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I don’t want to move to the Arctic - a HPC Data Center Take on PUE and Energy Efficiency

Torsten Wilde (LRZ), Detlef Labrenz (LRZ), iCAS‘15, Annecy, France

Facebook – Lulea

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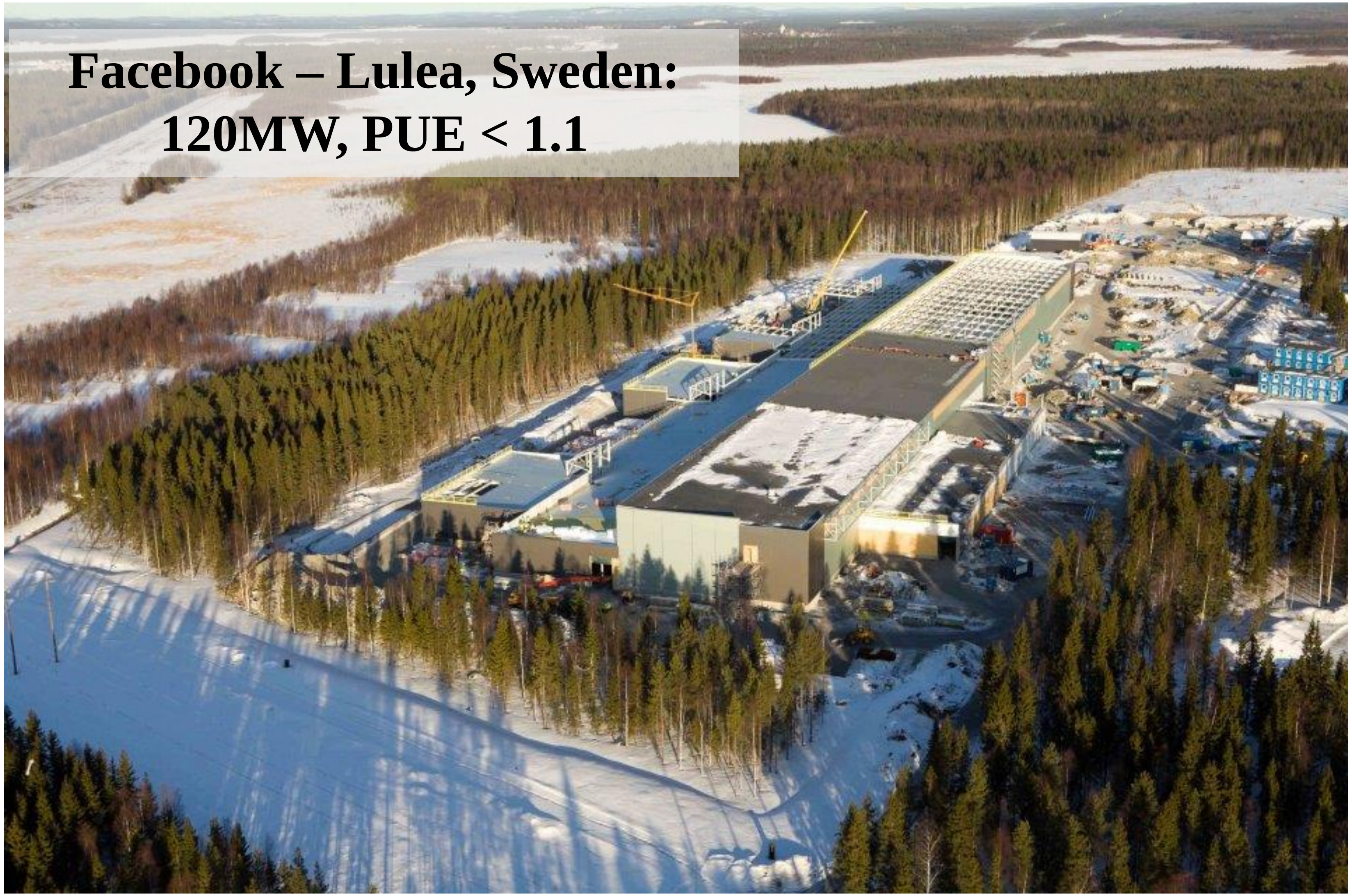

Google – Hamina

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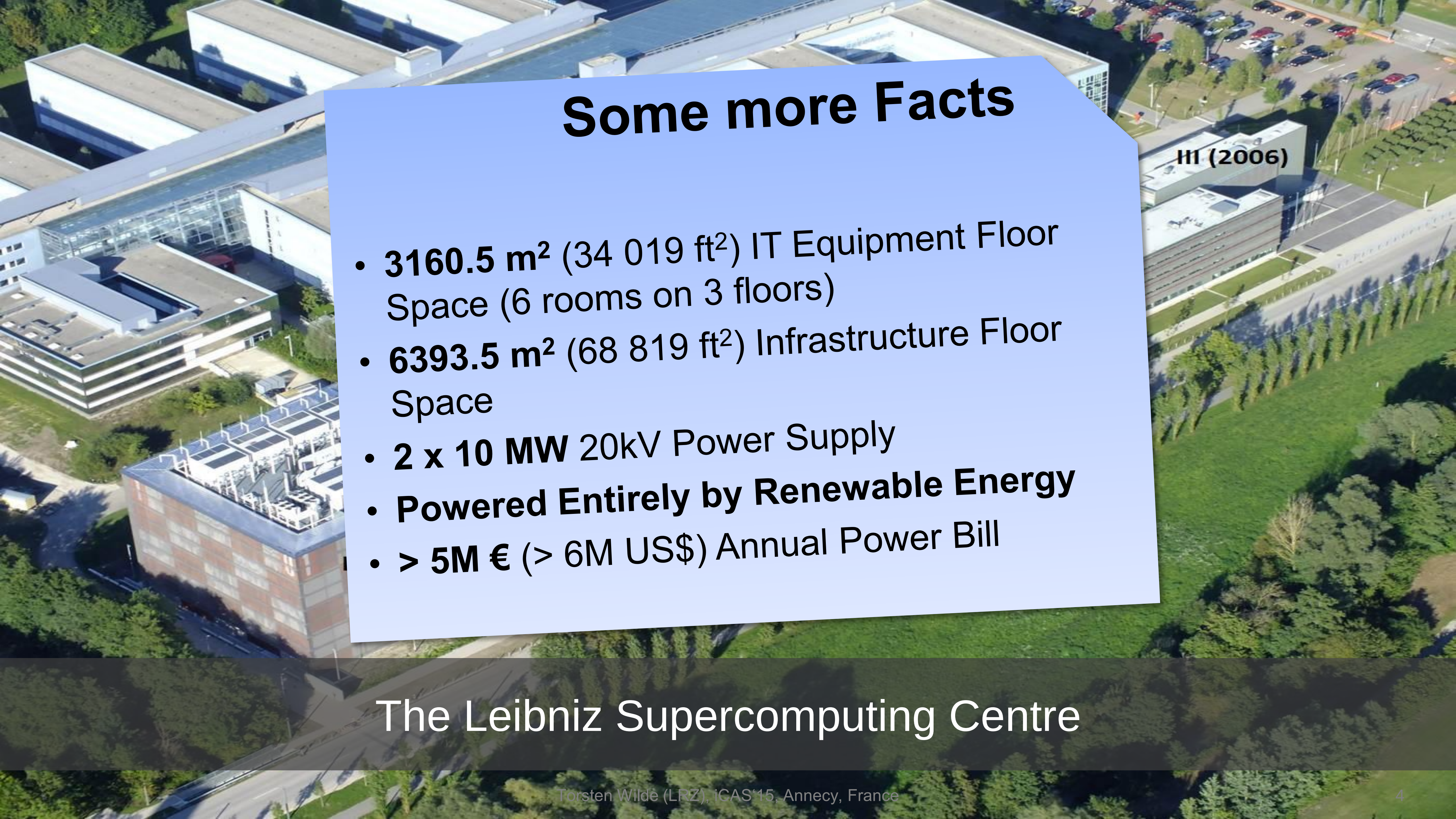


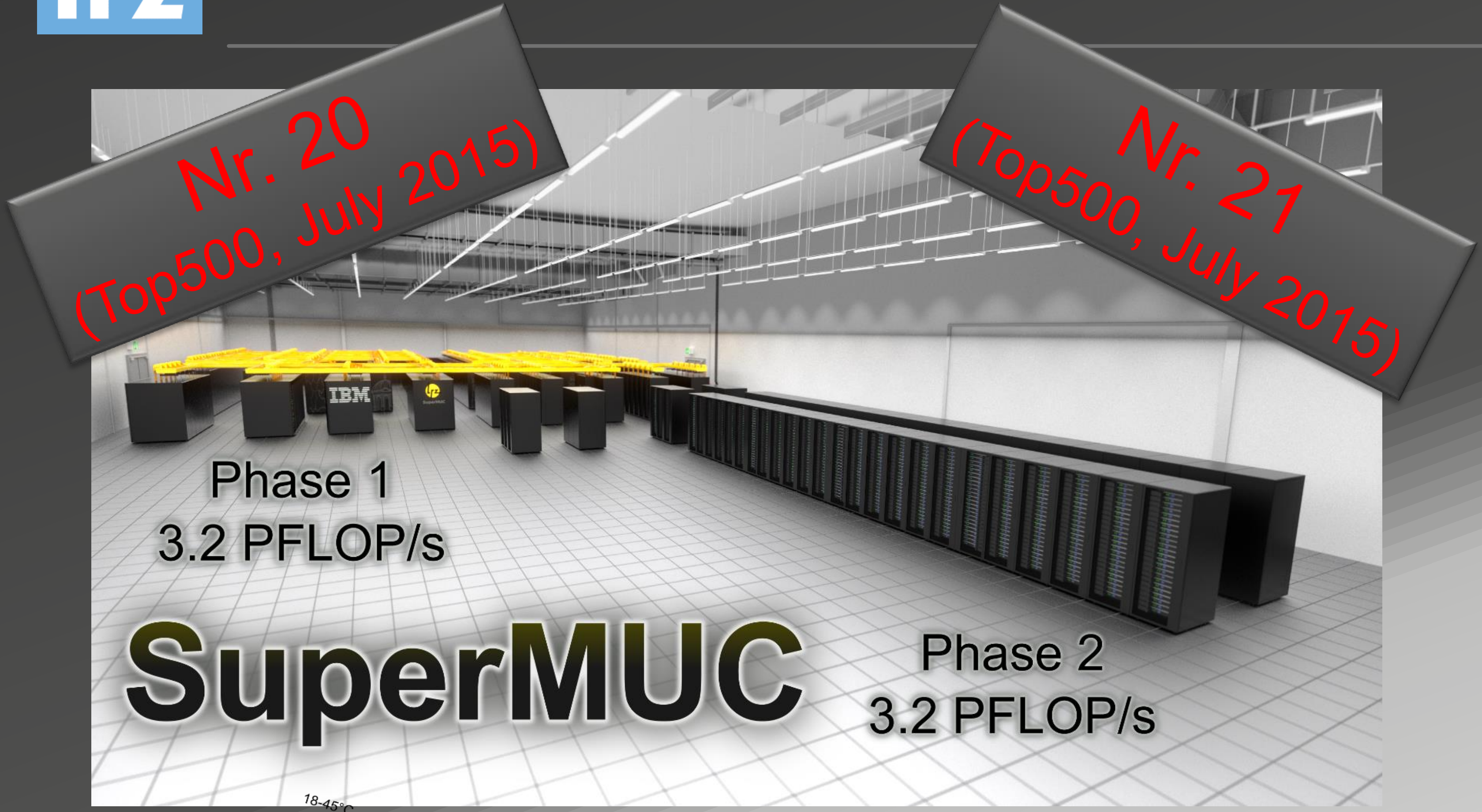
Some more Facts

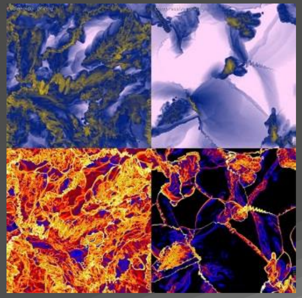
- **3160.5 m²** (34 019 ft²) IT Equipment Floor Space (6 rooms on 3 floors)
- **6393.5 m²** (68 819 ft²) Infrastructure Floor Space
- **2 x 10 MW** 20kV Power Supply
- **Powered Entirely by Renewable Energy**
- **> 5M €** (> 6M US$) Annual Power Bill

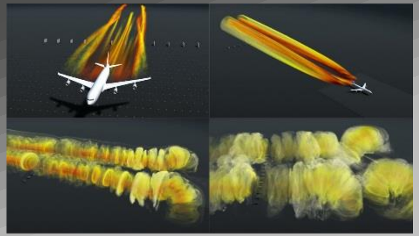
The Leibniz Supercomputing Centre

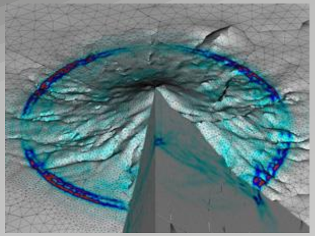
Scientific Computing at LRZ

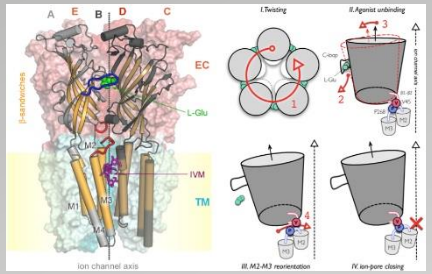
Gauss Centre for Supercomputing

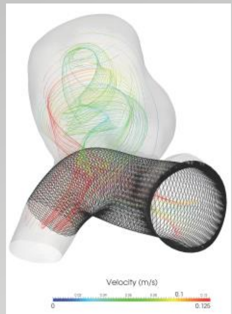


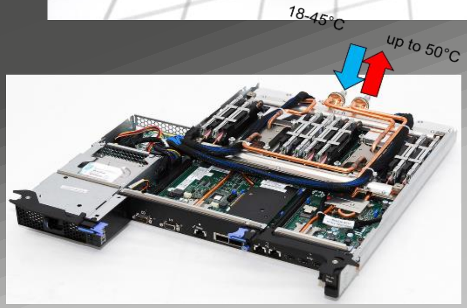


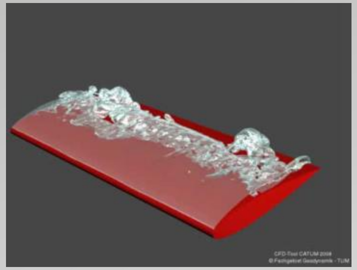


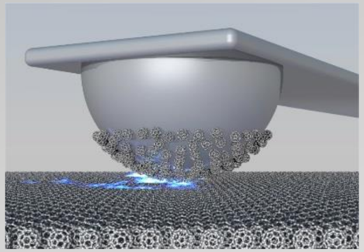


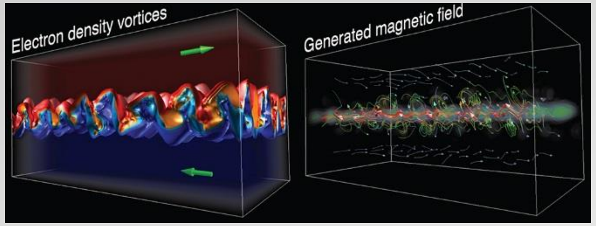








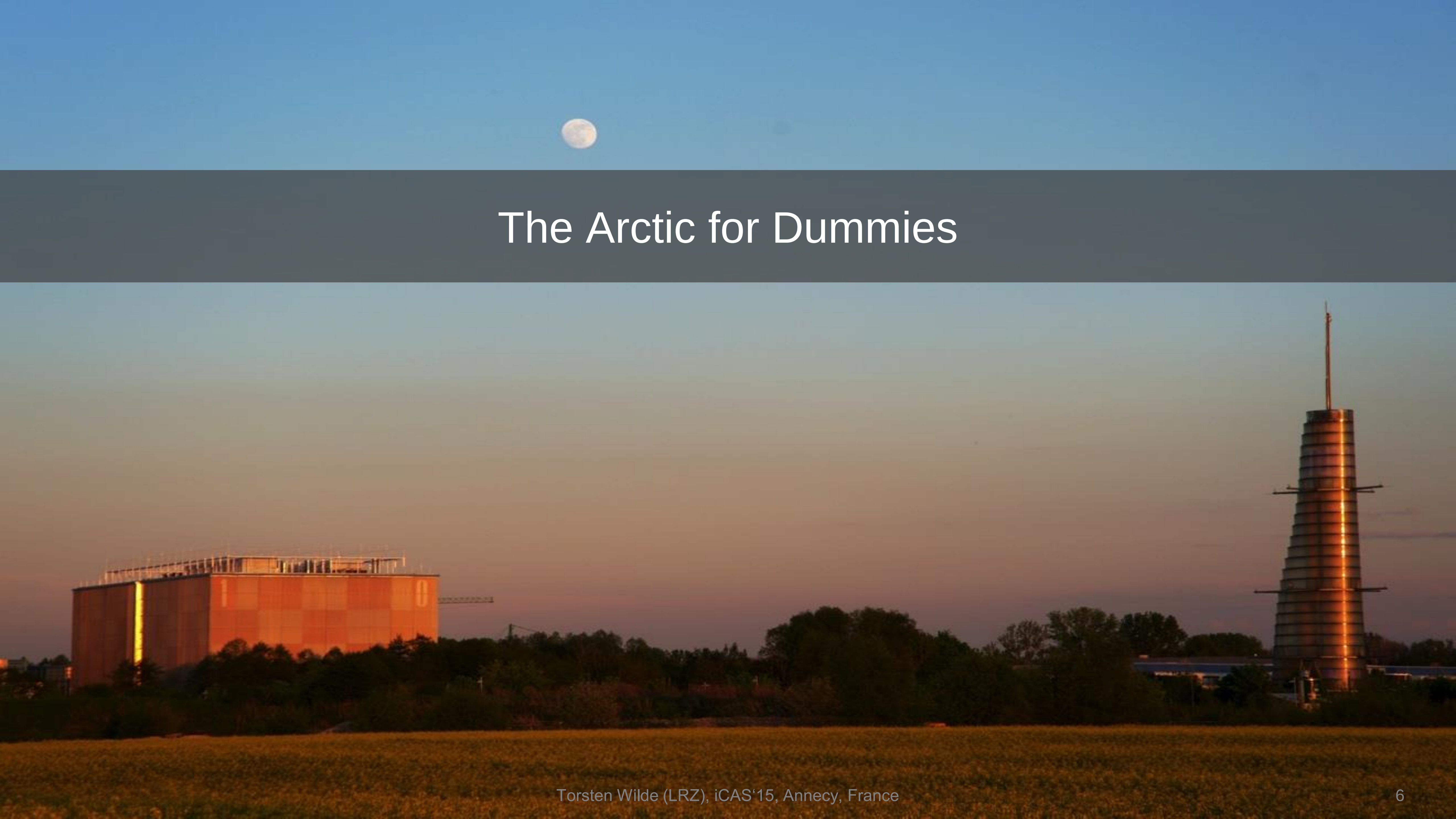




http://www.lrz.de/services/compute/supermuc/magazinesbooks/2014_SuperMUC-Results-Reports.pdf

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

The Arctic for Dummies



The Pros

- Very good (low) Power Usage Effectiveness (PUE)
  - Chiller-less cooling for either air or water cooling
  - Reducing cooling overhead
- Low population density, cheap real estate
- Most stable renewable energy grid in the world (Hydroelectric, Wind)
  - Low energy prices

The Cons - Snow, Snow, and …

Optimal PUE

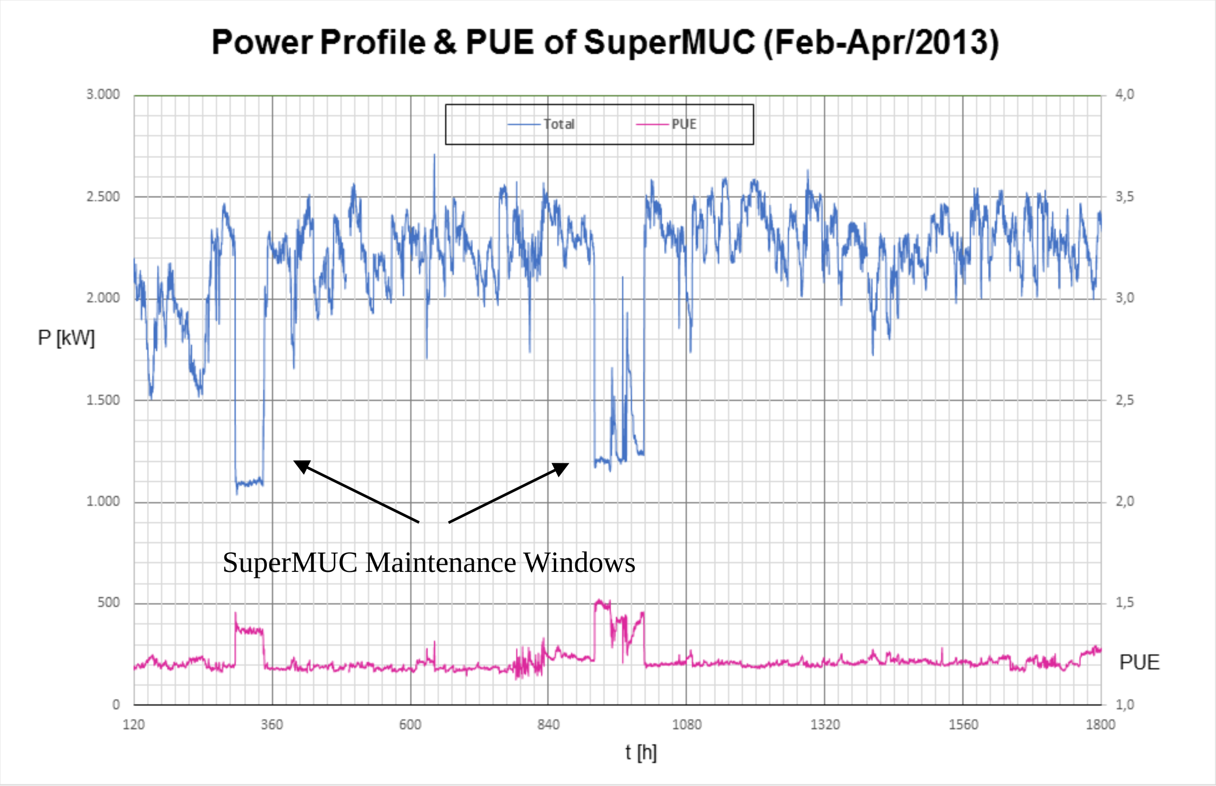
PUE

- Good to assess overall data center overhead

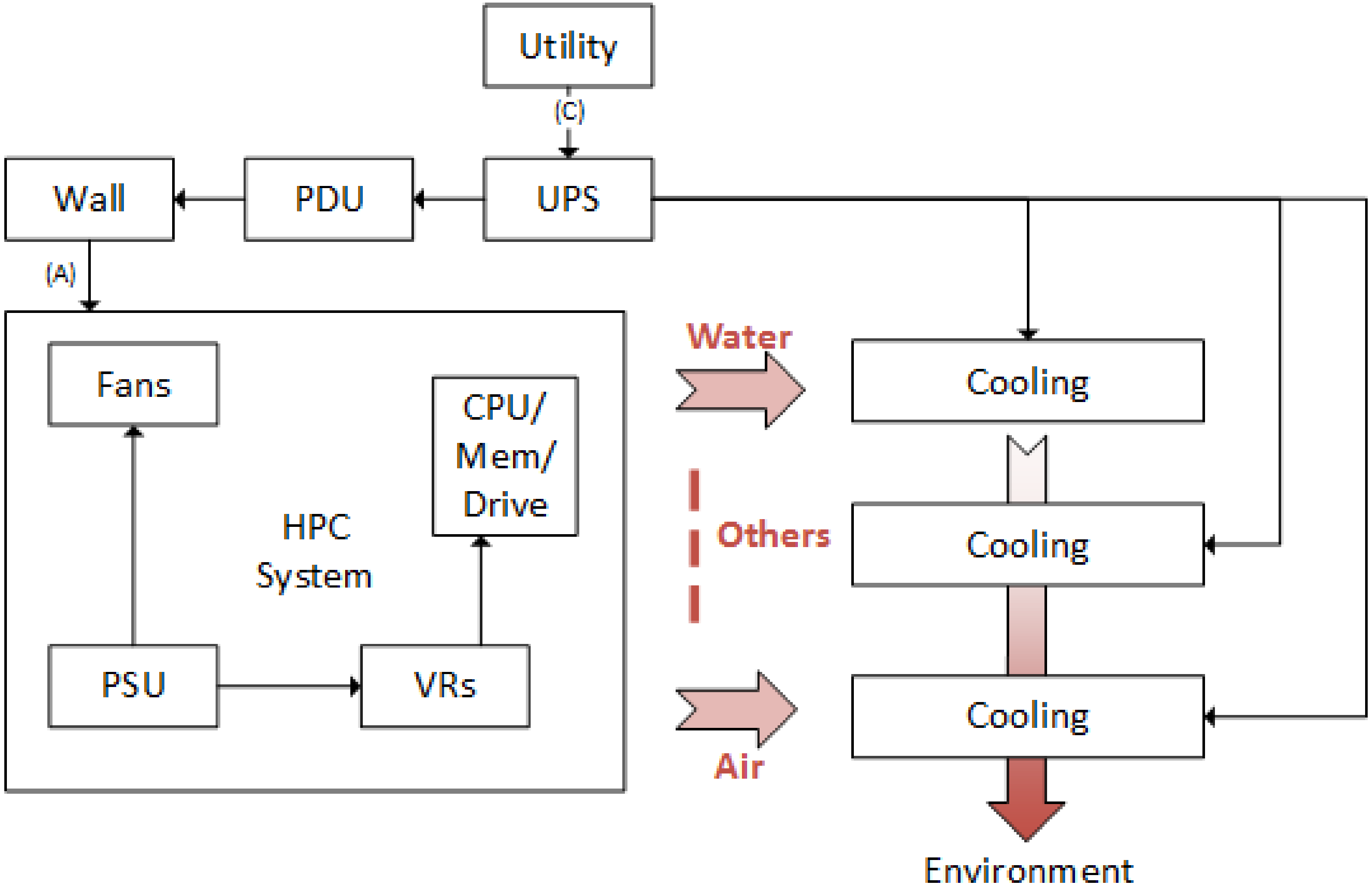
$$PUE = \frac{\sum P_i}{P_{IT}}$$

i: [IT, electrical power distribution and conversion losses, infrastructure, …]

- Does not determine if the IT power is efficiently used by IT systems
- Worst case:
  - One can very effectively waste a lot of energy
  - PUE ≠ Efficiency (Costs)



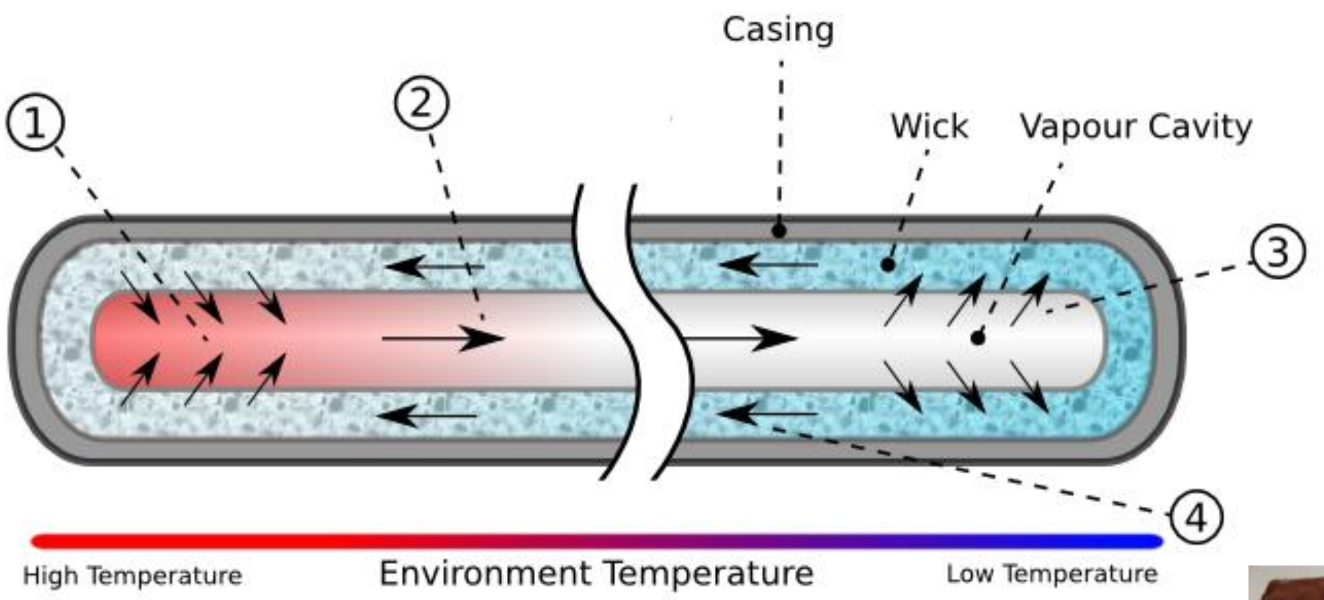
Data Center Infrastructure



Optimal PUE and Sustainability

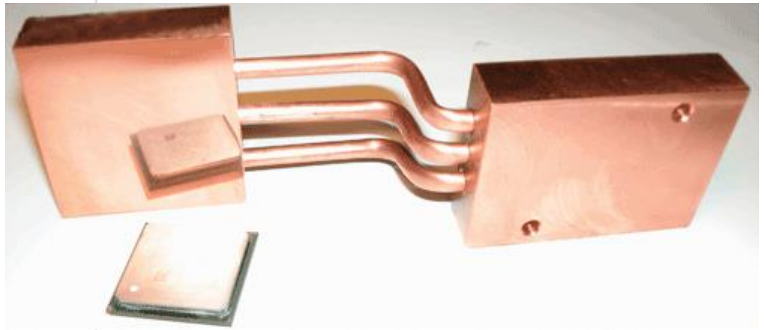
- No other power consumption than P_{IT}
  - Dark center, or only natural lighting
- No Electrical transmission losses
  - that’s hard, maybe super-conductors
- No power consumed by cooling system
  - Passive cooling
- No resource usage (carbon, water)
  - 100% renewable energy (challenging with only solar and wind power)
  - no water consumption (evaporative cooling)

Heat Pipes



Heat pipe thermal cycle

1) Working fluid evaporates to vapour absorbing thermal energy.
2) Vapour migrates along cavity to lower temperature end.
3) Vapour condenses back to fluid and is absorbed by the wick, releasing thermal energy
4) Working fluid flows back to higher temperature end.



http://mmu.ic.polyu.edu.hk/mu_proj/2011/ME/ME08/1.html

Passive Cooled Data Center

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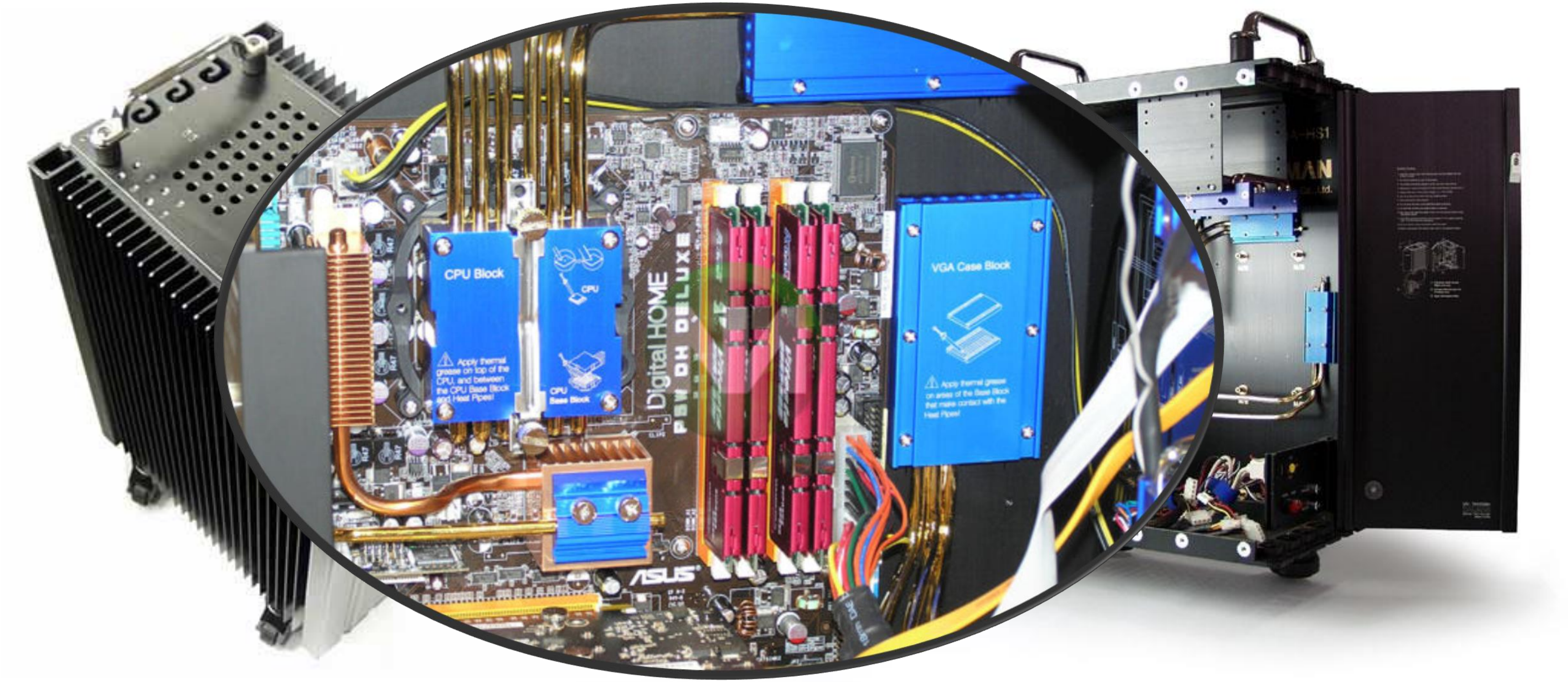

Zalman TNN500A

LRZ Data Center 100% Solar Powered and Passive Cooled

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- Solar Panels on roof and south side (20% efficiency, 200W per $1m^2$):
  - South side: 70m x 33m = $2380m^2$ => 476kW
  - Roof: 70m x 35m = $2450m^2$ => 490kW
  - ~ 1MW

- Cooling area ($4620m^2$):
  - North side: 70m * 33m = 2310 m^2
  - West and east side: (35m*2) * 33m = 2310 m^2
  - ~ 125 kw (delta T 10°C like for water example later)
- With 1m long fins in 1m intervals ($9273m^2$):
  - 1m*33m*141 = 4653 m^2
  - ~ 1 MW (delta T 30°C)

LRZ Cube With Heatsink and Fins (1m Distance, 1m Long) On North, East, and West Side With 30K delta T

1	Natural Convection Heat Transfer Coefficient Correlations (S.I. units)					
2						
3	1. With an isothermal vertical plane			Fluid =	air	
4						
5	**Inputs**			**Calculations**		
6						
7	Fluid Temp, T_∞ =	20	°C	Temp Diff, ΔT =	30	°C
8						
9	Surface Temp, T_w =	50	°C	Abs. Film Temp, T_f =	308	°K
10						
11	Film Temp., T_f =	35	°C	Prandtl Number, Pr =	0,69	
12	[$T_f = (T_\infty + T_w)/2$]					
13	Area of Plate, A =	9273,0	m^2	Grashof Number, Gr =	1,19,E+14	
14	Height of Surf., L =	33,0	m			
15				Rayleigh No., Ra =	8,23E+13	
16	Fluid Density, ρ =	1,1	kg/m^3			
17				Correlation #1 (for all values of Ra):		
18	Fluid viscosity, μ =	1,87E-05	$N\text{-}s/m^2$			
19				Nu =	4672	
20	Fluid Sp. Heat, C_p =	1	J/g-°K			
21				h =	3,82	$W/m^2\text{-}K$
22	Fluid Sp. Heat, C_p =	1000	J/kg-°K			
23						
24	Fluid Thermal			Correlation #2 (for RaL < 10^9):		
25	Conductivity, k =	0,027	J/s-m-K			
26				Nu =	1545	
27	Fluid Thermal					
28	Expans. Coeff, β =	0,003245	$°K^{-1}$	h =	1,26	$W/m^2\text{-}K$
29						
30	NOTE: For the example shown, correlation #2 shouldn't be used, because Ra > 10^9.					
31						
32	* For an Excel spreadsheet that can be downloaded to calculate the density of a gas					
33	with known molecular weight and specified temperature and pressure, see:					
34	"Excel Templates for Venturi and Orifice Flow Meter Calculations," at:					
35	http://www.brighthub.com/engineering/civil/articles/83825.aspx					

Equations for Natural Convection - Isothermal Vertical Plane

$$Nu = \frac{h\,L}{k} \qquad Pr = \frac{\mu\,C_p}{k}$$

$$Gr = \frac{L^3 \rho^2 g\, \Delta T\, \beta}{\mu^2}$$

$$Ra = GrPr$$

Dimensionless Numbers used in Natural Convection Heat Transfer Coefficient Correlations

Correlation #1:

for all values of Ra:

$$Nu = \left\{ 0.825 + \frac{0.387\, Ra^{1/6}}{[\,1 + (0.492/Pr)^{9/16}\,]^{8/27}} \right\}^2$$

Correlation #2:

Slightly better for laminar flow (Ra ≤ 10^9):

$$Nu = 0.68 + \frac{0.670\, Ra^{1/4}}{[\,1 + (0.492/Pr)^{9/16}\,]^{4/9}}$$

Q= 1063455 W

http://www.brighthubengineering.com/hvac/92660-natural-convection-heat-transfer-coefficient-estimation-calculations

Capacity:

1 MW

How About a "Water Cooled" Data Center?

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Submarine Typhoon Class:

length: 175m (574 ft 2 in)

draft: 12 m (39 ft 4 in)

volume displacement: 33,270 long tones = 1164450 feet^2 (1 lt = 35 feet^2)

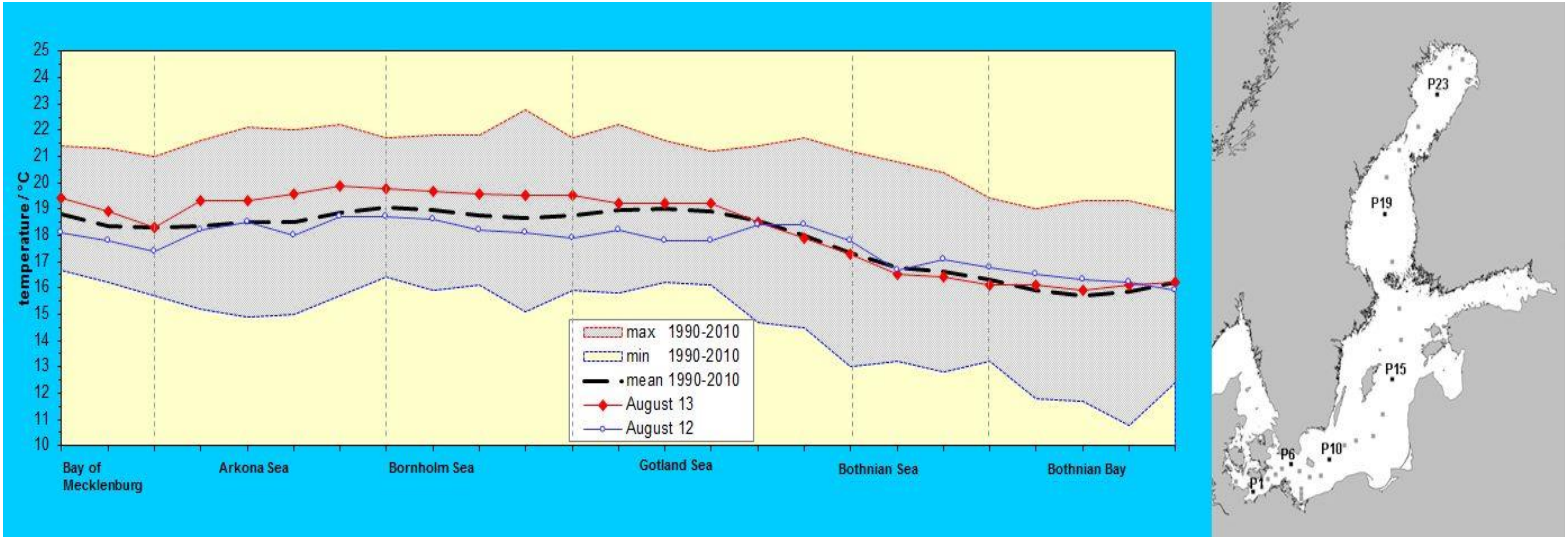
hull material: titanium

reactor: two OK-650 reactors (each 190MW)

surface area estimate*: 67914 feet^2 (6309 m^2)

* According to the technical development document for Phase I Uniform National Discharge Standards for Vessels of the Armed Forces, Naval Sea Systems Command, US Department of the Navy: SA = 1.7*(L)*(D) + (V) / (D)

Baltic Sea Max Surface Temperature



Source: http://www.helcom.fi/baltic-sea-trends/environment-fact-sheets/hydrography

Submarine Hull (6309 m²) heat transfer (30°C Hull temp -> 20 °C water temp)

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Natural Convection Heat Transfer Coefficient Correlations (S.I. units)

4. With an isothermal horizontal cylinder — Fluid = water

Inputs			Calculations		
Fluid Temp, T_∞ =	20	°C	Temp Diff, ΔT =	10	°C
Surface Temp, T_w =	30	°C	Abs. Film Temp, T_f =	298	°K
Film Temp., T_f =	25	°C	Prandtl Number, Pr =	5,43	
[$T_f = (T_\infty + T_w)/2$]					
			Grashof Number, Gr =	6,36,E+13	
Cylinder Diam., D =	11,1	m			
Cylinder Surface, A =	6309	m²	Rayleigh No., Ra =	3,46E+14	
Fluid Density, ρ* =	995,7	kg/m³			
Fluid viscosity, μ =	7,980E-04	N-s/m²			
			Nu =	9201	
Fluid Sp. Heat, C_p =	4,179	J/g-°K			
			h =	503,90	W/m²-K
Fluid Sp. Heat, C_p =	4179	J/kg-°K			
			Q =	31790980	W
Fluid Thermal Conductivity, k =	0,609	J/s-m-K			
Fluid Thermal Expans. Coeff, β =	3,03E-04	°K⁻¹			

* For an Excel spreadsheet that can be downloaded to calculate the density of a gas with known molecular weight and specified temperature and pressure, see: "Excel Templates for Venturi and Orifice Flow Meter Calculations," at: http://www.brighthub.com/engineering/civil/articles/83825.aspx

Als US-Dollar, Euro oder andere Währung formatieren.

Equations for Natural Convection - Isothermal Horizontal Cylinder

$$Nu = \left\{0.60 + \frac{0.387\,Ra^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}\right\}^2$$

$$Gr = \frac{D^3 \rho^2 g\, \Delta T\, \beta}{\mu^2} \qquad Nu = \frac{h\,D}{k} \qquad Pr = \frac{\mu\, C_p}{k}$$

for $Ra \le 10^{12}$ ($Ra = Gr\, Pr$)

Natural Convection Heat Transfer from an Isothermal Horizontal Cylinder

Water properties taken from:

- http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html
- http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

Cylinder estimation:

- d = 11,122m
- h = 175m
- A= 6309 m2

Good news:

31.8MW (submerged)

http://www.brighthubengineering.com/hvac/92660-natural-convection-heat-transfer-coefficient-estimation-calculations

LRZ System PUE SuperMUC

PUE Advantages for Hyperscale Data Centers

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$$PUE = \frac{P_{IT} + P_{PDCL} + P_{Cooling}}{P_{IT}} = 1 + \frac{P_{PDCL}}{P_{IT}} + \frac{P_{Cooling}}{P_{IT}} = 1 + Overhead_{PDCL} + \frac{P_{Cooling}}{P_{IT}}$$

- By moving to cooler climates $P_{Cooling}$ is reduced (no chillers)
- Low power density (5-12kw per rack *) is optimal for air cooling (SuperMUC Phase1 20kW per rack, SuperMUC Phase2 25kW per rack)
  - Power consumption of air cooling equipment (fans) in racks count as P_{IT}
  - Increasing air inlet temperatures for IT equipment reduces $P_{Cooling}$ and increases P_{IT}
- Control over full data center and specialized use-case allows hardware redundancy to move to software redundancy, reducing $Overhead_{PDCL}$
- Using full load condition for PUE calculation maximizes P_{IT}
- All this allows for a leading PUE of less than 1.1 (Side note: besides Google, nobody explained in full detail how PUE is measured)

* http://www.opencompute.org/assets/open-rack/Open_Compute_Project_Open_Rack_v1.0.pdf

LRZ Uptime Only Power Profile 2014

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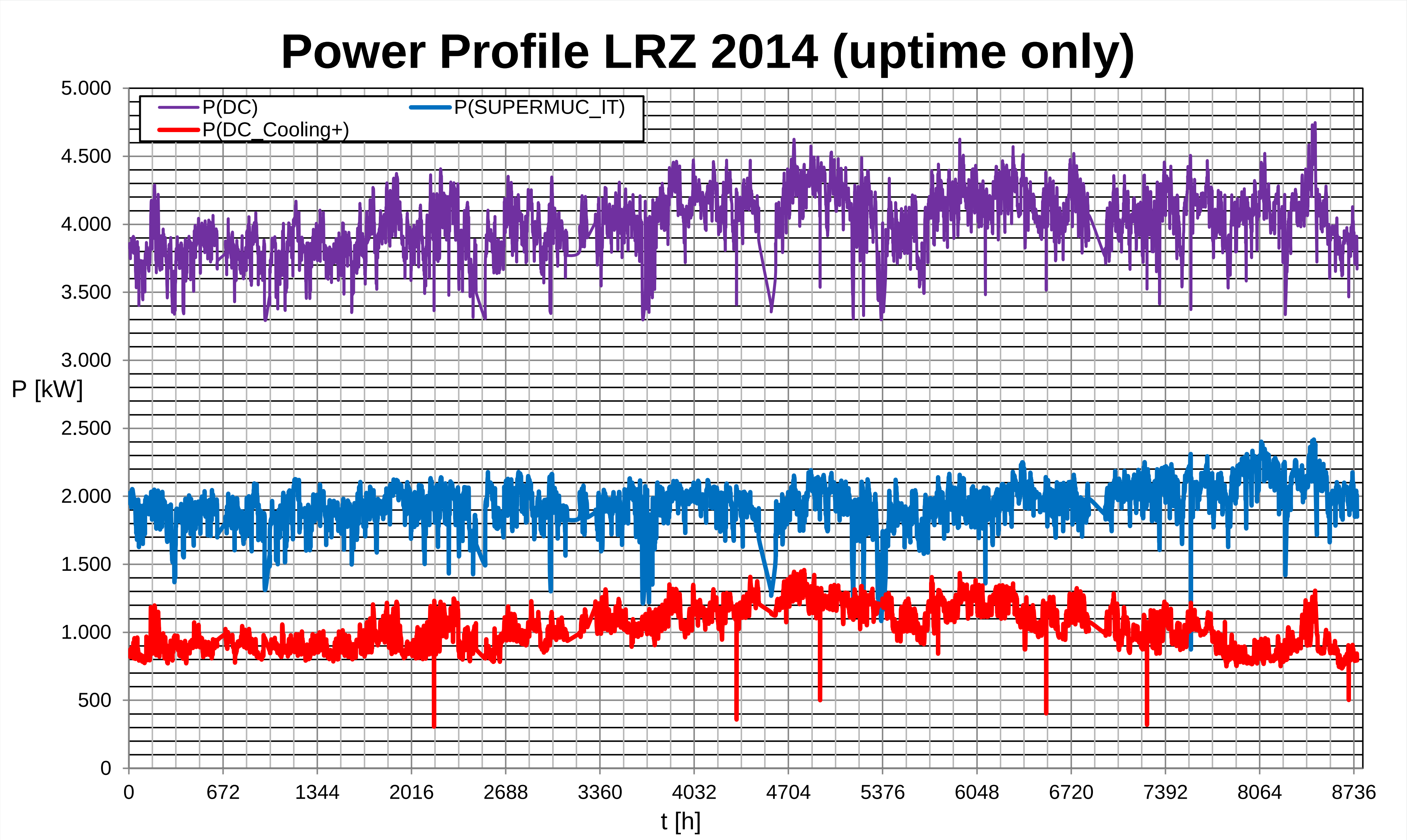

Fraunhofer SCAI · SorTech AG · IBM · Johnson Controls · GOHL · GCS Gauss Centre for Supercomputing

SuperMUC Uptime Only PUE

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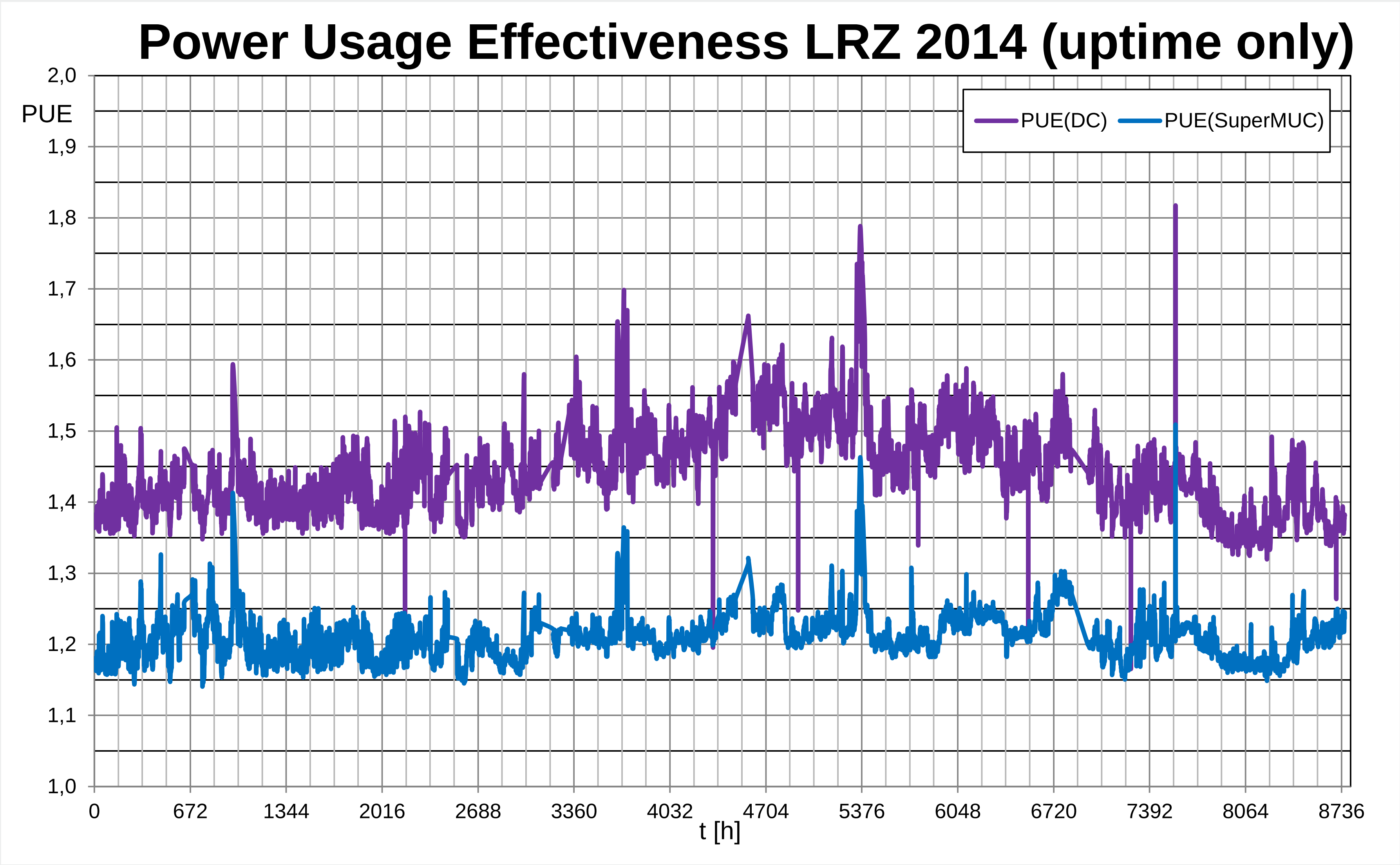

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SuperMUC Colling Overhead Comparison (Total vs Warm Water)

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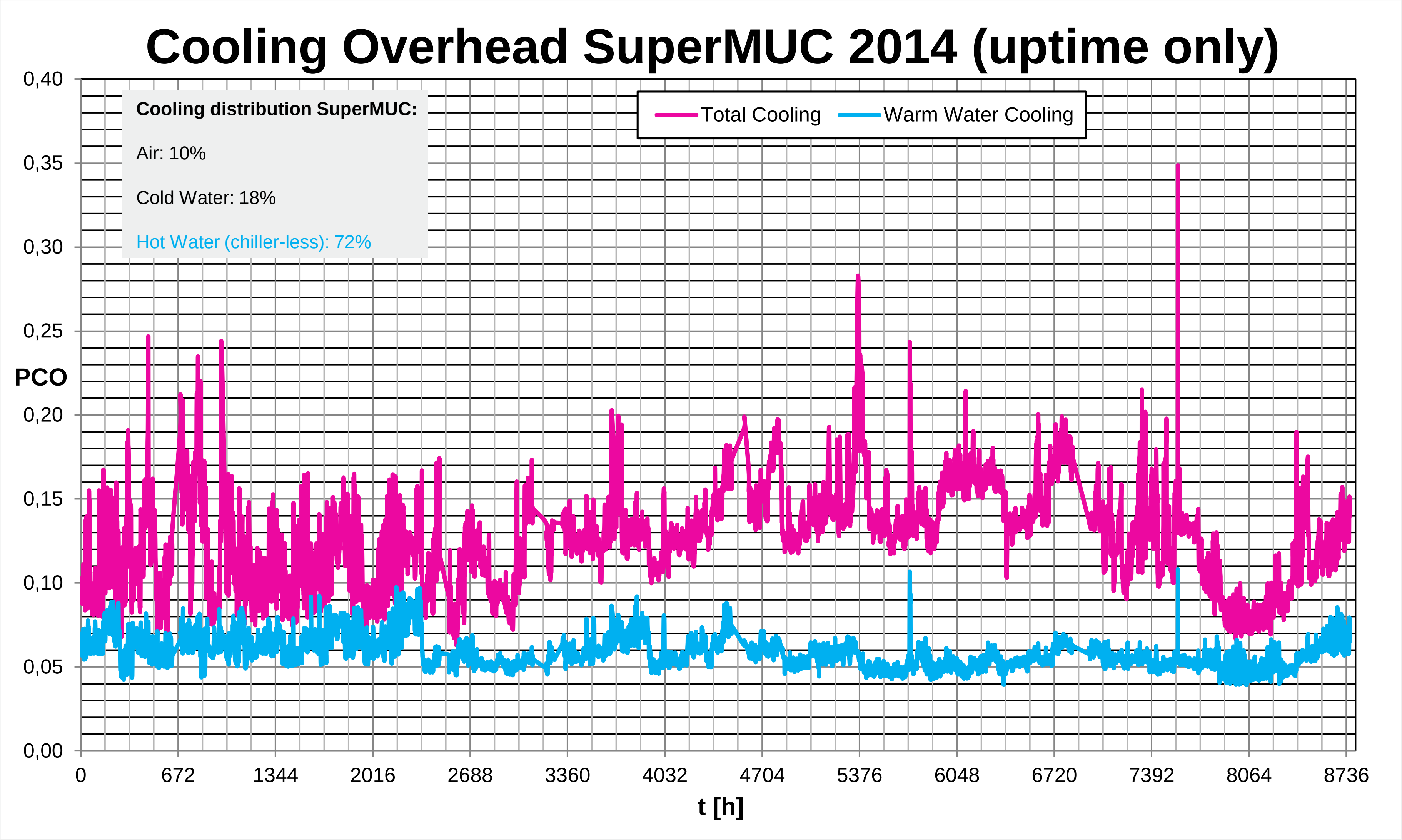
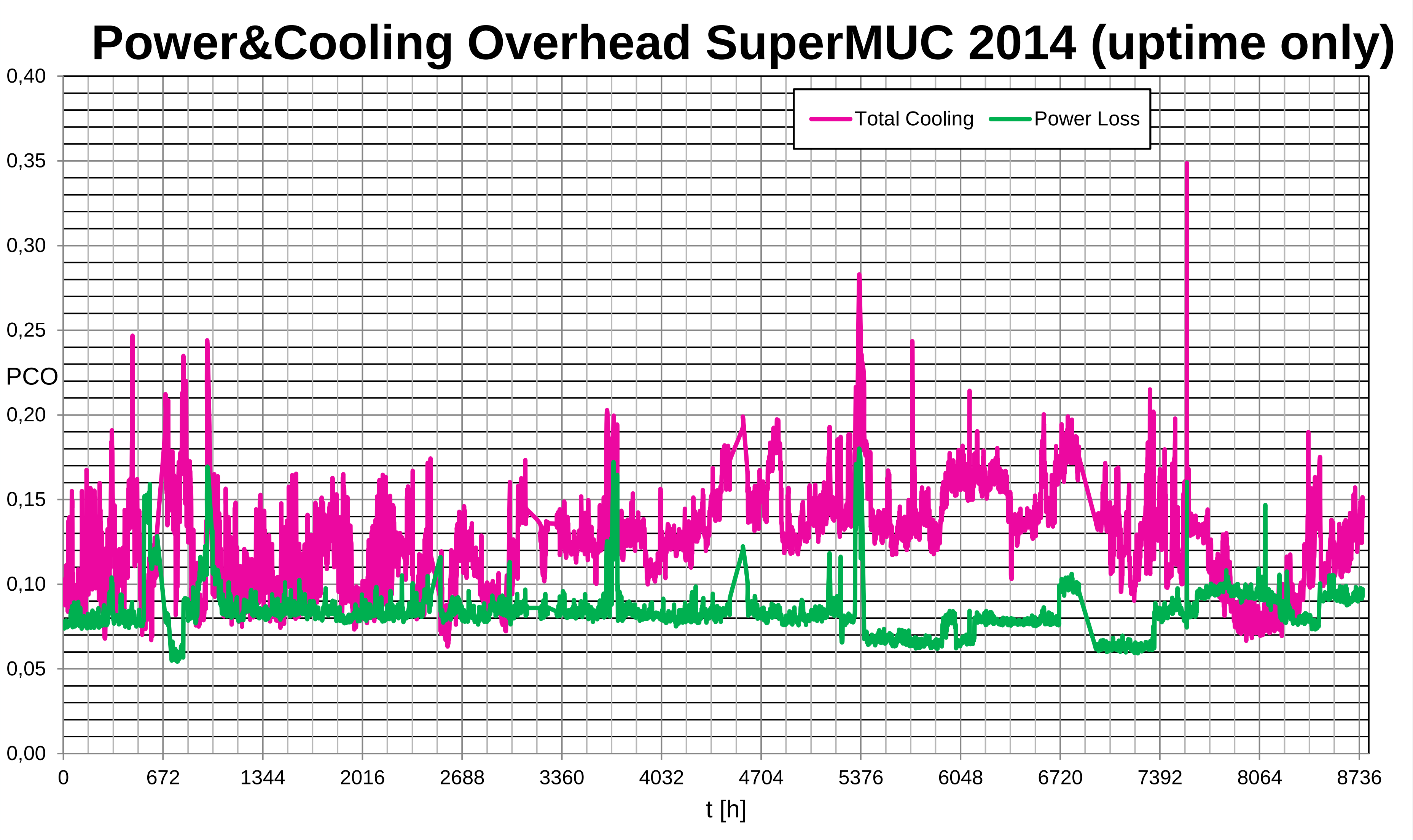


LRZ Uptime Only Power and Cooling Overhead SuperMUC 2014



How To Do It The Hyperscale-Way?

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- Use “designed load” as P_{IT} for PUE
  - Restricting data to SuperMUC power consumption > 2.0 MW (could be as high as 3.6MW for Linpack ☺)
  - **SuperMUC PUE: 1.20**
- Remove all UPS equipment (can remove the 8% off power distribution overhead)
  - **SuperMUC PUE: 1.12 – very close to arctic data center PUE’s**

Data Center Sustainability - Benefits of Direct Hot Water Cooling

Air vs Direct Liquid Cooling

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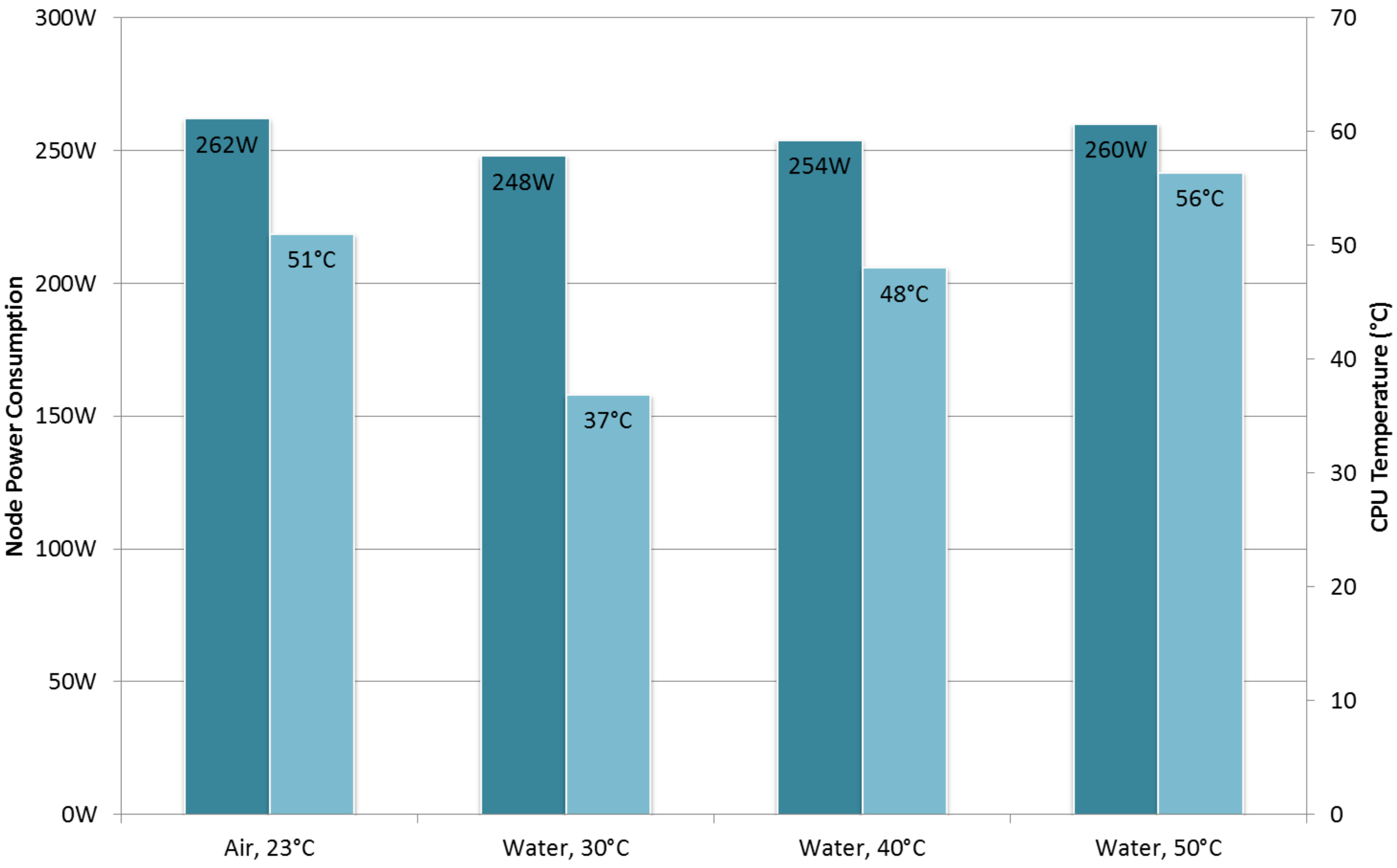

CooLMUC (178 nodes):

Measurement for single node

- two AMD Opteron 6128HE CPUs (MagnyCours) with 8 cores each
- 2GHz clock frequency
- 16GB RAM (eight 2GB DDR3 modules)

Characteristics will change with CPU and System architecture.

Re-Use Possibility (Building heating)

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120MW is 120MW - Is throwing away energy the best we can do?

- Data center needs to be located close to possible consumers
  - Heat requirement average single family home 150m^2 * 2.5m (http://www.haus-bau-blog.de/hausbau-planung/hausbau-deutschland-neubau-einfamilienhaus/)]
  - Outside -10°C (inside 20°C) 15.66 kW (https://de.trotec.com/tkl-mieten/infocenter/kapazitaetsberechnungen/heizleistung-berechnen/?tx_tklinfo_tklinfopi[action]=heating&tx_tklinfo_tklinfopi[controller]=Calculator&cHash=945e1742b4e0b6167df9f8d910f9083f)
  - SuperMUCs (2.4MW) waste heat would be sufficient to heat 153 single family homes under those conditions
  - **120MW == 7662 homes**
- Heat re-use with air cooling and low temperature water is hard

More Re-Use Possibilities

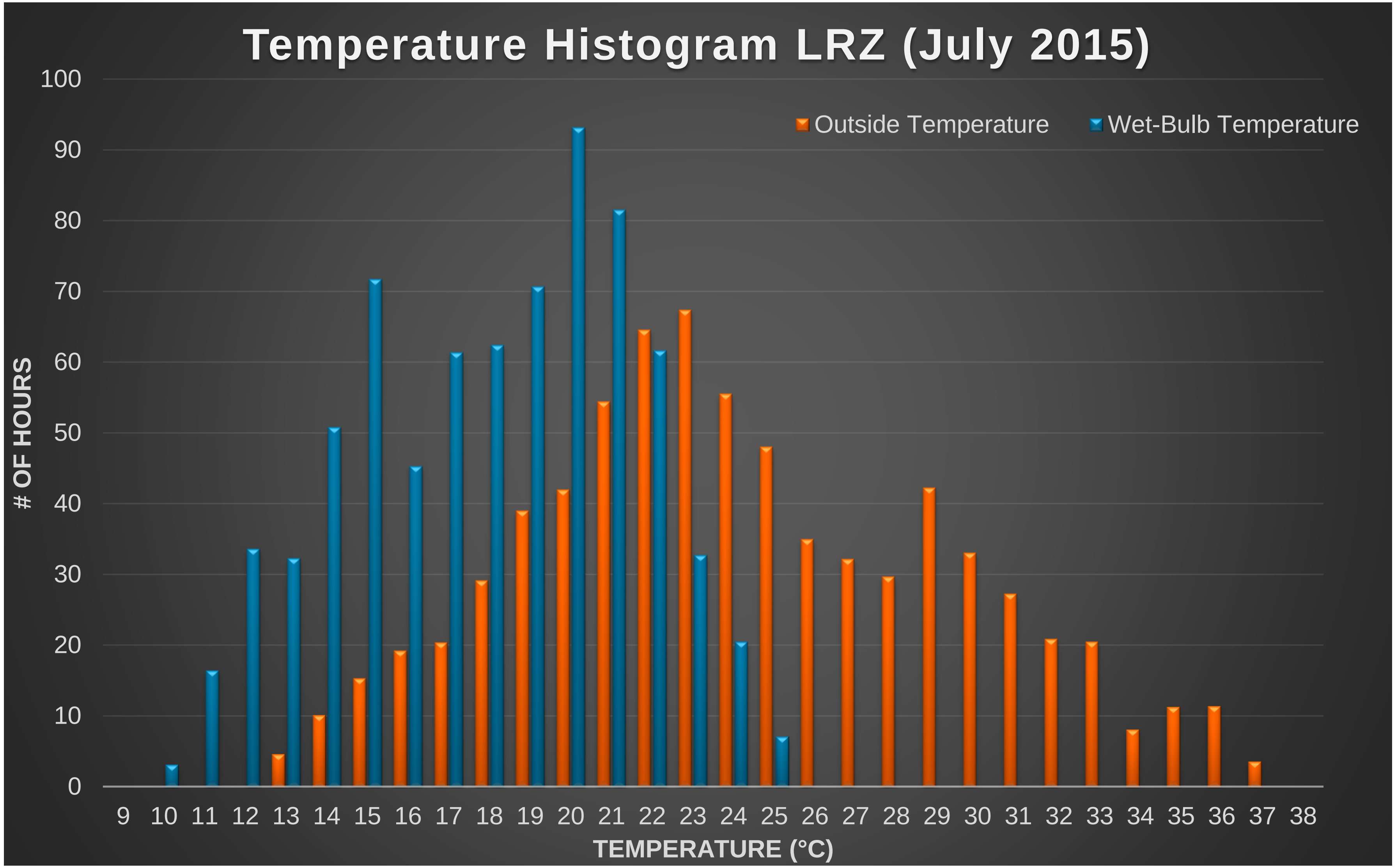
Currently Running Three Hot Water Cooled Machines at LRZ:
CooLMUC at: 41°C IN – 50 to 6…°C OUT (load dependent), *SuperMUC I*: 3…°C IN – 41 to 44°C OUT, *SuperMUC II*: 40 °C IN – 43 to 47°C OUT

- Ice-Cream production: 30-40°C
- Cloth washing: 40-80°C
- Decaffeinated coffee: 22-100°C
- Surface treatm…
  - anodizing 5-42…
  - plating cooper a… 70°C
- Pre-heating of bo… 30-100°C
- Adsorption cooling (…ently prototype, production ready installation)
- Beer production: 7-76°C

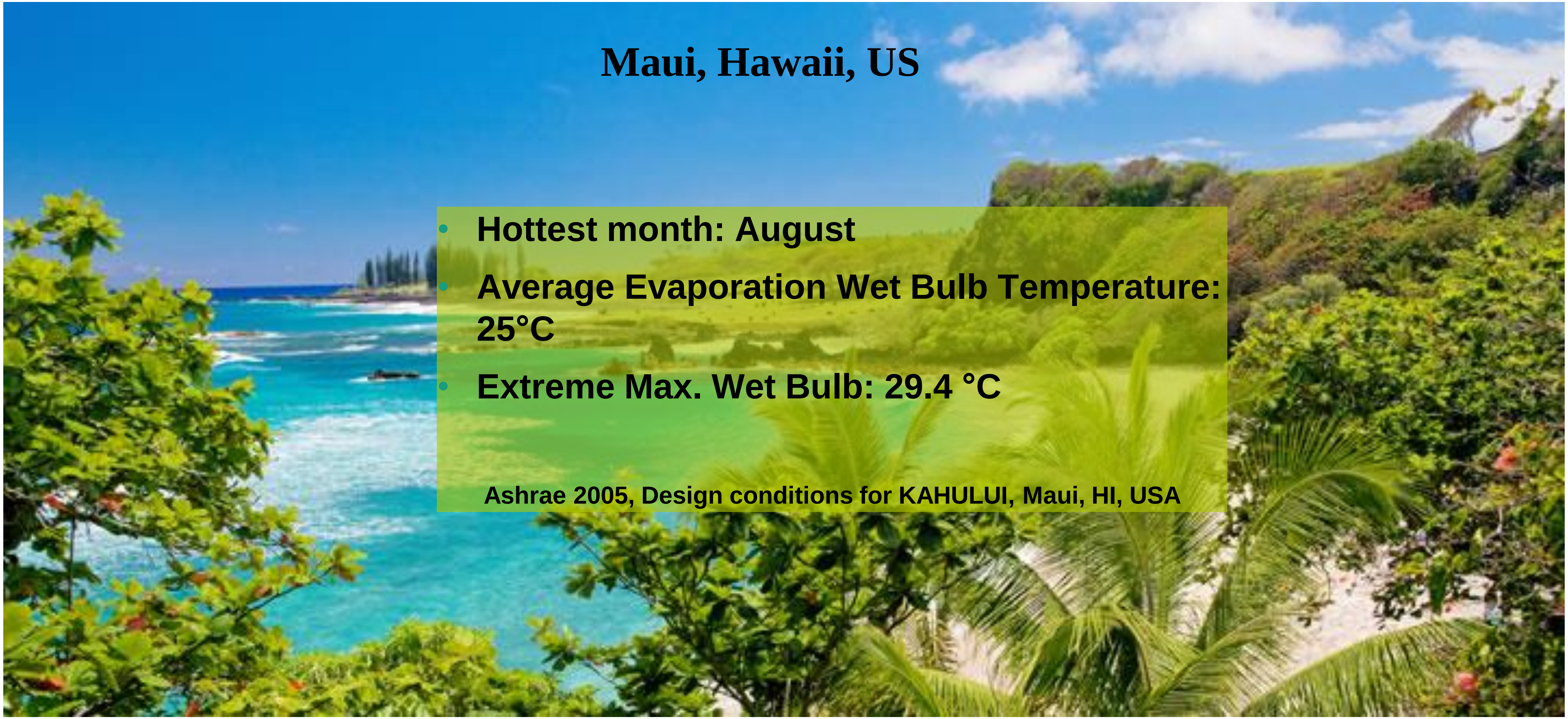
European Solar Thermal Industry Federation: Key Issues for Renewable Heat in Europe (K4RES-H) Solar Industrial Process Heat; http://www.estif.org/fileadmin/estif/content/policies/downloads/D23-solar-industrial-process-heat.pdf
Dr. Vlasta KRMELJ, Dipl.Ing. : Selected industrial processes which require low temperature heat; Energy agency of Podavje, Slovenia

Bringing It All Together

Temperature Histogram LRZ July 2015 (close to temperature record)



If not the Artic, where else?



Maui, Hawaii, US

- Hottest month: August
- Average Evaporation Wet Bulb Temperature: 25°C
- Extreme Max. Wet Bulb: 29.4 °C

Ashrae 2005, Design conditions for KAHULUI, Maui, HI, USA

Or just staying home

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Don't Forget to Pack your Swimming Trunks!

Torsten.wilde@lrz.de

www.simopke.de

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