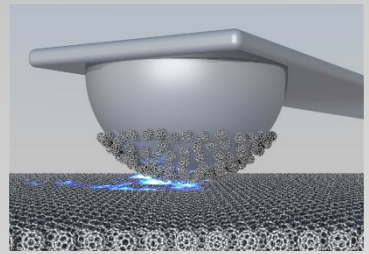


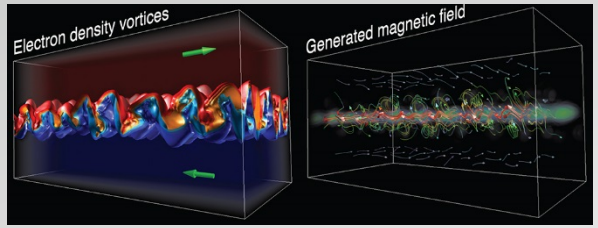










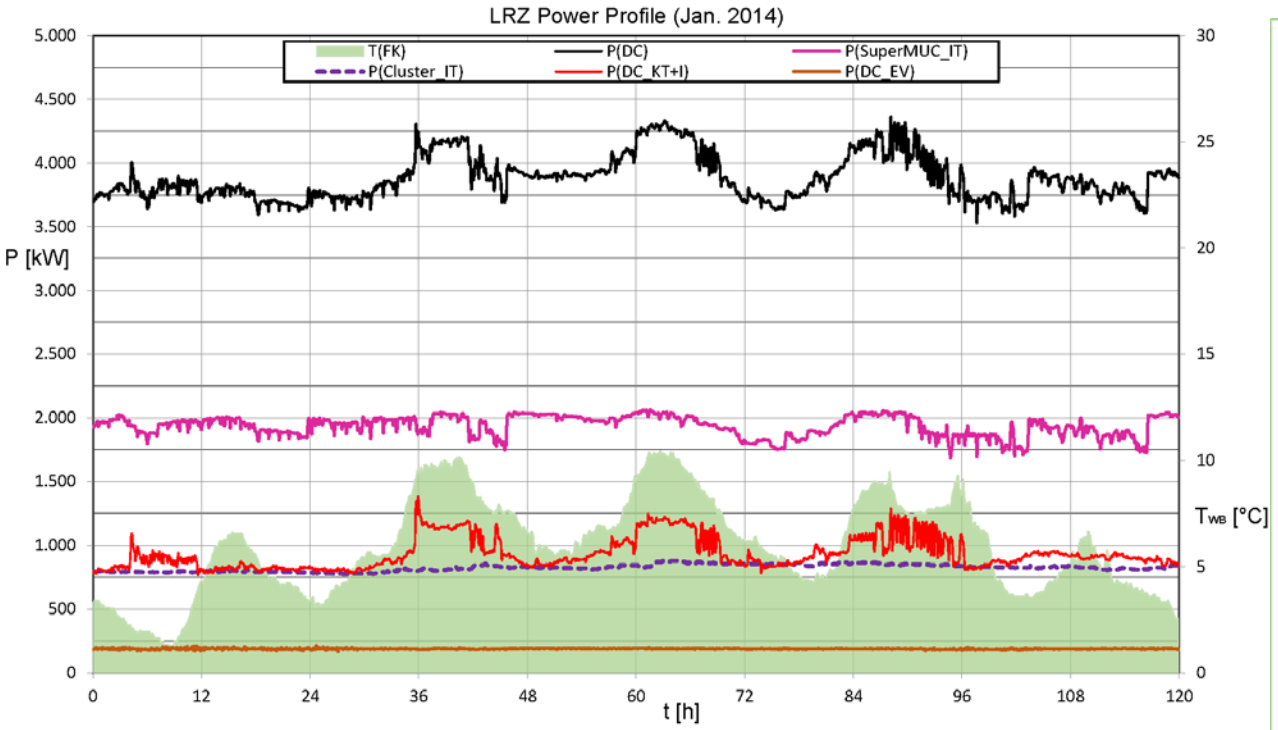


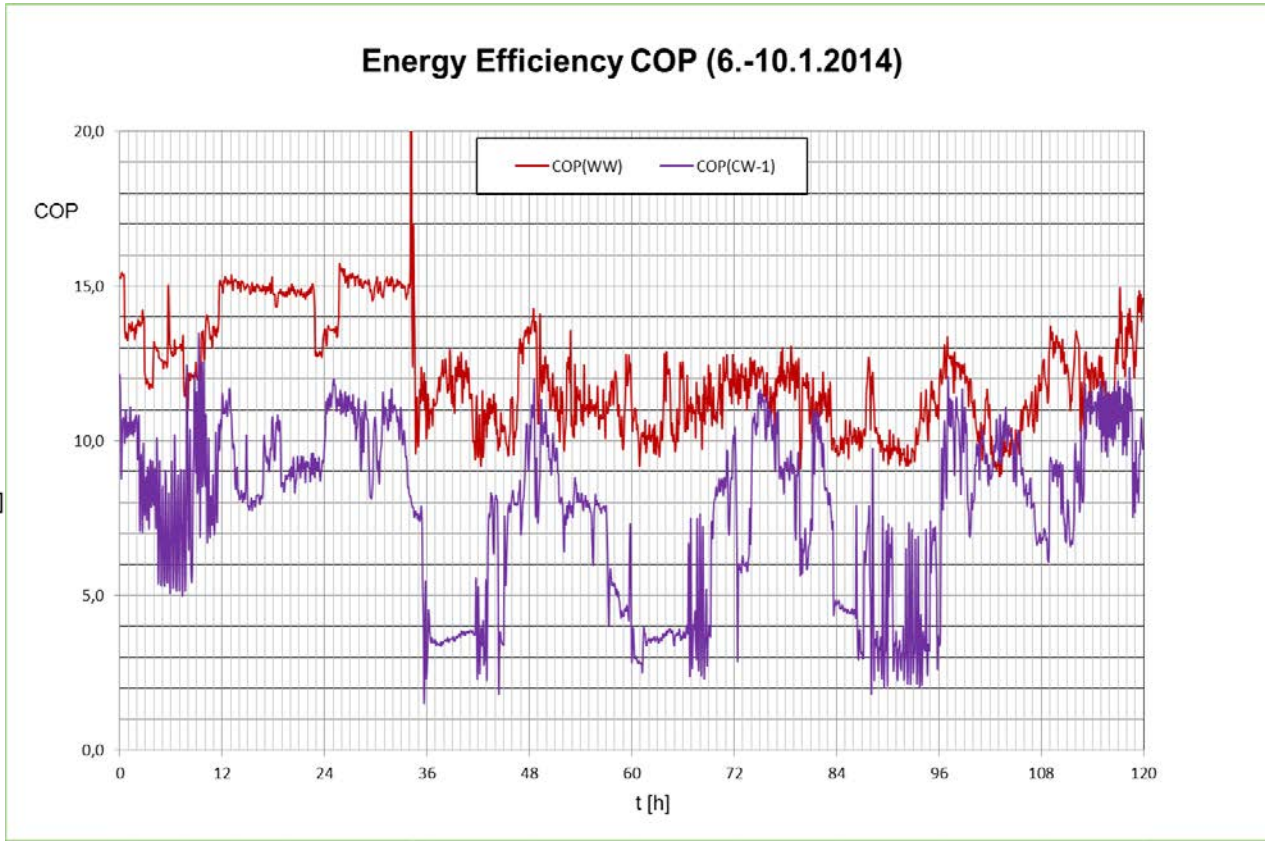
http://www.lrz.de/services/compute/supermuc/magazinesbooks/2014_SuperMUC-Results-Reports.pdf

http://www.gauss-centre.eu/gauss-centre/EN/Projects/projects_node.html

Challenges

Outside Conditions and LRZ Cooling Efficiency

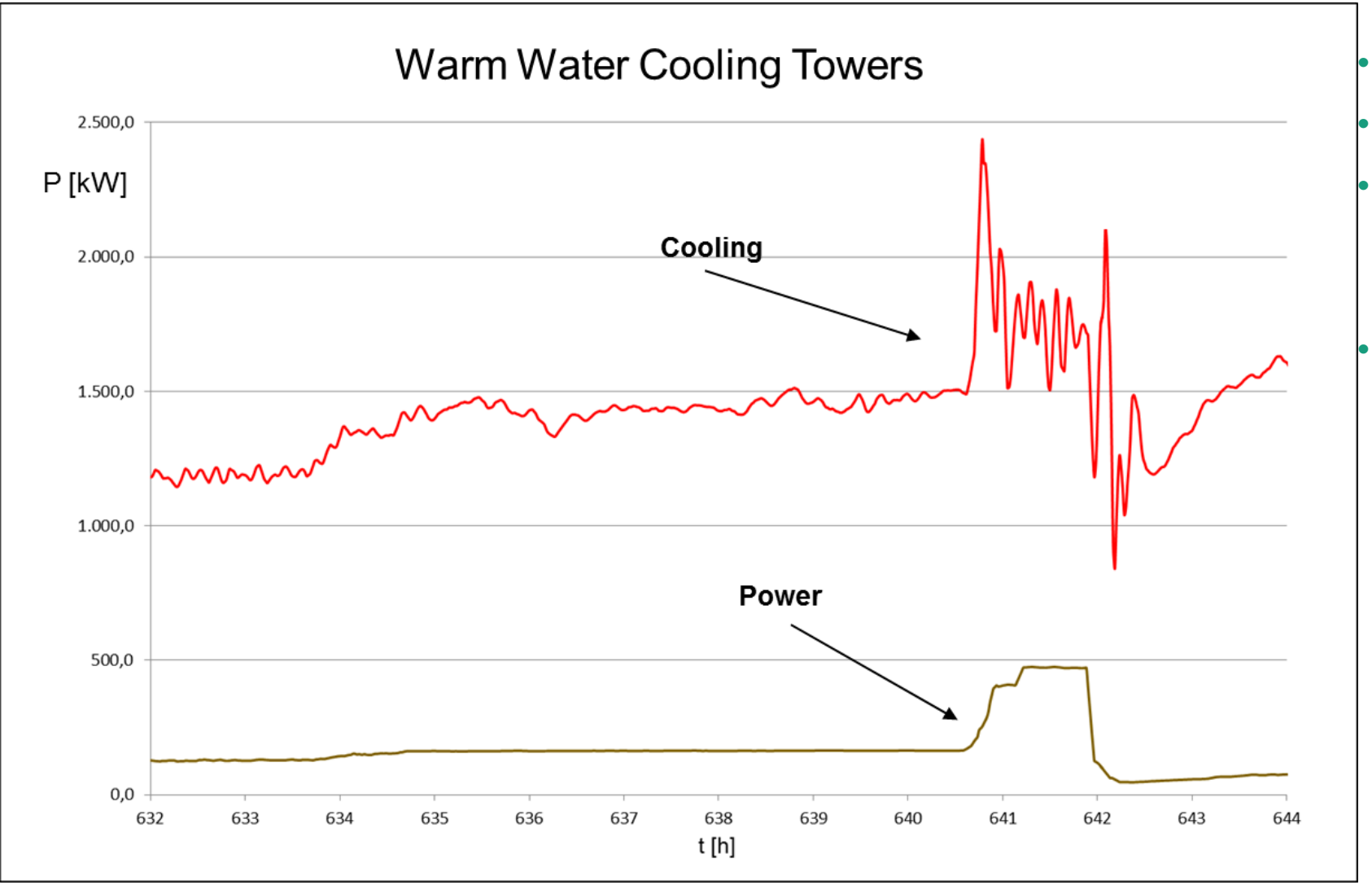




- IT power constant but cooling consumption increased by nearly 100%
- Outside temperature change
- Need instrumentation to figure out **WHERE**
- Much harder to figure out **WHY**

$$COP = \frac{Q}{P}$$

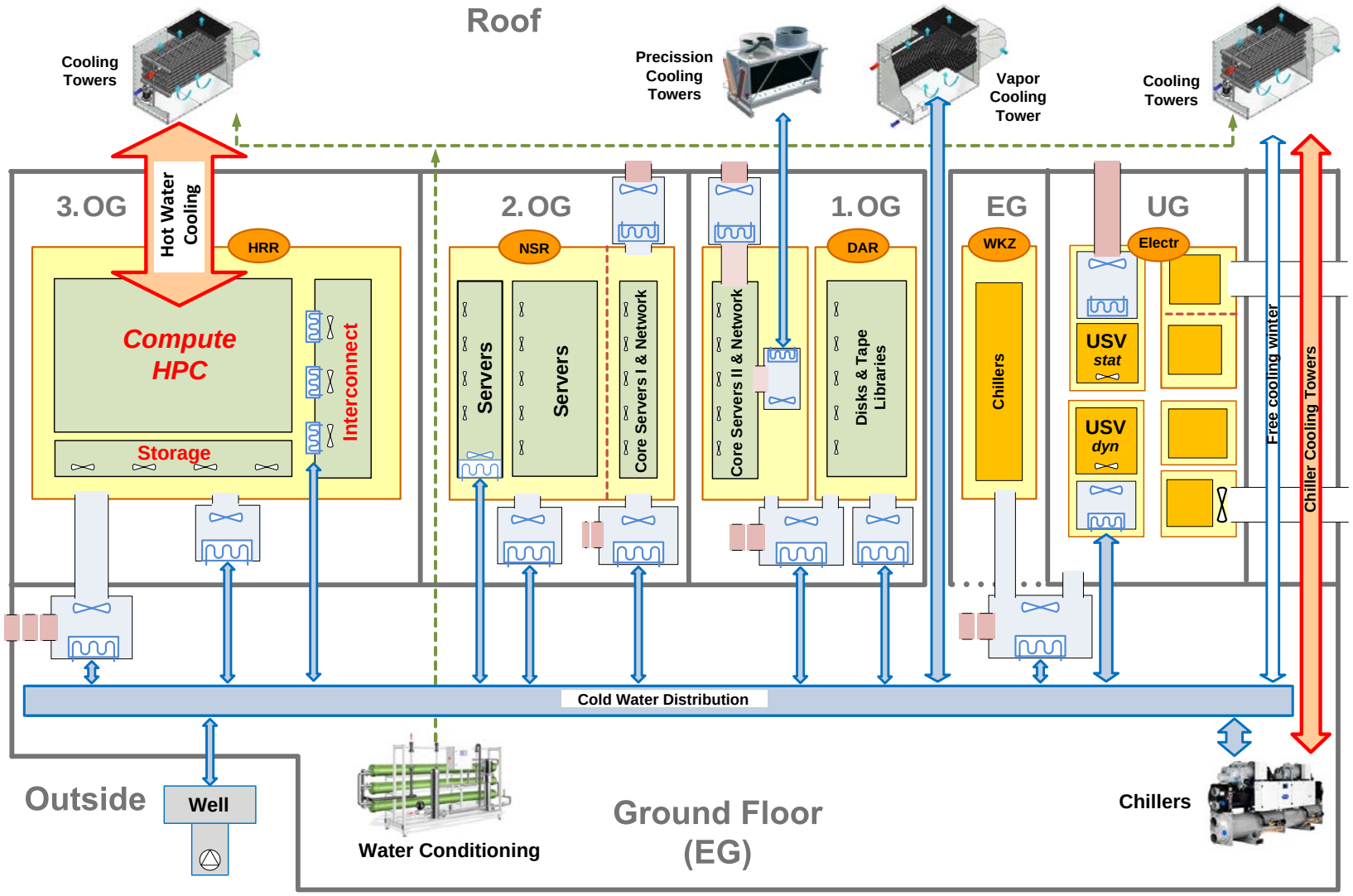
Operations Control: Test of ΔT_{inlet}(NSR) = -20 K
Response of Warm Water (Chiller-less) Cooling Infrastructure



- Chiller less cooling (4 towers 2MW each)
- No additional cooling needed
- IT power consumption did not change but not part of command and control loop
- 4 separate optimized cooling circuits -> need one control for all 4, need to integrate IT

Setting target temperature for NSR from 40°C (104°F) to 20°C (68°F) doubles the cooling system power consumption (Outside < 10°C (50°F))

New Generation of HPC Data Centers Use a Mix of Different Cooling Technologies



Cooling capacity LRZ (new construction):

- Vapor cooling: 2MW
- Well water: 600kW
- Chillers: 3.2MW
- Evaporative cooling towers: 8MW

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SIMOPEK - Extending Current Control Systems

- Add analytic and predictive capabilities to infrastructure control system
  - Use model and simulations to investigate infrastructure behavior
  - Use model and simulations to find optimal operating point for current workload and outside conditions

- Connect workload management systems with infrastructure management systems

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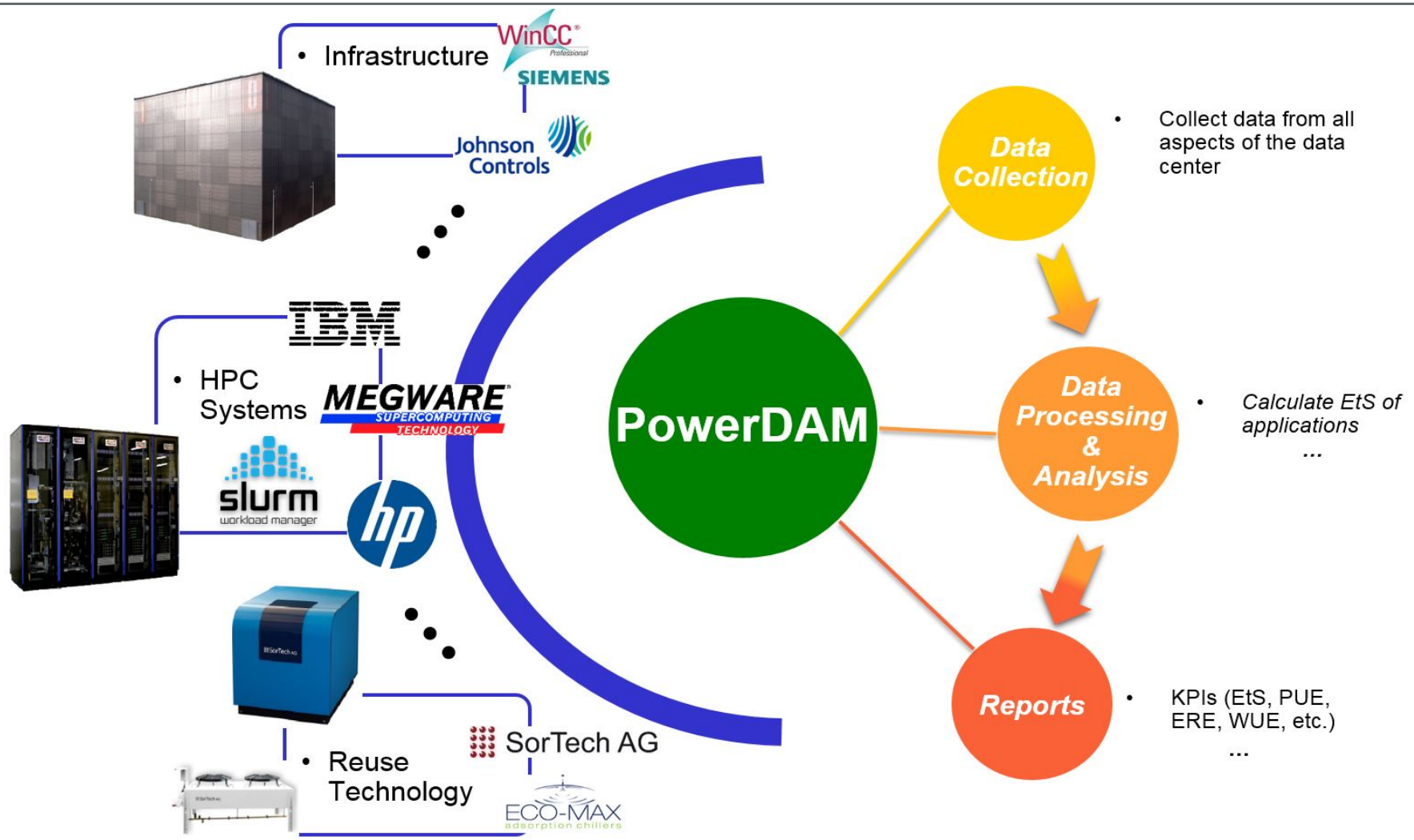
Processing requires Standards



Hayk Shoukourian, Torsten Wilde, Axel Auweter, Arndt Bode: "Monitoring Power Data: A first step towards a unified energy efficiency evaluation toolset for HPC data centers" published in Environmental Modelling & Software (Thematic issue on Modelling and evaluating the sustainability of smart solutions), Volume 56, June 2014, Pages 13–26; DOI: http://dx.doi.org/10.1016/j.envsoft.2013.11.011

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Fun With Sensor Names

Leibniz Rechenzentrum
Garching

Musterbezeichnungen

Festlegung Datenpunkt Adresse (Adress-Beispiel 1):
Bei Lüftungs / Heizung / Kälte Anlage:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
R	E	G	R	L	T	0	1	F	_	Z	U	T	_	M	W	0	1	REGRLT01F_ZUT_MW01
R	E	G	R	L	T	0	1	F	_	A	B	T	_	M	W	0	1	REGRLT01F_ABT_MW01
R	E	G	R	L	T	0	1	F	_	Z	U	F	_	M	W	0	1	REGRLT01F_ZUF_MW01
R	E	G	R	L	T	0	1	F	_	A	U	T	_	M	W	0	1	REGRLT01F_AUT_MW01
R	E	G	H	Z	G	0	1	F	_	V	L	T	_	M	W	0	1	REGHZG01F_VLT_MW01
R	E	G	H	Z	G	0	1	F	_	V	L	D	_	M	W	0	1	REGHZG01F_VLD_MW01
R	E	G	R	L	T	0	1	V	E	Z	U	F	U	S	B	0	1	REGRLT01VEZUFUSB01
R	E	G	R	L	T	0	1	V	E	Z	U	F	U	B	M	0	1	REGRLT01VEZUFUBM01
R	E	G	R	L	T	0	1	V	E	Z	U	F	U	S	M	0	1	REGRLT01VEZUFUSM01
R	E	G	R	L	T	0	1	V	E	Z	U	R	P	W	M	0	1	REGRLT01VEZURPWM01
R	E	G	R	L	T	0	1	V	E	Z	U	L	W	S	M	0	1	REGRLT01VEZULWSM01
R	E	G	H	Z	G	0	1	K	M	V	L	D	M	S	M	0	1	REGHZG01KMVLDMSM01
R	E	G	H	Z	G	0	1	K	M	V	L	D	X	S	M	0	1	REGHZG01KMVLDXSM01
R	E	G	H	Z	G	0	1	V	_	_	_	D	D	M	W	0	1	REGHZG01V__DDMW01
R	E	G	R	L	T	0	2	K	L	A	U	_	_	S	T	0	1	REGRLT02KLAU__ST01
R	E	G	R	L	T	0	2	K	L	A	U	_	_	R	M	0	1	REGRLT02KLAU__RM01
R	E	G	R	L	T	0	2	K	L	F	O	_	_	R	M	0	1	REGRLT02KLFO__RM01
R	E	G	R	L	T	0	2	K	L	M	I	_	_	R	M	0	1	REGRLT02KLMI__RM01

Stelle 1:	Gebäude (R/I/H)
Stelle 2+3:	Geschoß
Stelle 4+5+6:	Anlagenart
Stelle 7+8:	Anlagennummer 2-stellig
Stelle 9+10:	Gerät
Stelle 11+12:	Gerätestandort
Stelle 13+14:	Funktionsart (Fühlertyp)
Stelle 15+16:	Datenpunktart
Stelle 17+18:	Zähler

PowerDAM API:

$$RootResource(.Resource) * _SensorType = Value; Timestamp$$

jci.IUGSS41.EZ04_MW__PE_power

- IUGSS_41EZ__PEMW04
- @JCSQL:NAE054-01:NAE054-01/N2 Trunk1. NAE054-MIG136.IUGSS_41EZ__PEMW04.Present Value

WinCC

- Names relate to individual circuit names without any regard to possible structure
- Use of German Umlaute

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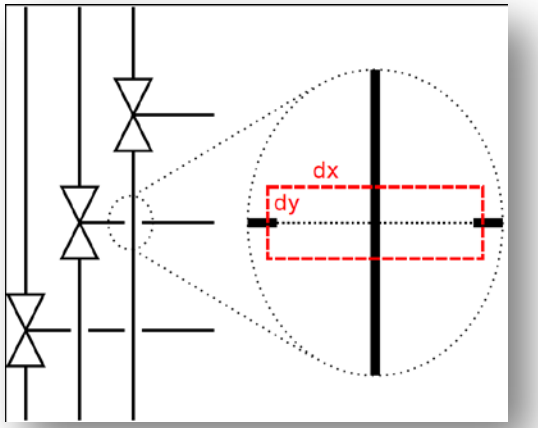
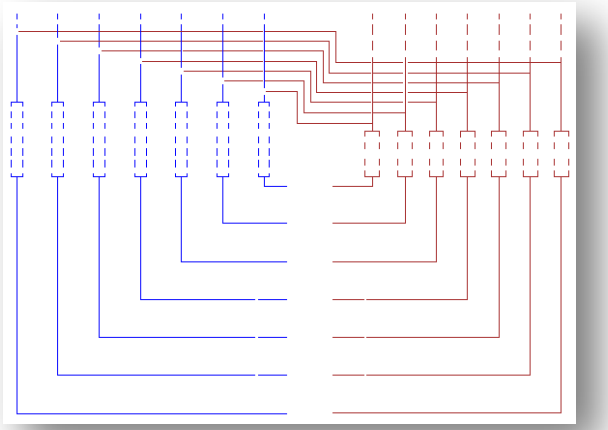
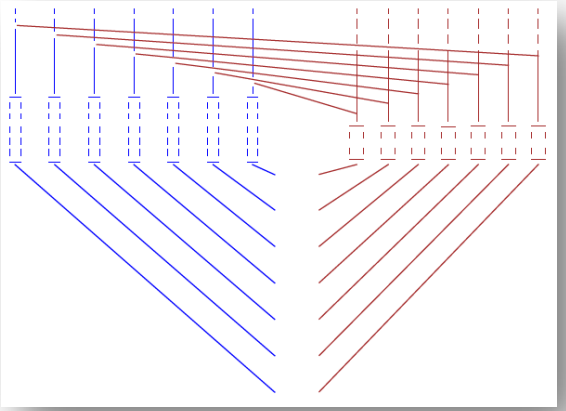
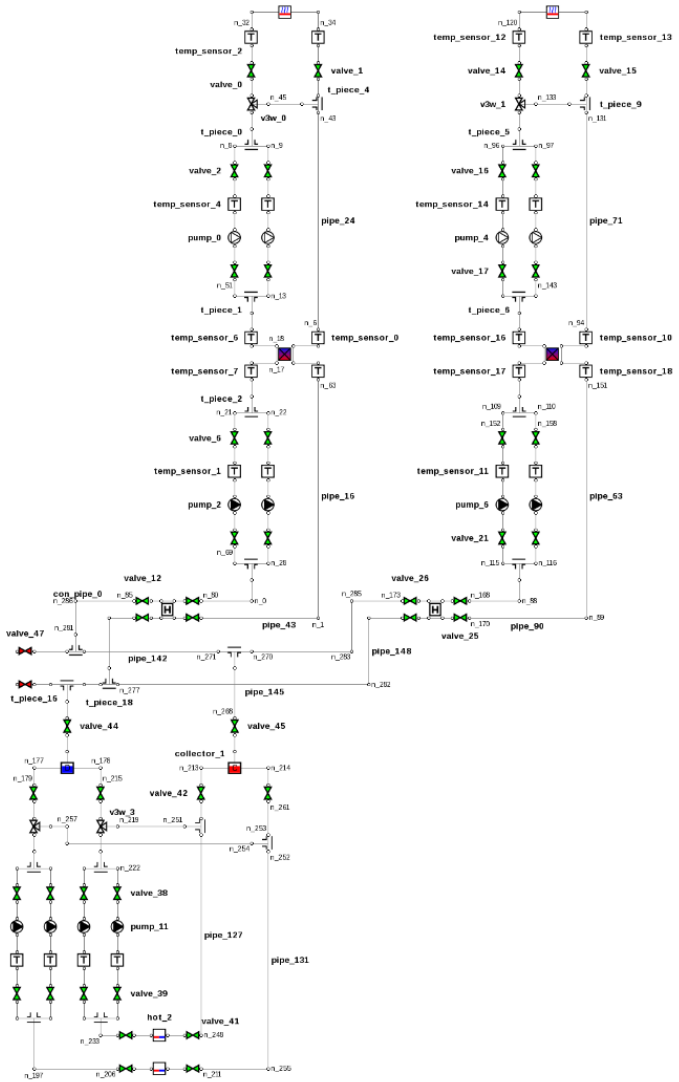
(Semi-) automatic Generation of Cooling Network

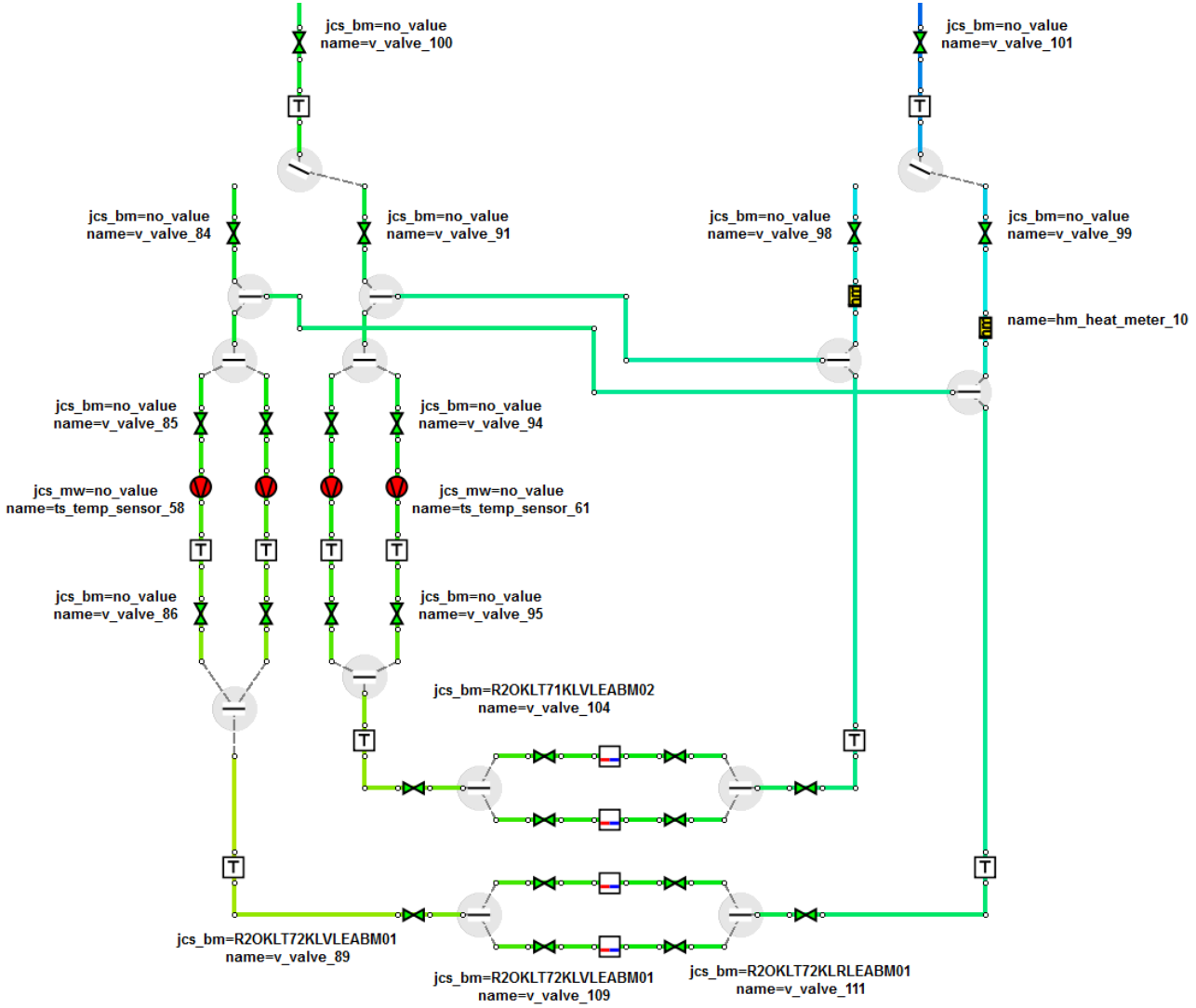








(Semi-) automatic Generation of Cooling Network



- Requires manual mapping from auto-generated devices to monitoring system device names
- Technical descriptions / characteristic curves for each installed device
  - Regulated and unregulated pumps
  - Heat exchangers
  - Cooling towers
  - 1- and 3-way valves
  - Resistors, regulators, and pipes
  - Special devices (adsorption chiller, SorTechAG)
- Control logic

Lessons Learned 1/2

- Need parsable topology maps (network topology description and technical details on its elements) of the data center infrastructure
  - Helps to check whether components are really installed according to specifications in the infrastructure plan.
- Need electronic versions of element descriptions (characteristic curves and diagrams)
  - Reduces manual labor substantially
- Need to be involved in defining the sensor naming schemas for all monitoring systems
  - Allows for easy automatically processing of data by other data center tools
  - Allows for name coherence checking tools.

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Lessons Learned 2/2

- Stick to the English alphabet everywhere in your data center software
  - Less worries when processing the data later on
  - Otherwise be aware of possible UTF-8 related issues.

- Avoid data center monitoring and automation tools that require proprietary access tools.
  - If not possible, include any extra tools and installations needed to access the data in the procurement .

- Treat collected sensor data with an appropriate amount of skepticism.
  - In most cases, invalid sensor data is the cause of strange data center infrastructure behavior.

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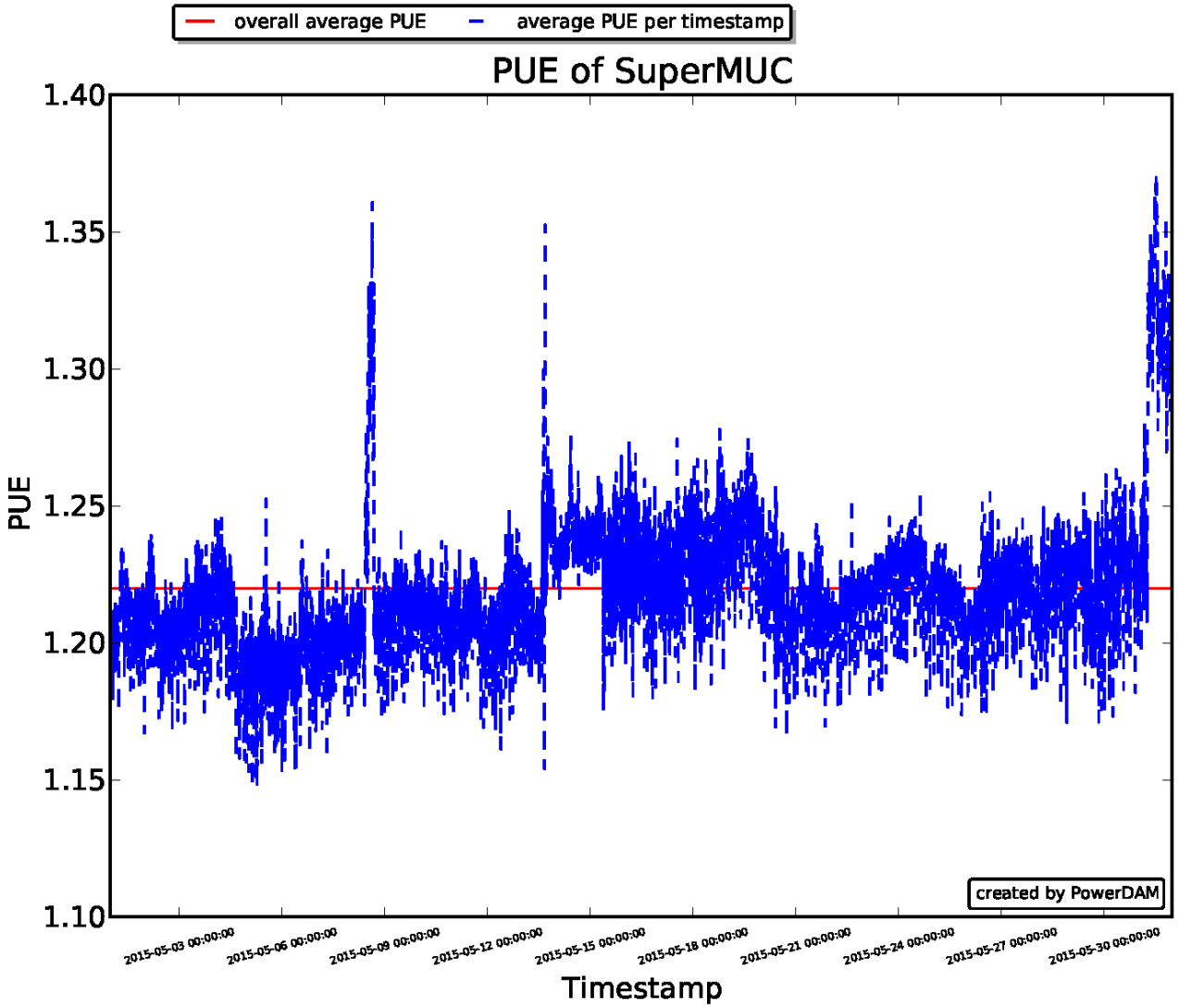
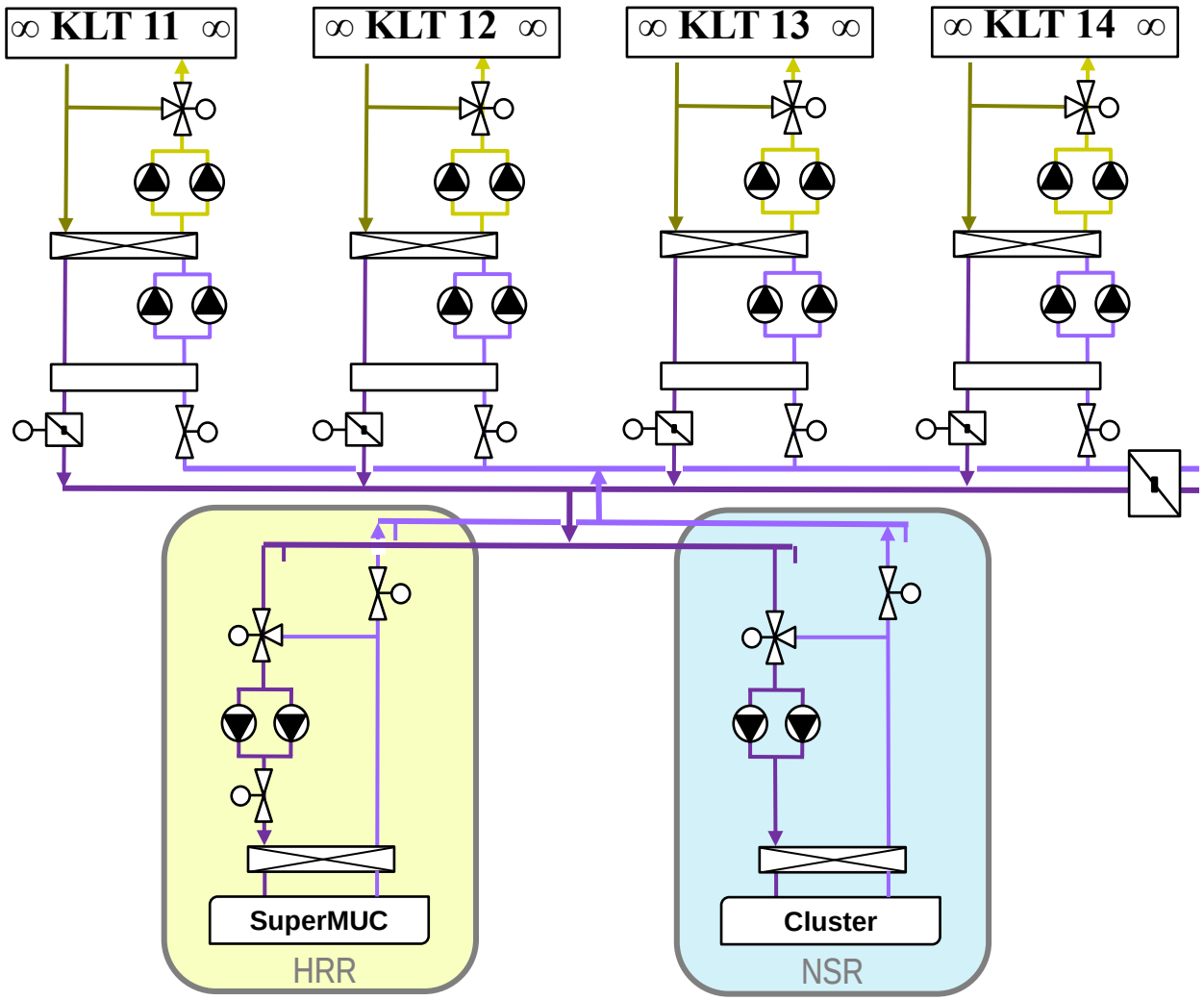
Current Status and Future Work

System Specific PUE



LRZ Chiller-free Cooling Circuit Overview Schematic



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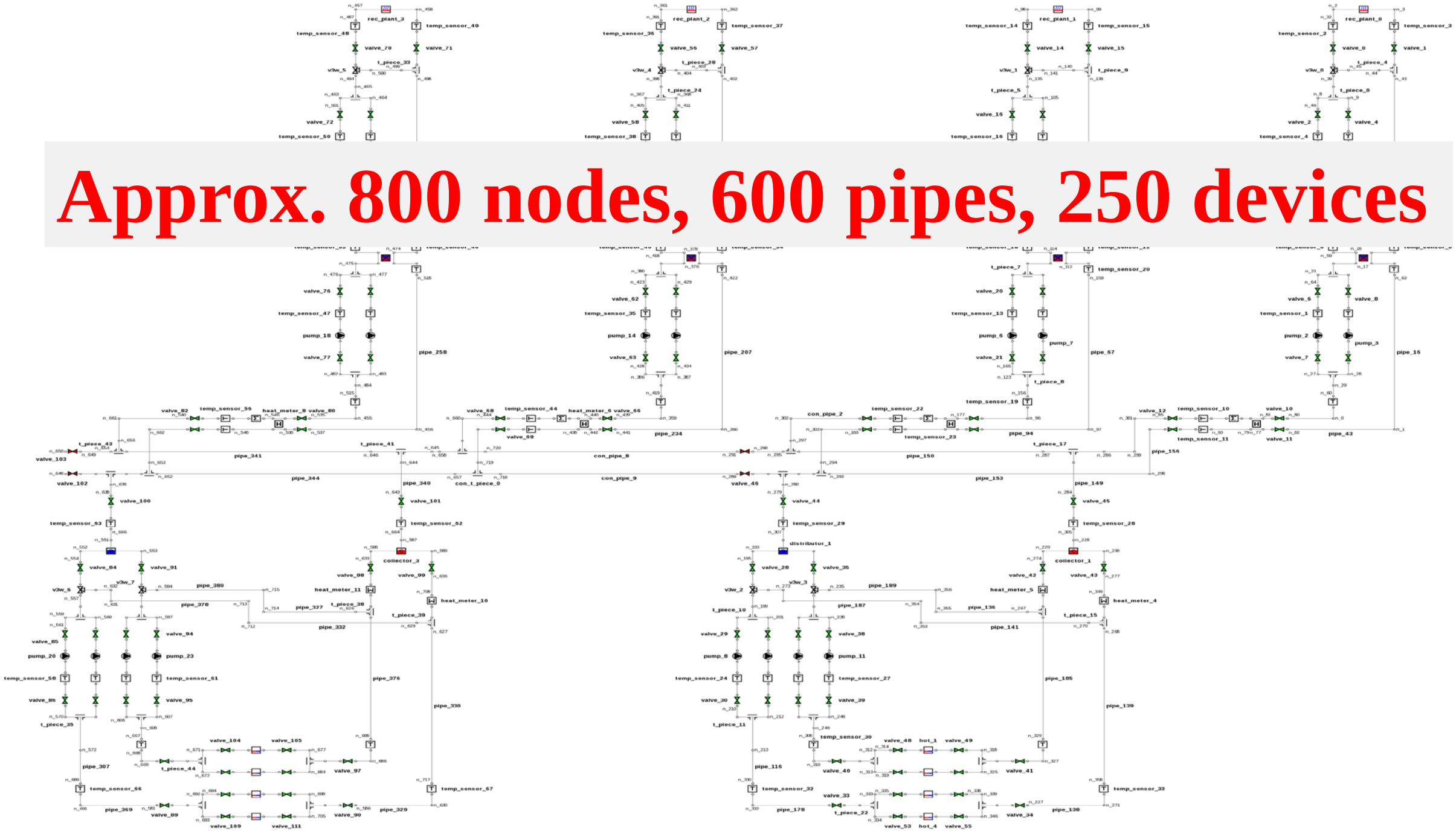
Approx. 800 nodes, 600 pipes, 250 devices



Future Work

- Extend NSR cooling infrastructure model with CooLMUC internal cooling circuit.
  - Simulation of the model and its use to find an optimal adsorption chiller design.

- Model and simulate one complete cooling circuit (HRR+NSR and KLT11)
  - Hopefully, the simulation can provide information about possible optimization potential.
    - Do we need the hydraulic gates in the chiller-less cooling circuits?

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der Bayerischen Akademie der Wissenschaften

Next Steps and Closing Statements

- CONTROLS DATA ELEMENTS: a list of data elements deemed important for liquid cooling controls from both the IT systems and the data center building
  - This work is exploratory, as there are few implementations of dynamic integrated liquid cooling controls
  - We are now collecting information on use cases to test and expand upon the initial list of data elements.
- BoF "Dynamic Liquid Cooling, Telemetry and Controls; Opportunity for Improved TCO?" Tuesday, 5:30-7:00PM
- We are looking for more examples of liquid cooling controls
- Presentations and audio recording posted on EE HPC WG website https://eehpcwg.llnl.gov/pages/webinar.htm

EE HPC WG and SC15

6th Annual Workshop for the Energy Efficient HPC Working Group
Monday, 9:00AM-5:30PM
- Keynote, Justin Rattner, CTO Intel (retired)
- Opening Remarks, Satoshi Matsuoka, Tokyo Institute of Technology

BoF “Dynamic Liquid Cooling, Telemetry and Controls; Opportunity for Improved TCO?” Tuesday, 5:30-7:00PM

BoF “The Green500 List and its Continuing Evolution” Wednesday, 5:30-7:00PM

BoF “Identifying a Few, High-Leverage Energy Efficiency Metrics” Thursday, 12:15-1:15PM

Paper “Node Variability in Large-Scale Power Measurements: Perspectives from the Green500, Top500 and EEHPCWG” Thursday, 2:00-2:30PM

EE HPC WG Booth