SUSTAINABILITY

Fan, PSU, & Idle Power in Air-Cooled / Direct-Liquid-Cooled Servers

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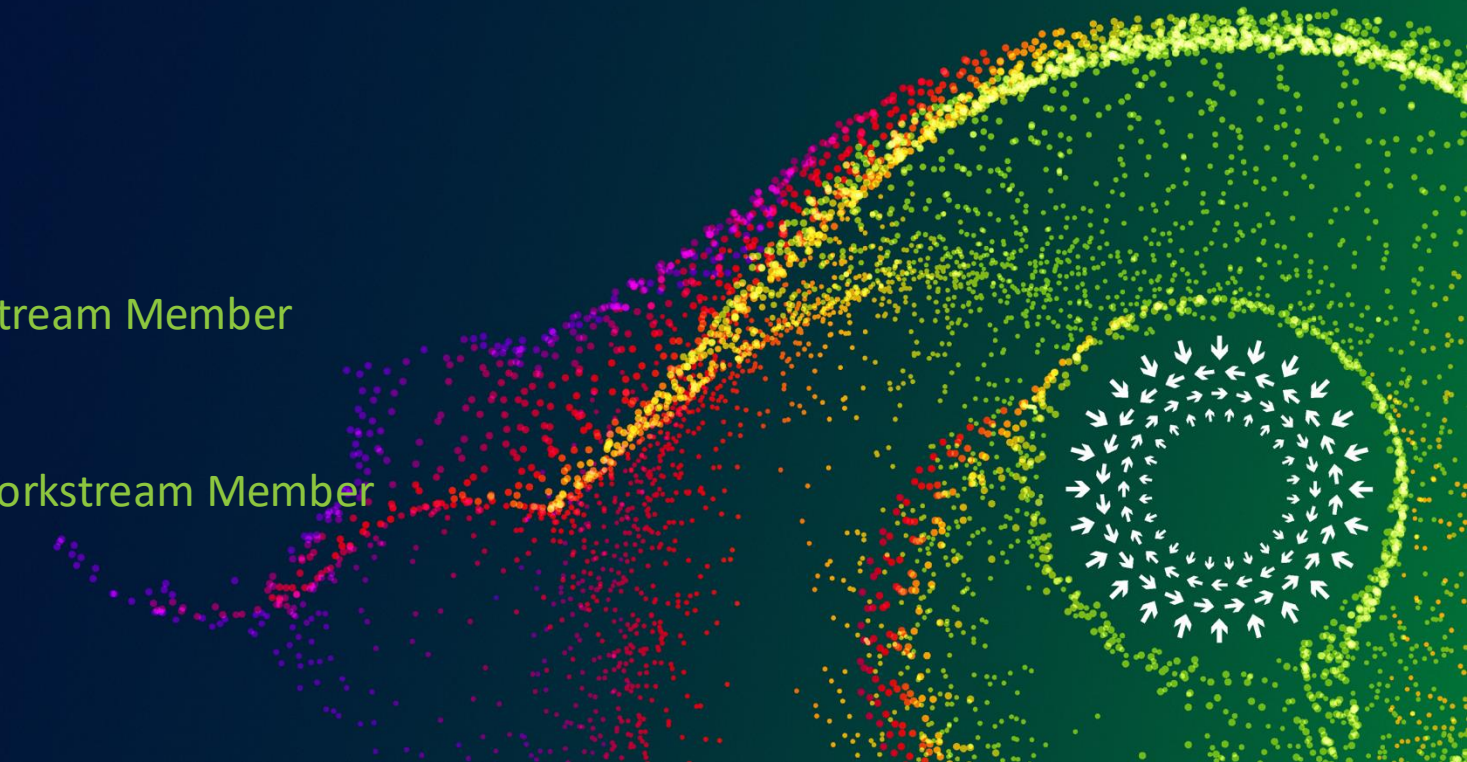

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Barcelona, Spain

DCEM Workstream

- Break down and measure power delivered to server
  - Racks are going to DC busbars and direct liquid cooling (DLC)
  - Need to isolate fan and PSU power
  - Measure idle power
- What is IT power?
  - $E_{IT} = E_{PSU} + E_{Fan} + E_{Idle} + E_{Compute}$
- IUE = Infrastructure Usage Efficiency
  - $IUE = E_{Compute} / E_{IT}$
  - Number between 0 and 1 (not on the same scale as PUE)

Our Questions

1. How to measure idle power (E_{idle})?
2. What fraction of server power (E_{IT}) is fan power (E_{fan})?
3. What is IUE for common use cases?
4. How does direct liquid cooling affect PUE?

Our Testbed: EcoCloud at EPFL (ecocloud.ch)

Server	HPE ProLiant DL380 Gen11
CPUs	Dual Socket Intel Sapphire Rapids
	Dual Socket AMD Zen 4
RAM	256 GB
Fans	High Performance Fan Kit (6x fans)
DLC CDU	CoolIT CHx200
PSU	2x HPE Artesyn PSU
PDU	RNX RN3517

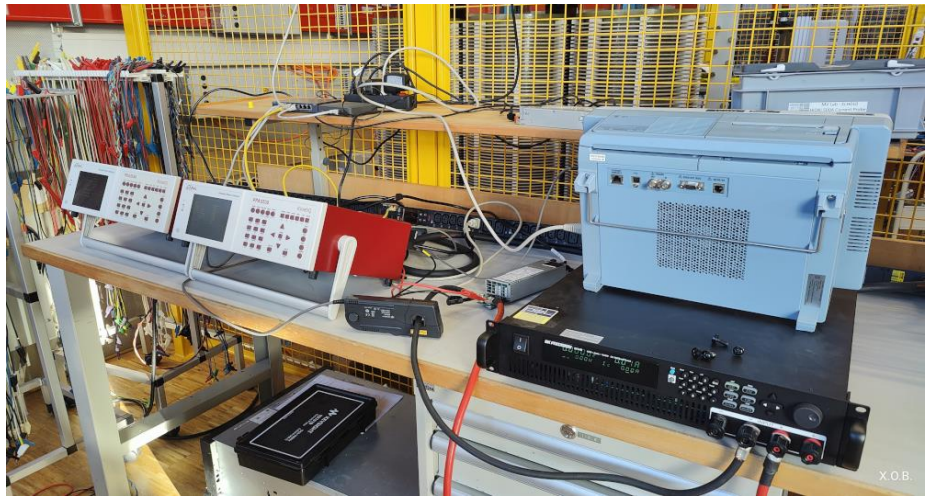
Direct liquid cooling is CPU only

Experiments

- Characterize the PDU – PSU losses
- Characterize the fan behavior and then deduce the idle power
- Characterize compute power via running stress tests
  - Stress-ng matrix benchmark running for 10 minutes
  - Intel Sapphire Rapids: 64 cores
  - AMD Zen 4: 128 cores

PSU Loss

- Chain testing:
  - PDU → input PSU → output PSU
  - PDU → IPMI



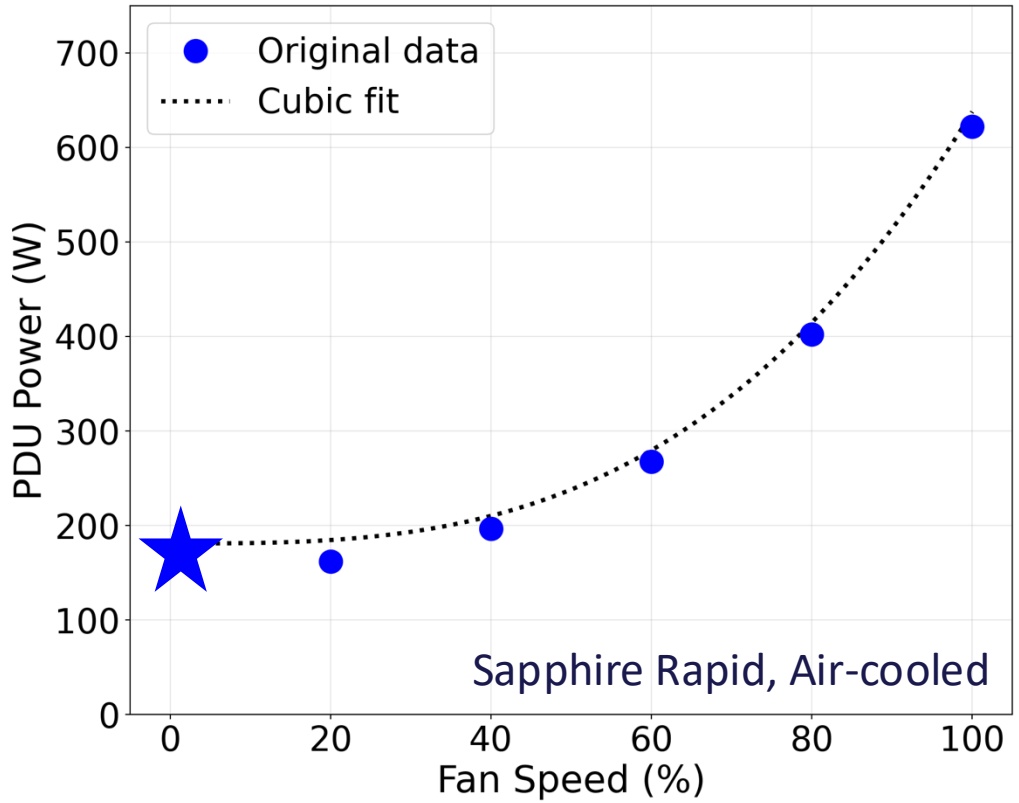
PSU yield varies by load

Load PSU	Power PDU	Power PSU input	Power PSU output	Yield PSU
160W (10%)	179	179	158	0.886
320W (20%)	346	345	319	0.924
480W (30%)	514	513	482	0.936
640W (40%)	686	685	645	0.941
800W (50%)	861	860	808	0.940
960W (60%)	1040	1039	973	0.936
1120W (70%)	1224	1223	1139	0.931
1280W (80%)	1413	1410	1306	0.926
1440W (90%)	1608	1604	1473	0.918
1500W (limit)	1686	1682	1536	0.913

Fan & Idle Power

Idle power = server power (post-PSU) when CPUs have no load and fans are off

Fan power $\propto$ (fan speed)^3 $\rightarrow$ sweep fan speed and use a cubic fit to find idle power



Fan Speed	20%	40%	60%	80%	100%
Fan Power	3W	28W	93W	221W	432W

	Sapphire Rapids Air-Cooled	Sapphire Rapids DLC	Zen 4 Air-Cooled
PDU	180W	190W	210W
Idle Power	155W	165W	182W

M. K. Patterson, "The effect of data center temperature on energy efficiency", ITHERM 2008

Use Cases

Use Case Assumptions

Use Case	PUE* (24°C)	Server Utilization	DLC Fan Speed	DLC CDU Power†
Hyperscaler	1.1	60%	20%	20W
Co-location	1.3	15%	20%	20W

*Assuming identical racks and cooling solutions throughout the datacenter, negligible PDU loss
†Assuming 200W CDU pump power for a 20kW rack with 10 servers

DC operators are interested in increasing ambient temps (32°C)

Babak Falsafi, “To Measure is To Know: Breaking Down Datacenter Power Consumption”, Computer Architecture Today, 2025
“Custom Cooling Fan Options for Dell EMC PowerEdge Servers”, DELL EMC Technical White Paper, 2019
Sebastian Moss, ”Meta ups server room temperatures to 90 degrees F, in effort to reduce water usage” Data Center Dynamics, 2022

Fan Power vs Server Power @ 32°C

Baseline 20% fan speed @ 24°C → fan power is ~1% of server power

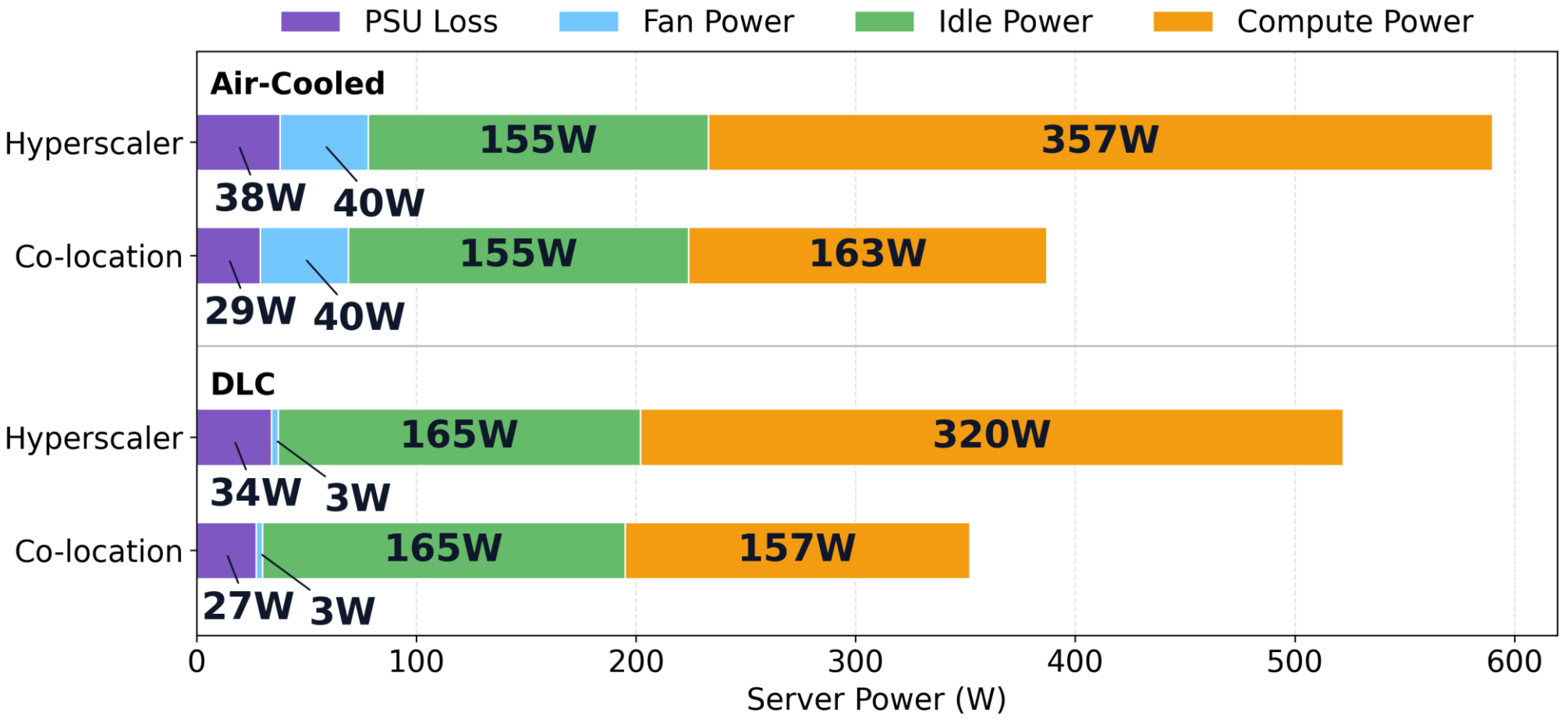
Use Case	Ambient Temp	Fan Speed	Fan Power	Server Power	Fan/Server Power %
Hyperscaler	32°C	45%	40W	590W	6.7%
Co-location				387W	10.2%

Fan power becomes important for co-located servers when operating at high ambient temps

Increasing fans from 20% to 45% → 10× fan power

Air-Cooled vs DLC – IUE @ 32°C

$$IUE = E_{Compute} / (E_{PSU} + E_{Fan} + E_{Idle} + E_{Compute})$$

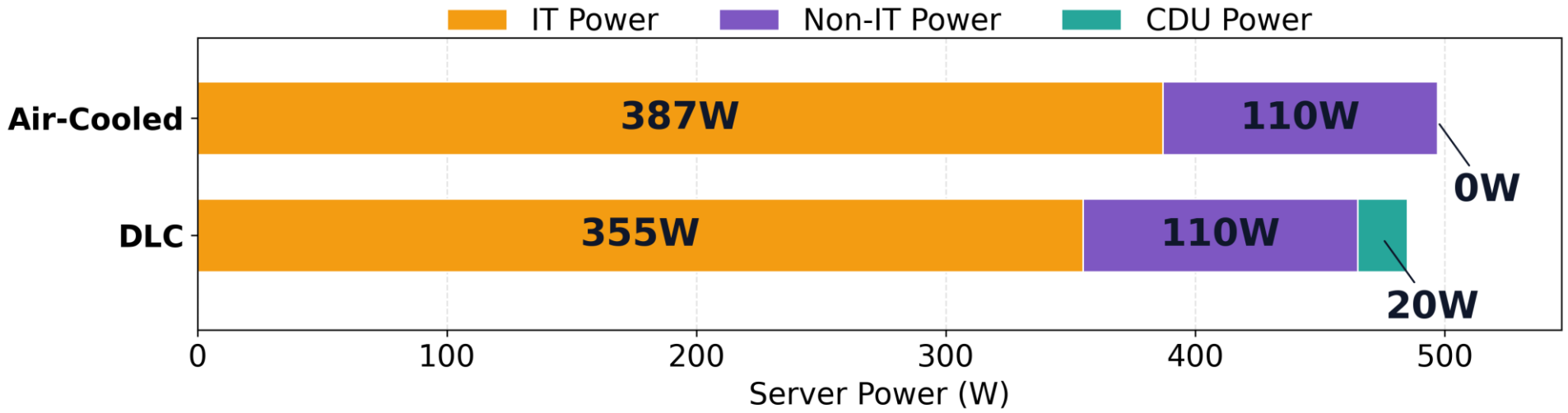


	IUE
Air-Cooled Hyperscaler	0.61
Air-Cooled Co-location	0.42
DLC Hyperscaler	0.61
DLC Co-location	0.44

Air-Cooled vs DLC – PUE @ 32°C

$$PUE = (E_{IT} + E_{non\text{-}IT}) / E_{IT}$$

Co-location (PUE = 1.3 @ 24°C)



PUE

1.28

1.37

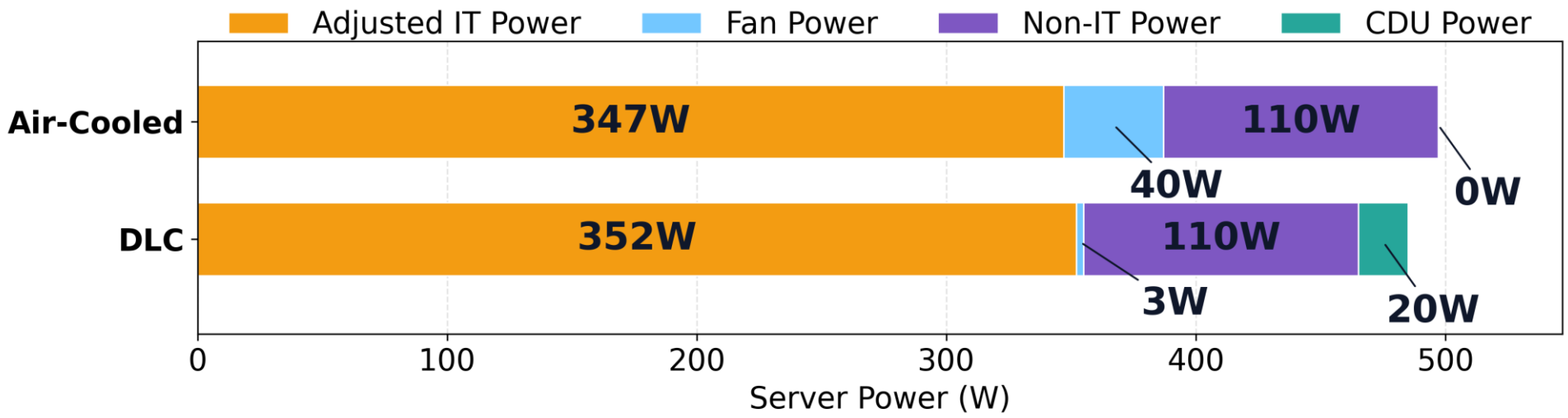
At higher ambient temps, increased fan power decreases PUE

DLC has higher PUE despite using less overall power!

Air-Cooled vs DLC – Fan-Adjusted PUE @ 32°C

$$PUE_{FA} = (E_{IT} + E_{non\text{-}IT}) / (E_{IT} - E_{fans})$$

Co-location (PUE = 1.3 @ 24°C)



	PUE_{FA}
Air-Cooled	1.43
DLC	1.38

Server fans are used for cooling and should be non-IT power

Wrap-up

- Measuring IUE better characterizes server power consumption
- Reliable source of information
  - 80 PLUS certification
  - Idle power shall be adequately defined and computed (requires extrapolation)
  - Accurate fan power monitoring
- Fans are for cooling and hence should not be accounted as IT
  - Importance of optimizing fan speed for energy efficiency
  - Each half decreasing in speed = 87.6% power savings
  - Rise of DLC → cooling power shifts away from fans
- Importance of optimizing idle power

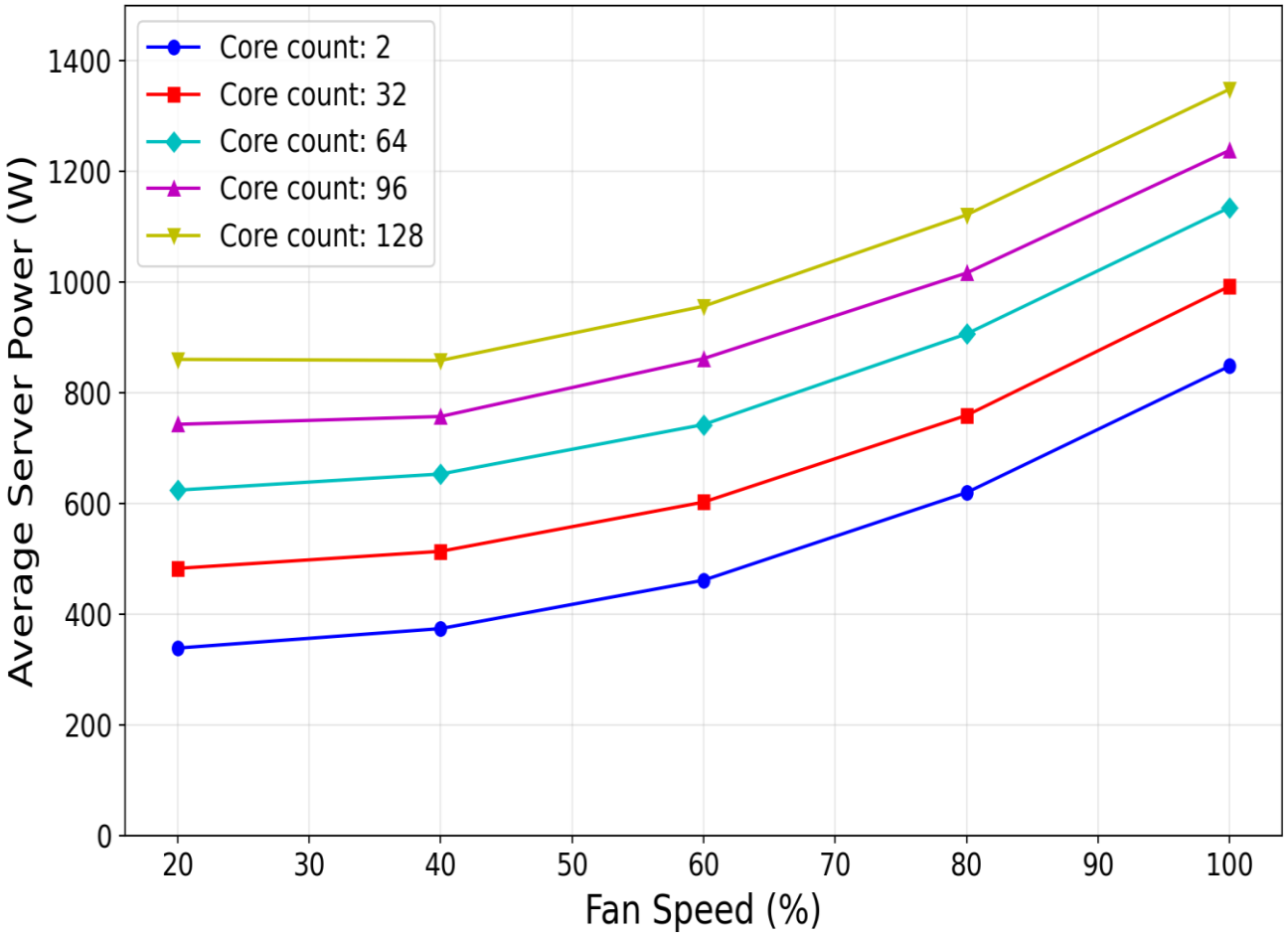
Call to Action

- Additional experiments are needed
  - Experiments controlling ambient temperature
  - Experiments with full DLC
  - Experiments with GPUs: air-cooled vs DLC (vs immersion)
- Call for financial/hardware support
  - Specification for sustainable OCP DCEM on how to measure IUE
  - White paper target for end 2026
- How to get involved in the project/sub-project community
  - Join the OCP-DCEM workstream, bi-monthly meeting on Friday

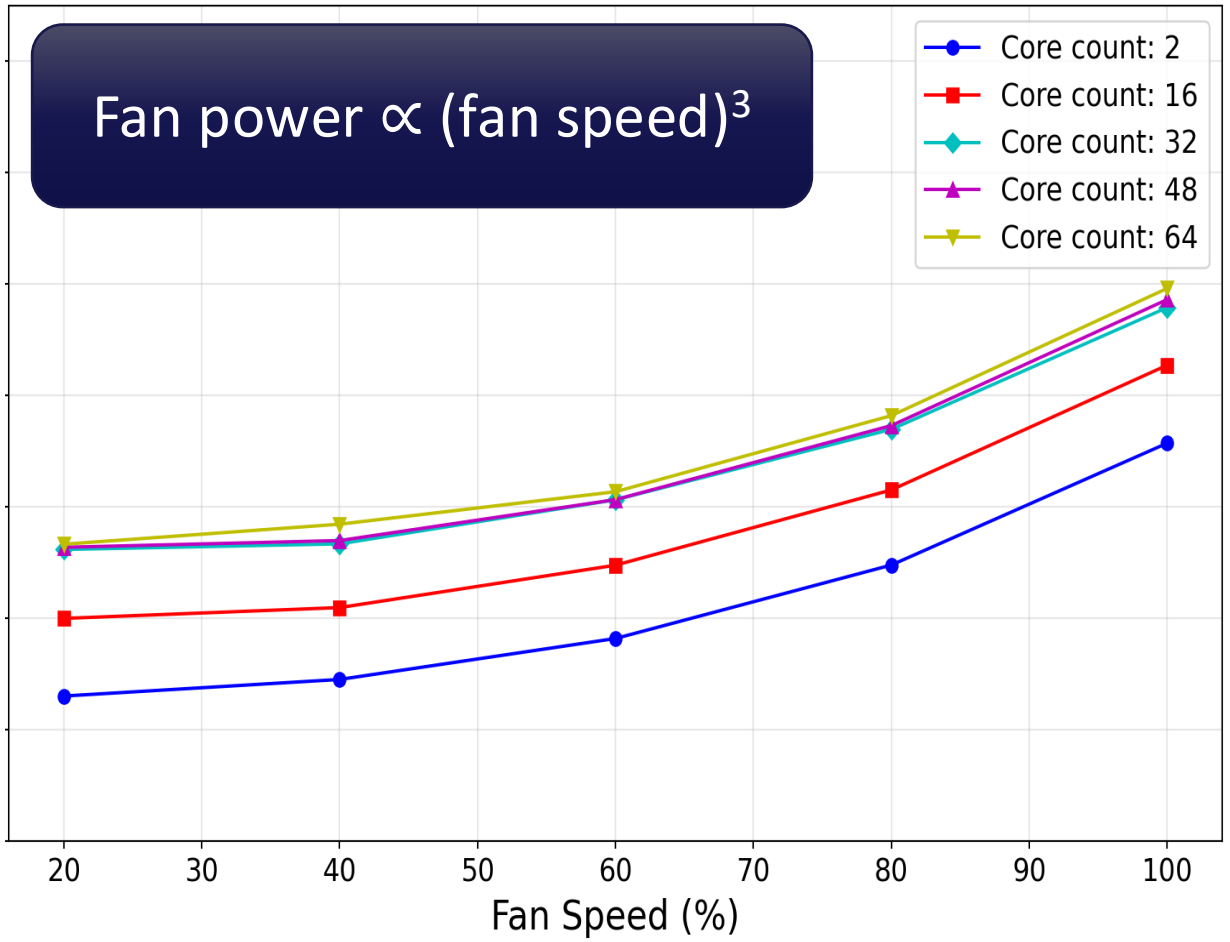
Thank You!

Fan Speed vs Server Power

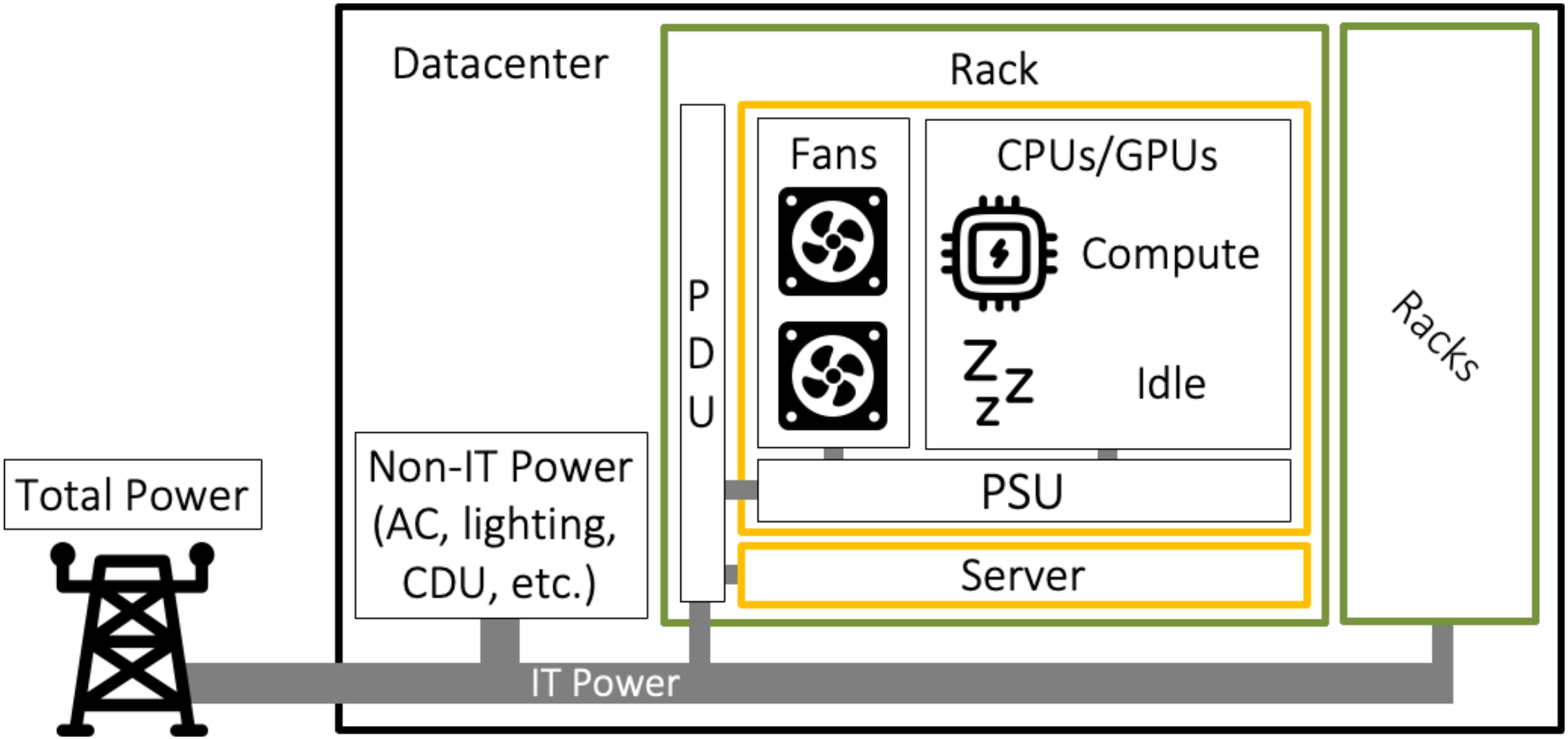
Zen 4, Air-cooled, stress-ng



Sapphire Rapids, Air-cooled, stress-ng



Datacenter Power Breakdown



Air-Cooled vs DLC – IUE @ 32°C

$$IUE = E_{Compute} / (E_{PSU} + E_{Fan} + E_{Idle} + E_{Compute})$$

Air-Cooled

Use Case	Server Power	PSU Loss	Fan Power	Idle Power	Compute Power	IUE
Hyperscaler	590W	38W	40W	155W	357W	**0.61**
Co-location	387W	29W	40W	155W	163W	**0.42**

Direct-Liquid-Cooled

Use Case	Server Power	PSU Loss	Fan Power	Idle Power	Compute Power	IUE
Hyperscaler	525W	34W	3W	165W	320W	**0.61**
Co-location	355W	27W	3W	165W	157W	**0.44**

Air-Cooled vs DLC – PUE @ 32°C

$$PUE = (E_{IT} + E_{non\text{-}IT}) / E_{IT}$$

Co-location (PUE = 1.3 @ 24°C)

Cooling	IT Power	Non-IT Power	CDU Power	PUE
Air-Cooled	387W	110W	0W	**1.28**
DLC	355W	110W	20W	**1.37**

At higher ambient temps, increased fan power decreases PUE

DLC has higher PUE despite using less overall power!

Air-Cooled vs DLC – Fan-Adjusted PUE @ 32°C

$$PUE_{FA} = (E_{IT} + E_{non\text{-}IT}) / (E_{IT} - E_{fans})$$

Co-location (PUE = 1.3 @ 24°C)

Cooling	IT Power	Fan Power	Non-IT Power	CDU Power	PUE_{FA}
Air-Cooled	387W	40W	110W	0W	**1.43**
DLC	355W	3W	110W	20W	**1.38**

Server fans are used for cooling and should be non-IT power

Fan Speed vs CPU Load Impact

Zen 4, Air-cooled, stress-ng
Server Power (PDU)

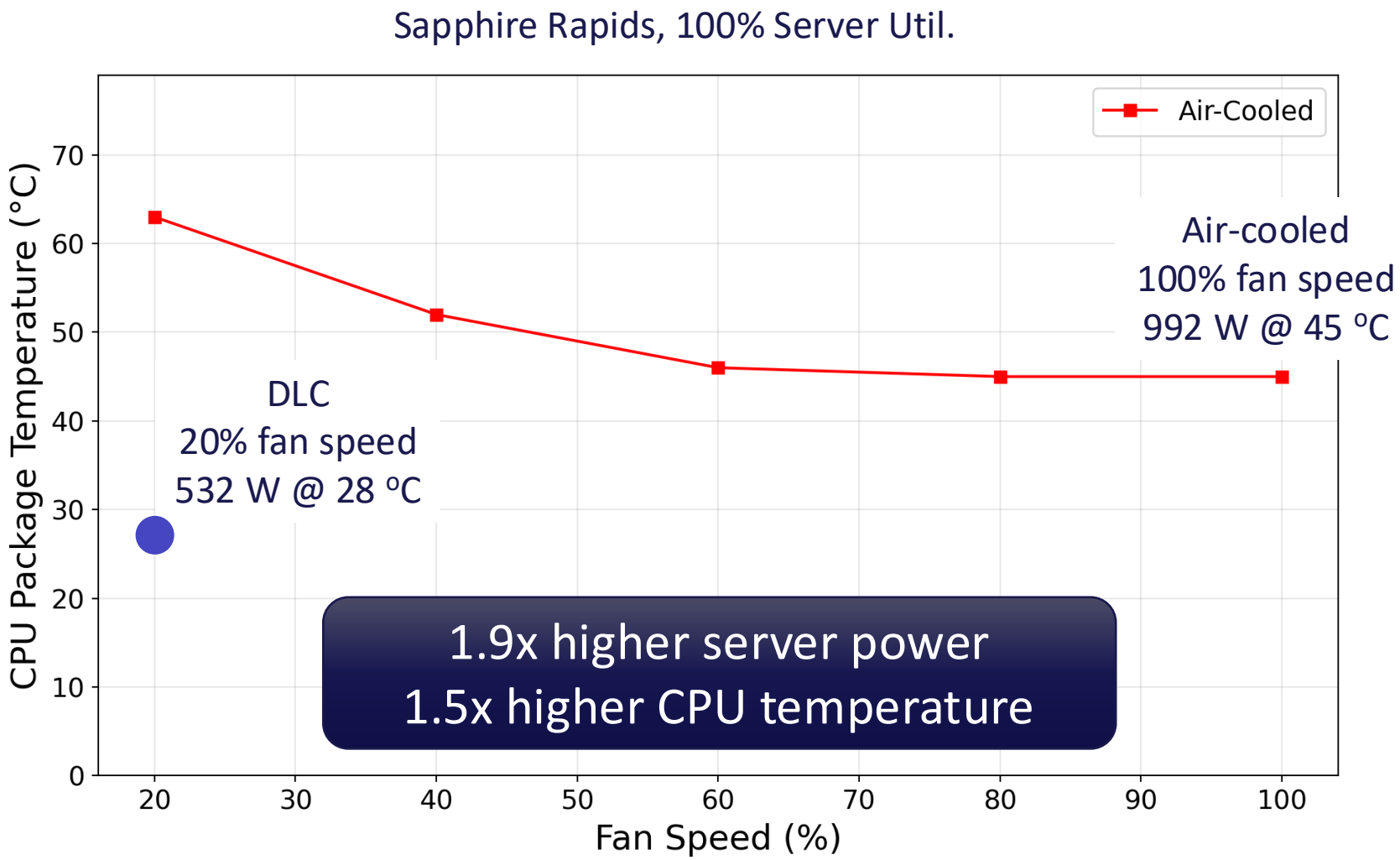
Fan Speed	2 cores	128 cores	
20%	339W	860W	+521W, 2.54x
100%	848W	1349W	
	+509 W, 2.50x		

Sapphire Rapids, Air-cooled, stress-ng
Server Power (PDU)

Fan Speed	2 cores	64 cores	
20%	260W	533W	+270W, 2.05x
100%	714W	992W	
	+454W, 2.75x		

100% Fan power can be greater than 100% load CPU power!

Air-Cooled vs DLC on CPU Package Temperature



Max Fan Speed Study

Sapphire Rapids, Air-cooled, 75% CPU util.

Ambient Temp	Fan Speed	Server Power
Conventional (20-22°C)	20%	529W
High Ambient (35°C+)	100%	939W

+410W, 1.78x

Sapphire Rapids, Air-cooled, 25% CPU util.

Ambient Temp	Fan Speed	Server Power
Conventional (20-22°C)	20%	414W
High Ambient (35°C+)	100%	831W

+417W, 2x

David L. Moss, “Data Center Operating Temperature: The Sweet Spot”, Dell Technical White Paper, 2011
El-Sayed et al., “Temperature Management in Data Centers: Why Some (Might) Like It Hot”, SIGMETRICS 2012

Hypothetical GPU Servers

How does IUE change for GPU servers?

GPU Assumptions (based on NVIDIA L40S)

Additional Idle Power	Additional Compute Power
40W	285W

Server Fan Speed Assumptions

Ambient Temp	Air-Cooled	CPU-Only DLC	CPU + GPU DLC
24°C	80%	60%	40%
32°C	100%	75%	40%

GPU Servers – IUE

24°C Ambient Temp

Cooling	Server Power	PSU Loss	Fan Power	Idle Power	Compute Power	IUE
Air-Cooled	1119W	75W	221W	195W	628W	**0.56**
CPU-Only DLC	963W	60W	93W	205W	605W	**0.64**
CPU + GPU DLC	892W	55W	27W	205W	605W	**0.68**

32°C Ambient Temp

Cooling	Server Power	PSU Loss	Fan Power	Idle Power	Compute Power	IUE
Air-Cooled	1351W	96W	432W	195W	628W	**0.46**
CPU-Only DLC	1061W	69W	182W	205W	605W	**0.57**
CPU + GPU DLC	892W	55W	27W	205W	605W	**0.68**

IUE reflects the changes in fan power