Water Implications of Energy-Efficient Data Centre Design

Energy Studies Institute

NUS National University of Singapore

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Today's Talk

Agenda

01 **Why data centres are water-hungry**
AI's physical footprint, how cooling works, and why water is used

02 **The hidden water footprint**
Water across the value chain and real hyperscaler's consumption

03 **Data centre efficiency metrics**
PUE vs WUE, the energy-water trade-off, and climate impact

04 **Evolving Cooling technologies**
From air cooling to liquid and direct-to-chip cooling for AI

05 **Water reduction & governance**
Reclaimed supply, innovation, and the APAC & Singapore picture

AI Has Physical Footprint

AI in our everyday

Ask anything….

- ChatGPT
- Microsoft Copilot
- Gemini
- Claude
- Perplexity
- Many more…

- Media generation
- Text generation
- Search
- Analyse
- Work & productivity
- Coding & troubleshooting

Runs real physical infrastructure – Data centres

Compute
CPU, GPU, Racks
Storage, Networking devices

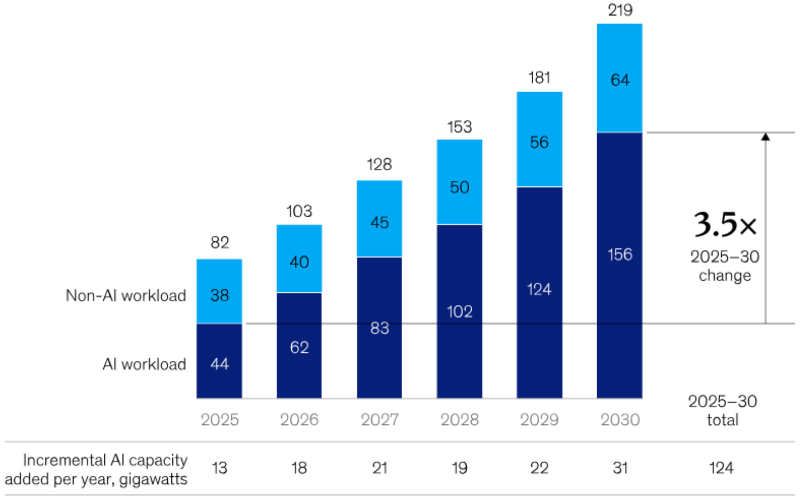
Power
Electricity from grids, renewable energy sources

Cooling
Thermal Management Systems

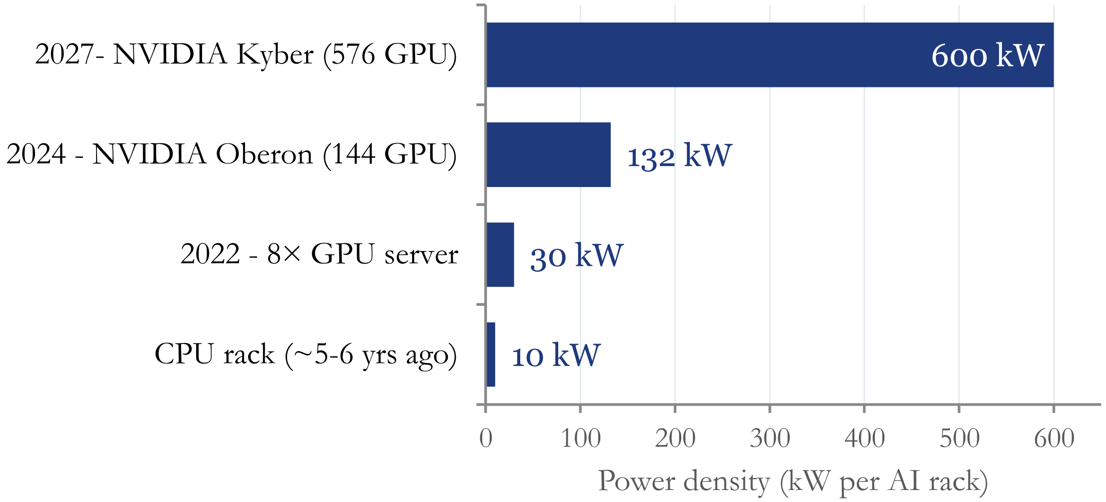
Data centers are infrastructures consumes power, generates heat and requires cooling to maintain in optimal conditions.

Impact of AI on Data Centre Landscape

PROJECTED GLOBAL DATA CENTRE CAPACITY DEMAND GROWTH



Note: Figures may not sum to totals, because of rounding.
Source: McKinsey Data Center Demand Model; Gartner reports; IDC reports; Nvidia capital markets reports



220 GW
Projected data centre demand by 2030

US $6.7T
Projected cumulative investment by 2030

50×
more kW per rack vs CPU racks 5 yrs ago

One 2027 Kyber rack powers
500 homes
in the space of a filing cabinet

As rack power density increases, heat generation increases proportionally, requiring more cooling capacity.
Heat removal becomes the bottleneck. Cooling gets complicated.

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Source:https://www.mckinsey.com/industries/private-capital/our-insights/scaling-bigger-faster-cheaper-data-centers-with-smarter-designs

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How Data Centres Remove Heat

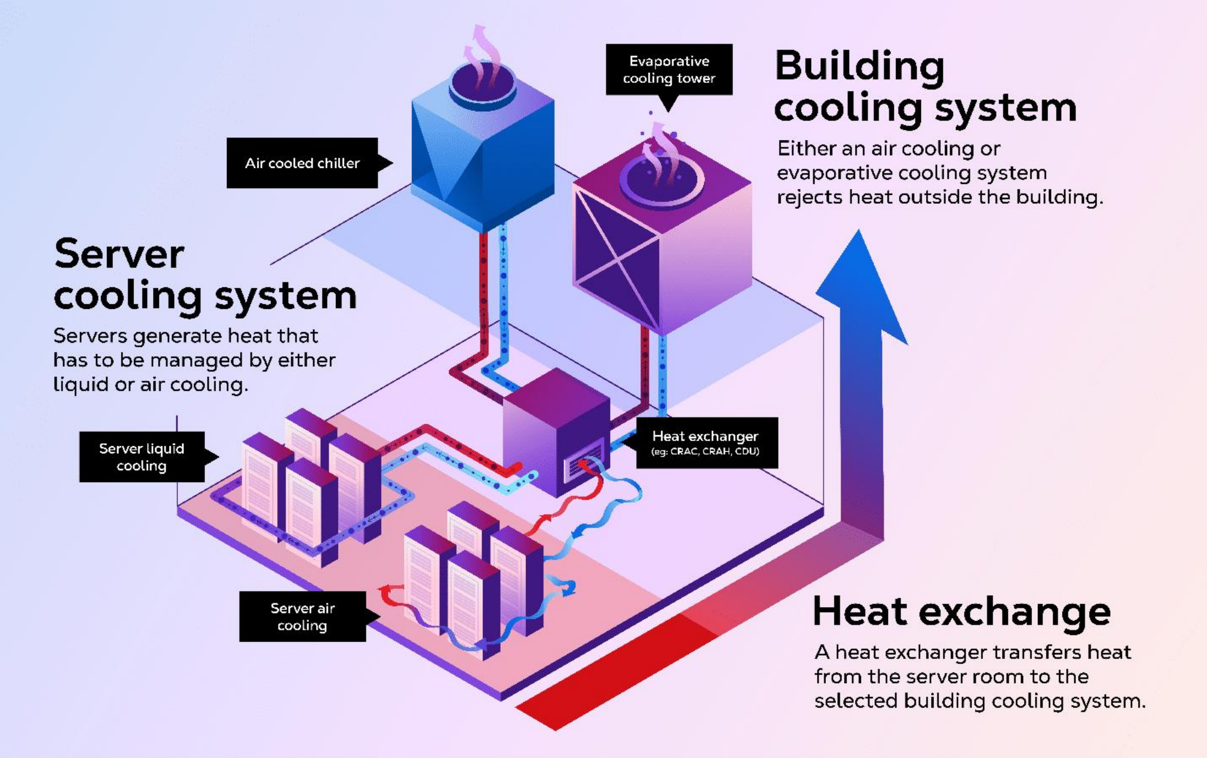
Cooling system has two jobs: first, capture heat from servers; second, reject it outside the facility.

SERVER LEVEL COOLING SYSTEM

Server-level cooling system moves the heat away from the servers to a heat exchanger.

Air cooled: Current Industry Standard. Fans deliver cold air to servers and remove hot air.

Liquid Cooling: A method that uses cooling fluid to move heat away from servers.



BUILDING HEAT REJECTION

The building-level system then rejects the heat from the building.

Air cooling systems, which reject hot air from the facility.

Evaporative cooling systems, which reject water vapor from the facility.

Main Source of onsite water consumption

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https://blog.equinix.com/blog/2025/04/08/how-to-speak-like-a-data-center-geek-cooling/

Climate Plays Pivotal Role in Cooling Choices

The best strategy depends on **climate, ambient conditions, and water availability**.

FAVOURABLE AMBIENT CONDITIONS

Naturally, cool air or water can replace chillers, or reduce their load, by providing cooling without consuming energy. This is called free cooling

Cool air from outdoor climate

Deep lake water systems

Seawater coastal

Lower energy use. Lower water consumption

HOT & HUMID CONDITIONS

Outdoor air provides little cooling benefit, so active cooling systems must work harder.

- High Temperature and Humidity → Limited free cooling opportunity
- Cooling system works harder → Higher electricity consumption

Higher energy use. More cooling load.

EVAPORATIVE HEAT REJECTION

Water is used because evaporation can reject large heat loads with low electricity use.

- **~4×** more heat per kg than air
- Water is far denser than air. The same pipe volume can carry **~800x** more mass compared to air ducts
- Evaporation removes heat very efficiently

More energy efficient Higher water consumption

As per Infocomm Media Development Authority of Singapore , cooling towers in data centre consume nearly **97%** of the water used

Microsoft data centre's (2022) WUE in Asia Pacific was **1.65** litres per kWh
WUE global average was **0.5** litres per kWh

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IMPLICATION FOR SOUTHEAST ASIA

Southeast Asia is largely **hot and humid** year-round, with limited room for free cooling. **Evaporative (water-assisted) cooling** is often the most practical way to manage cooling energy.

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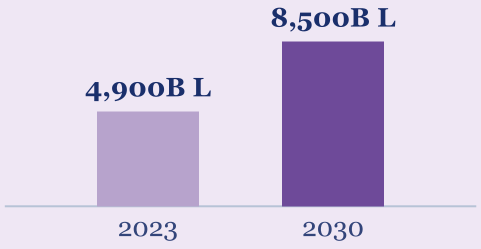
The Hidden Water Footprint of Data Centres

Water is used across the entire value chain of data centres. By 2030, global data centre water consumption **more than doubles**.

ELECTRICITY GENERATION

Water used to generate electricity that powers data centers.

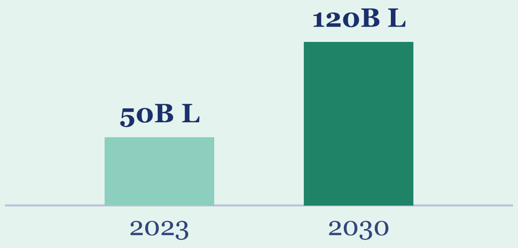


~65%

of total in 2023

CHIP MANUFACTURING

Water used in manufacturing semiconductors for data centres

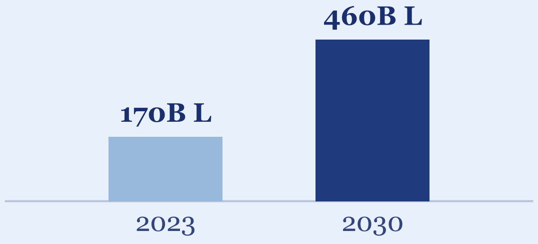


~5%

of total in 2023

ON-SITE COOLING

Water used on-site to cool IT equipment



~30%

of total in 2023

TOTAL WATER CONSUMPTION

2023

560 B

litres/year

2030

1,200 B

litres/year

~1.64x times the yearly water demand of Singapore

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Source: International Energy Agency, Energy and AI (2025)

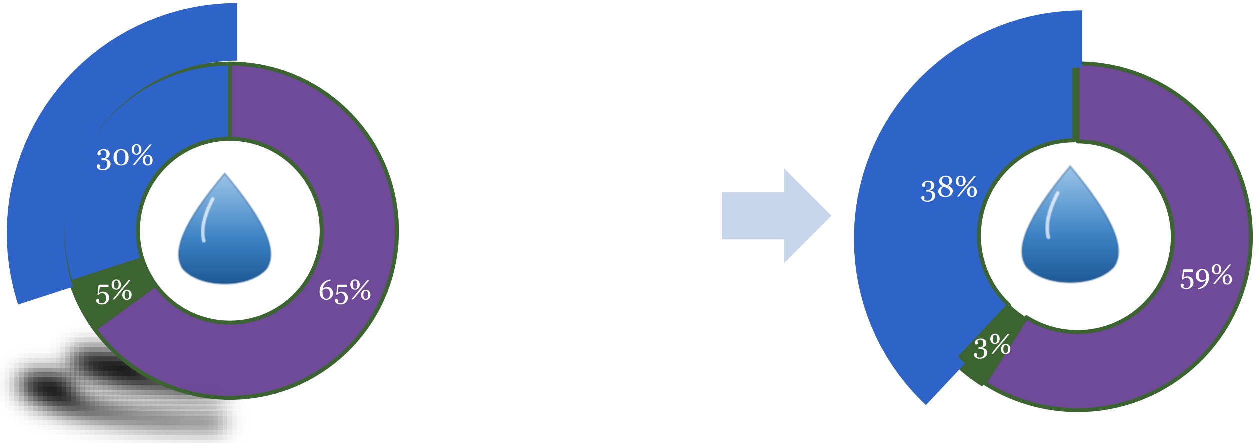
Cooling Drives the Onsite Water Story

On-site cooling is the part of water use most directly influenced by design and operation.

GLOBAL DATA CENTER WATER CONSUMPTION (BILLION LITRES PER YEAR)

2023 ~560 BILLION LITRES

2030 ~1.2 TRILLION LITRES



ELECTRICITY GENERATION

CHIP MANUFACTURE

ON-SITE COOLING

KEY TAKEAWAY

On-site cooling water use

2.7x

by 2030

From ~30% of total water use in 2023 to ~40% in 2030

Embedded water used by power consumption can be reduced by adapting onsite renewable energy sources like solar, wind etc.

Hyperscale Data centres Water Consumption

Google's global data-centre water footprint - 2024

34B

litres withdrawn

Total freshwater pulled from local supply for cooling.

29B

litres consumed

Lost permanently mostly evaporated, not returned.

80%

was potable

Potable water still dominates the feedstock.

31B

stewardship offsets

Few operators yet replenish what they consume locally.

Water stewardship refers to actions taken to replenish, restore, or improve water resources at a local or regional level of water consumption. Examples include watershed restoration, water recycling projects, improving local water access, and funding conservation initiatives.

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Source: Google 2025 Environmental Report

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Data Centre Efficiency Metrics

POWER USAGE EFFECTIVENESS (ISO/IEC 30134-2)

Lower PUE is Better

$$PUE = \frac{\text{Total Facility Energy (Cooling + IT + Others)}}{\text{IT Equipment Energy}}$$

Measures energy efficiency of data centre. If Power consumed by cooling system reduces PUE reduces

WATER USAGE EFFECTIVENESS (ISO/IEC 30134-9)

Lower WUE is Better

$$WUE = \frac{\text{DC Water Usage}}{\text{IT Equipment Energy}}$$

Measures total amount water used by the Data centre.

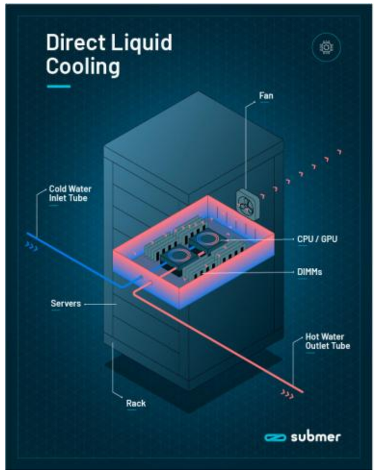
Trade Off:
An energy efficient data centre design can still be water intensive.

Keynote:
WUE remains useful, but incomplete. It does not tell us whether the water is potable, reclaimed, recycled, rainwater, condensate or seawater. It does not capture local water stress, peak demand, discharge quality.

Liquid Cooling is Becoming a Necessity for AI

As rack density keeps increasing. Air cooling can no longer keep up. The thermal transfer properties of air pale in comparison to liquids.

1 Direct-to-Chip Liquid Cooling

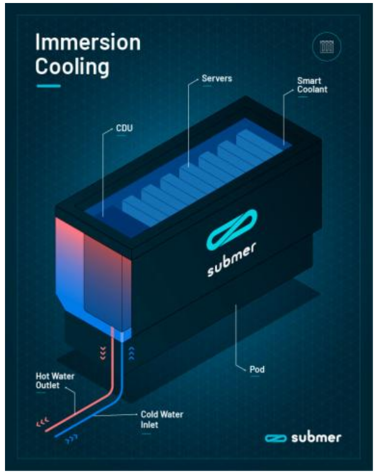


How it works
Liquid is delivered to cold plates mounted on CPUs/GPUs to remove heat directly at the source.

Key characteristic
Fans can still be used to provide airflow through the server to remove the residual heat. While the air cooling reduced

Best suited for
High-density AI and HPC workloads needing greater cooling capacity and efficiency.

2 Immersion Cooling



How it works
Servers are fully or partially immersed in a non-conductive liquid that absorbs heat directly.

Key characteristic
Highest heat-removal capability with little or no reliance on server airflow.

Best suited for
Ultra-high-density deployments and specialised use cases where maximum performance is critical.

No single cooling technology is universally best.

Technology depends on multiple factors:

Climate Density Water Cost Reliability Maintenance

These technologies address how we **capture heat at the server side**. Not building heat rejection system. i.e. it does not reduce total water consumption but makes making each workload more water and energy efficient.

Pathways For Water Reduction at the Building Level

A water-smart data centre draws from technology, supply, siting and operations

01

Reclaim & recycle the supply

Treated effluent, NEWater, and on-site greywater loops shrink potable draw. Cycles-of-concentration upgrades extract more from each litre.

02

Data centre heat export

Allow a portion of the heat in a data centre to be transferred to a third-party heat network rather than being rejected into the atmosphere. The heat can then be used for heating homes and businesses.

03

Tap alternative cold sources

LNG regasification cold, deep-lake cooling (Toronto, Stockholm), and seawater loops.

04

Site, plan, and operate by water risk

WRI Aqueduct screening, climate-vulnerability mapping, and AI-driven dynamic load shifting move workloads toward water-rich grids.

No single fix. Each pathway shifts the trade-off; the right mix depends on hydrology, grid, and infrastructure readiness.

Need For Governing Water Usage in Asia Pacific Region

Around half of projected data centre water consumption by 2030 is in Asia Pacific countries where a typically warm and humid climate makes cooling more water intensive.

WHY IT MATTERS

Among the world's
fastest-scaling DC regions

For Example: Johor

3,299 MW
planned and under construction

WHAT'S HAPPENING

Oct 2025 — Sungai Johor pollution
Treatment plants halted; ~800,000 residents affected. DCs depend on uninterrupted supply. Compete with local domestic, agricultural and industrial water use.

Nov 2025 — 18-month deferral
Authorities pause new water-cooled DC approvals until mid-2027 to ease drought-stressed supplies.

Reframed approval criteria
Future projects prioritised on water efficiency, reclaimed-supply readiness, and cooling design.

Source: International Energy Agency, Energy and AI (2025)

Case Study: Singapore

Governing water scarcity in a digital economy

Tropical DC Standard (SS697:2023)
Every 1° C increment in supply air temperature can cut cooling energy ~2–5%.

Green DC Roadmap
Approvals tightly controlled; water and energy efficiency are gating criteria.

Water Efficiency Plans
Mandatory annual tracking and reporting for large facilities.

Water Efficiency Fund
Government co-funds upgrades to recycling and high-efficiency systems.

Govtech Singapore was able to achieve 40% energy savings by increasing their supply temperature by 2 degrees.

Key Takeaways

01 **Energy efficiency ≠ water efficiency always.**
Optimise the pair. The lever you pull on PUE often shows up on the WUE side of the ledger.

02 **Tropical climates pay a “water tax”.**
Higher cooling loads, higher WUE. Climate has to be priced into design, siting and metric setting.

03 **Liquid cooling uses energy and water more efficiently.**
Liquid cooling does not eliminate water consumption as it is determined by building-level heat rejection system.

04 **Water-smart design is a system, not a single fix.**
Engineering, governance, grid mix, and siting have to move together.

Thank You

LinkedIn: Lalitha Ravi

Singapore's Data Centre Approval & Efficiency Governance

How new capacity is approved and evaluated

01 Capacity approval

- Infocomm Media Development Authority (IMDA) and the Economic Development Board (EDB) manage the Data Centre Call for Application (DC-CFA)
- New capacity is competitively allocated, not automatically approved
- Operators must show strong energy efficiency, green energy pathways, sustainable cooling, and efficient IT equipment

→

02 Latest DC-CFA2 expectations

- At least 200 MW of new capacity is available
- Potential for more capacity if innovative green energy pathways are used
- Selected applicants must obtain Green Mark for Data Centres 2024 Platinum
- Target Power Usage Effectiveness (PUE): 1.25 or better at 100% IT load

→

03 Evaluation Scheme: Green Mark for Data Centres

- Building and Construction Authority (BCA) and IMDA assess projects through the BCA-IMDA Green Mark for data centres.
- A facility-level rating and certification system.
- Similar in purpose to Leadership in Energy and Environmental Design (LEED), but tailored to Singapore's climate, building rules, and data centre sustainability needs
- Assessment areas:
  - energy efficiency,
  - carbon efficiency,
  - sustainable operations,
  - digital monitoring, and maintainability

Green Data Centre Roadmap & Tropical Data Centre Standards

How Singapore guides efficient and reliable data centre operation

01

IMDA Green Data Centre Roadmap

- The Green DC Roadmap was developed to chart a sustainable pathway for the continued growth of DCs in Singapore.
  - Refreshed Green Mark for DCs 2024 (GMDC:2024): GMDC:2024
  - Energy Efficiency Grant (EEG) for the DC sector: The EEG for the DC sector helps DC end-users accelerate their upgrades to more energy efficient IT equipment by co-funding investments in such pre-approved equipment options.
  - Singapore Standard on Energy Efficiency of Data Centre IT Equipment (SS 715:2025): This standard supports data centre operators and users to deploy energy efficient IT equipment.

02

Tropical Data Centre Standard 697:2023 (SS 697:2023)

- Voluntary framework
- Provides assurance to operate safely at higher temperatures in Singapore's tropical climate
- Helps reduce cooling energy consumption while maintaining reliability.

Water Usage & Reporting Requirements

For water, the main public authority is Public Utilities Board (PUB) – Singapore's National Water Agency.

01 Public Utilities Board

- Oversees water supply
- Oversees discharge
- Oversees water-efficiency requirements

02 Water Efficiency Tracking

- Applicable large water users, including relevant data centres, must comply with Mandatory Water Efficiency Management Practices (MWEMP)
- Track water consumption
- Submit annual water consumption details
- Submit business activity indicators
- Submit water efficiency plans

03 Benchmarking Water Usage

- Develops sectoral water-efficiency benchmarks
- Data centres are one of the relevant sectors

04 Support for Improvement

- Water-efficiency guidance
- Benchmarking support
- Best-practice guides for cooling towers
- Water Efficiency Fund (WEF) for projects that improve water efficiency

Energy used for inference and for learning