Sustainability Aspects in Supercomputing

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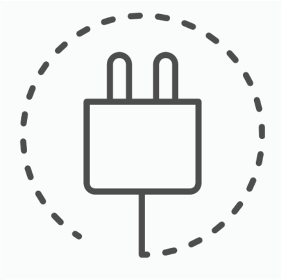
Outline

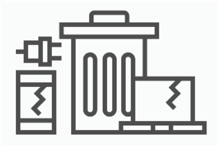
- Sustainability Aspects of Supercomputing
- What is Energy Efficiency?
- How to improve Energy Efficiency & Have Less Environment Impact

1. Sustainability Aspects of Supercomputing

With Great (Computing) Power Comes Big Responsibility

- Supercomputers have become critical tools for scientific research, data analysis, and other applications that require **massive amounts of computing power**.
- However, these powerful machines also come with **several sustainability issues.**





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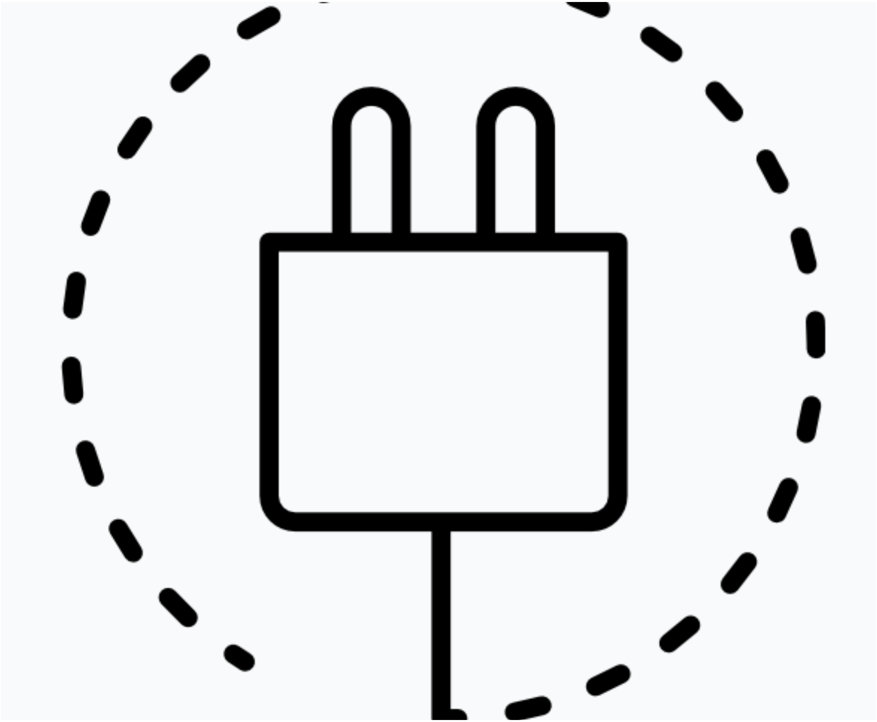
Sustainability Issues with Supercomputing

- High Power Consumption
- Carbon Emissions
- Heat Generation
- Limited Lifespan / E-waste
- Resource Intensive Manufacturing & Logistics
- Water Usage

High-Power Consumption

- Supercomputers, especially large-scale ones, consume massive amounts of electrical power.
- This high power demand contributes to increased energy costs, carbon emissions, and strains on electrical grids.



Power Consumption - Supercomputers

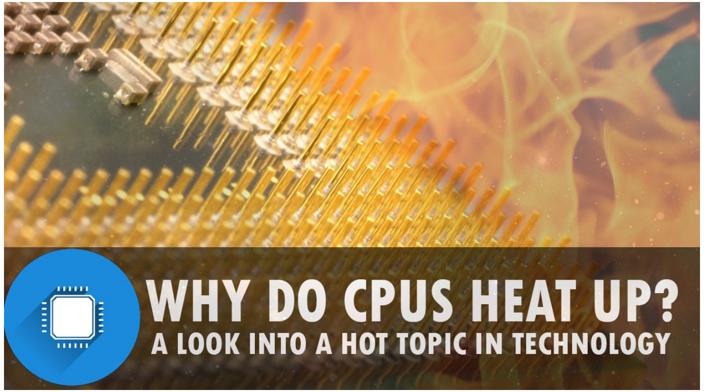
Supercomputers require **massive amounts of energy** to operate, which can lead to significant environmental impact and increased energy costs.

Require Electricity for two things:

1. **Calculations** ← Electricity

   Heat is a major, if not the only, result of the calculations ☺

2. **Remove Heat** ← Electricity



Courtesy:https://centralvalleycomputerparts.com/articles/why-do-cpus-get-hot/

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The Top500 List - https://top500.org/lists/top500/2024/06/

Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	8,699,904	1,206.00	1,714.81	22,786
2	**Aurora** - HPE Cray EX - Intel Exascale Compute Blade, Xeon CPU Max 9470 52C 2.4GHz, Intel Data Center GPU Max, Slingshot-11, Intel DOE/SC/Argonne National Laboratory United States	9,264,128	1,012.00	1,980.01	38,698
114	**Dardel GPU** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE KTH - Royal Institute of Technology Sweden	52,864	8.26	10.21	146
5	**LUMI** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE EuroHPC/CSC Finland	2,752,704	379.70	531.51	7,107

→ 22 MW!

→ 38 MW!
Can't start all the system!

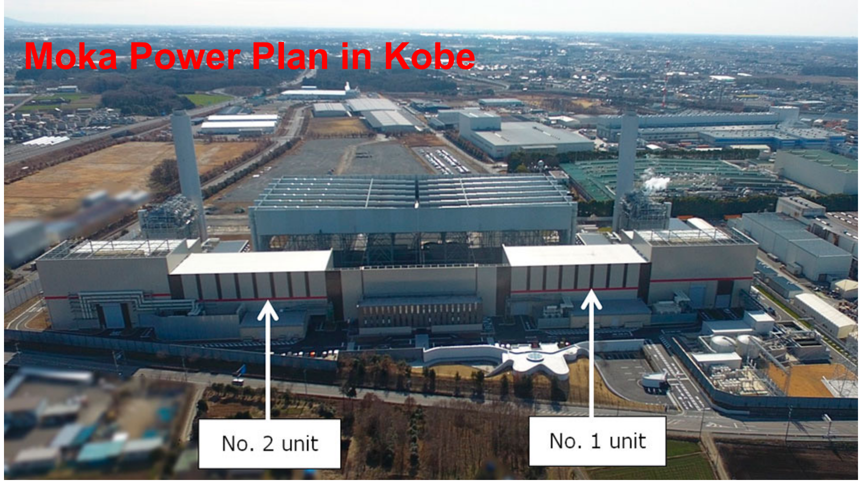
→ European System: relatively power drain

Power Consumption - Supercomputers

Frontier #1: 22 MW
Aurora #2: 38 MW
Fugaku #4: 29 MW
LUMI #5: 7 MW

The power usage of a small town can range from a **few MW to tens of MW**.

Power stations provide approx. GW.



Company name	Kobelco Power Kobe, Inc.	Kobelco Power Moka, Inc.	Kobelco Power Kobe No. 2, Inc.
Location	Kobe, Hyogo Prefecture (within Kobe Works)	Moka, Tochigi Prefecture (adjacent to Moka Plant)	Kobe, Hyogo Prefecture (within Kobe Works)
Fuel	Coal	City gas	Coal
Power generation capacity	1,400 MW (700 MW x 2 units)	1,248 MW (624 MW x 2 units)	1,300 MW (650 MW x 2 units)

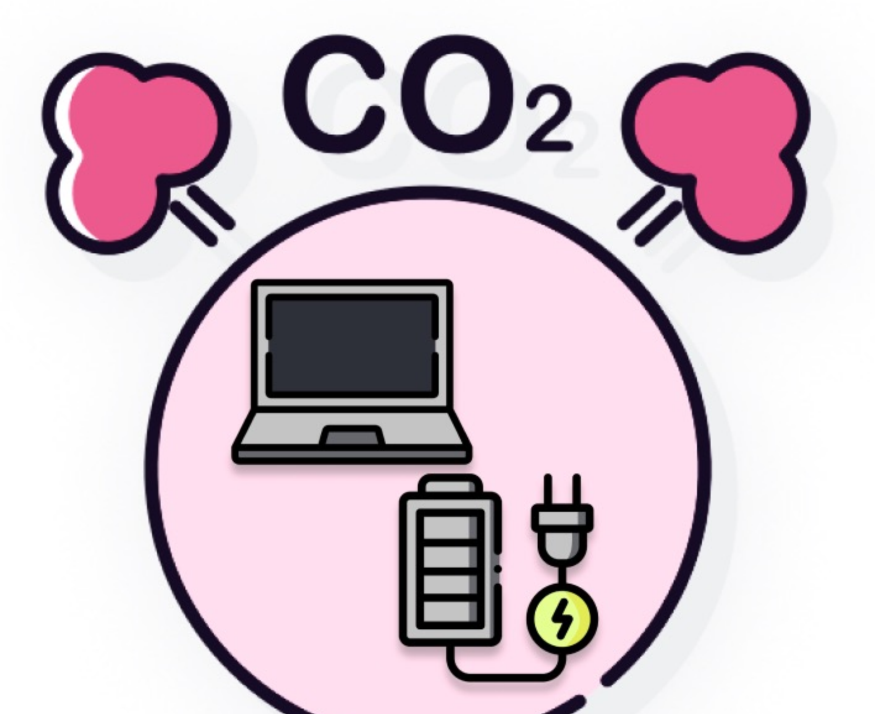
Courtesy: https://www.kobelco.co.jp/english/releases/1203382_15581.html

Supercomputing Carbon Footprint

- The carbon footprint refers to the total amount of **greenhouse gas emissions**

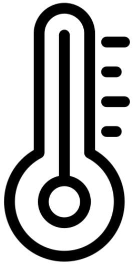
  primarily carbon dioxide CO_2

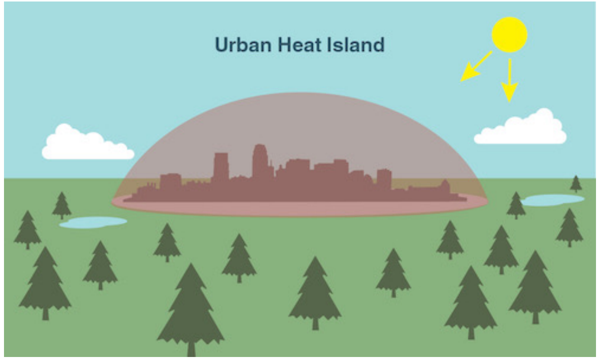
  - For supercomputers, this includes the energy used to manufacture, operate, and dispose of the machines.
- The energy used to power supercomputers is typically derived from **non-renewable sources** such as coal, oil, and natural gas, which are major sources of **greenhouse gas emissions**.



Supercomputing Heat generation

- Supercomputers generate a tremendous amount of **heat during operation**, which must be **dissipated to prevent damage** to the system.
- This can require additional energy to cool the system and contribute to urban heat islands and other environmental concerns.
    - Health hazard



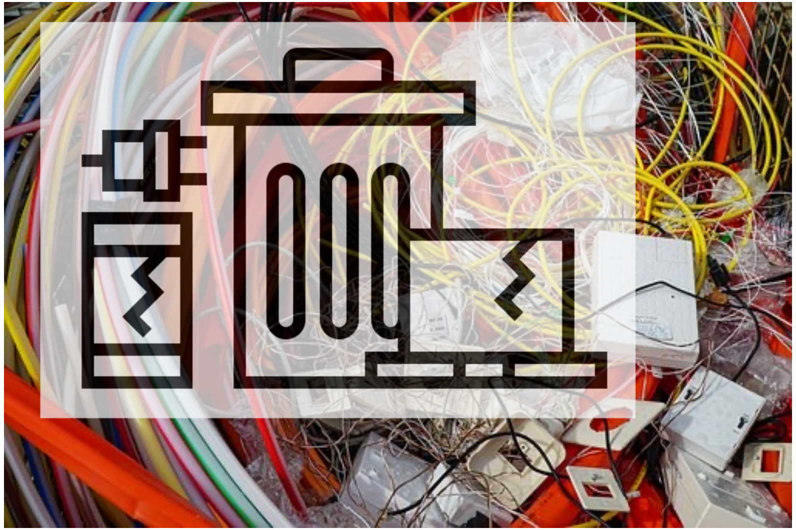


Courtesy: https://climatekids.nasa.gov/heat-islands/

Supercomputer Lifespan & Electronic Waste

Supercomputers are **often replaced every 5-6 years** (technologies become obsolete and much more efficient technologies), leading to a significant amount of e-waste.

- Many of the components used in supercomputers, such as processors and memory modules, contain **hazardous materials that can pose a risk to the environment if not disposed of properly**.



Resource Intensive Manufacturing & Supply Chain

- The production of supercomputers requires a significant amount of resources, including **rare earth metals** and other **materials that may be difficult to source sustainably**.
- Additionally, **the production and transport of supercomputers** can contribute to carbon emissions and other environmental impacts**.**

Supercomputer Water Usage

- Some cooling methods for supercomputers involve large quantities of water.
- Water usage for cooling, particularly in regions with water scarcity, can be a concern.

Courtesy: https://www.vistechcooling.co.uk/knowledge-centre/articles/best-practice-for-replacing-cooling-heating-pipework/

Reflection & Awareness

- Important to think about the impact of our calculations on the environment
- Paper: https://onlinelibrary.wiley.com/doi/10.1002/advs.202100707
- We can evaluate our impact: http://calculator.green-algorithms.org/
- Report estimate in your computational work, see example below

The effect of data encoding on the expressive power of variational quantum machine learning models

Maria Schuld,[1] Ryan Sweke,[2] and Johannes Jakob Meyer[2]

[1] *Xanadu, Toronto, ON, M5G 2C8, Canada*
[2] *Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany*

(Dated: March 10, 2021)

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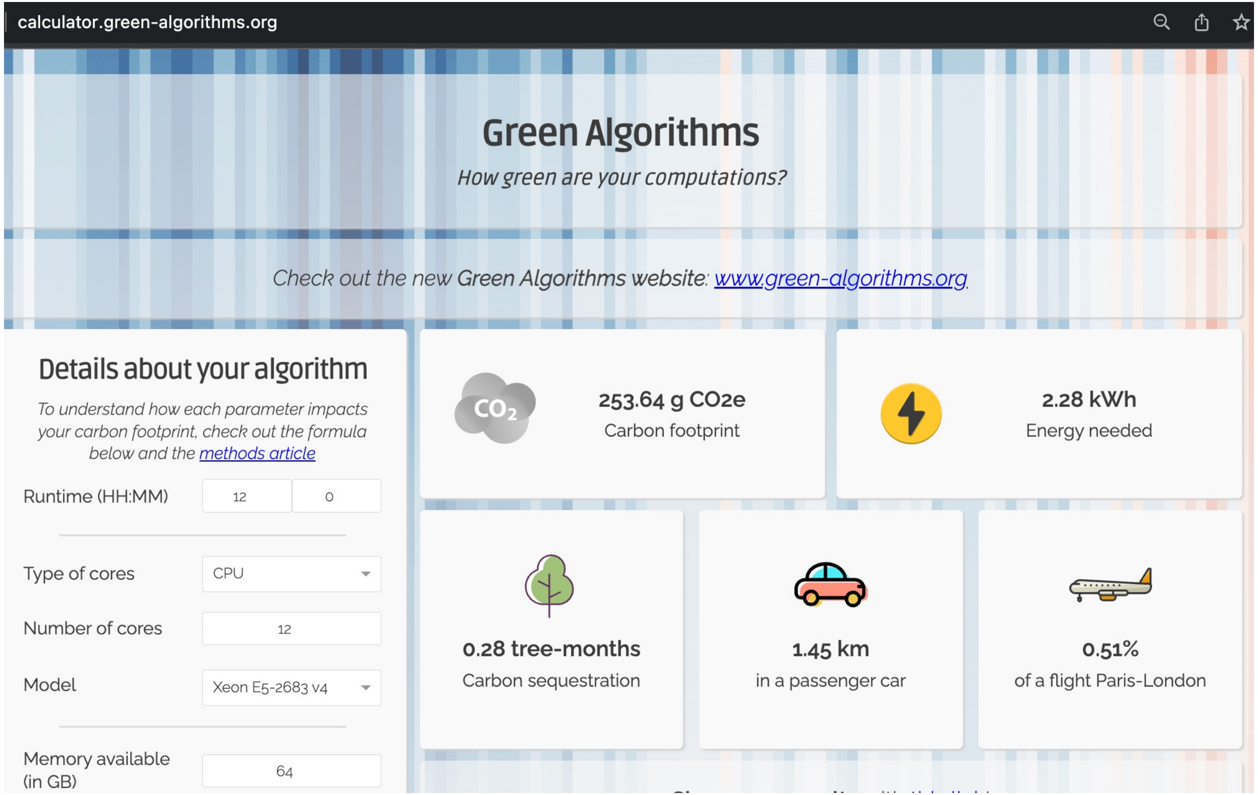
MS wants to thank Nathan Killoran, Nicolas Quesada and Josh Izaac for helpful discussions. RS and JJM acknowledge funding from the BMWi under the PlanQK initiative. The authors endorse Scientific CO_2nduct [44] and provide a CO_2 emission table in Appendix D.

Appendix D: CO_2 Emission Table

Numerical simulations	
Total Kernel Hours [h]	≈ 100
Thermal Design Power Per Kernel [W]	≈ 50
Total Energy Consumption Simulations [kWh]	≈ 5
Average Emission Of CO_2 In South Africa [kg/kWh]	≈ 1.5
Total CO_2 Emission For Numerical Simulations [kg]	≈ 7.5
Transport	
Total CO_2 Emission For Transport [kg]	0
Total CO_2 Emission [kg]	≈ 7.5
Were The Emissions Offset?	Yes

In-Class Exercise



https://calculator.green-algorithms.org/

2. What is Energy Efficiency in Supercomputing

Supercomputing: Understanding Energy Efficiency

- What is Energy Efficiency?
  - Ability of the supercomputer to perform a given amount of computational work while **minimizing its energy consumption**.
    - It's a measure of how effectively the supercomputer uses electrical power to accomplish its tasks
    - Quantified as the **ratio of computational performance** (measured in FLOPS, or floating-point operations per second) **to power consumption** (measured in Watts).

The Green500 List: Ranking Energy Efficiency

The Green500 list is a ranking of supercomputers based on their energy efficiency and performance in terms of floating-point operations per second (FLOPS).

- **Energy Measurement:** This is typically done using power meters or specialized instrumentation that monitors power usage at various points within the supercomputer and its associated infrastructure.
- **Performance Measurement:** The supercomputer's performance is assessed by running the HPL benchmark.

https://www.top500.org/lists/green500/

Green500 List – June 2023

Rank	TOP500 Rank	System	Cores	Rmax (PFlop/s)	Power (kW)	Energy Efficiency (GFlops/watts)
1	255	**Henri** - ThinkSystem SR670 V2, Intel Xeon Platinum 8362 32C 2.8GHz, NVIDIA H100 80GB PCIe, Infiniband HDR, Lenovo Flatiron Institute United States	8,288	2.88	44	65.396
2	34	**Frontier TDS** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	120,832	19.20	309	62.684
3	12	**Adastra** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE Grand Equipement National de Calcul Intensif - Centre Informatique National de l'Enseignement Suprieur (GENCI-CINES) France	319,072	46.10	921	58.021
4	17	**Setonix – GPU** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE Pawsey Supercomputing Centre, Kensington, Western Australia Australia	181,248	27.16	477	56.983
5	77	**Dardel GPU** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE KTH - Royal Institute of Technology Sweden	52,864	8.26	146	56.491
6	1	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	8,699,904	1,194.00	22,703	52.592

https://www.top500.org/lists/green500/2023/06/

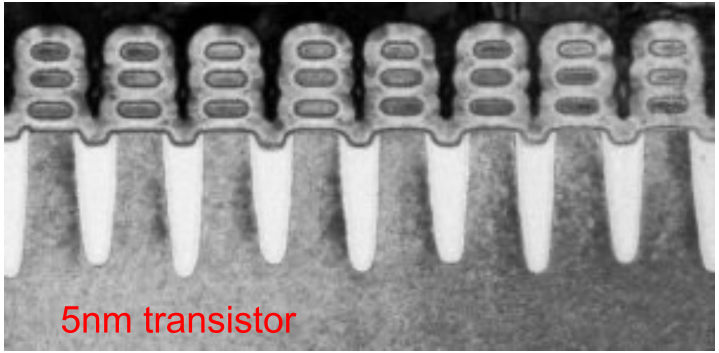
3. How to Increase Energy Efficiency & Lower the Impact on the Environment

Advancements in Energy Efficiency

- The supercomputing industry constantly innovates to enhance energy efficiency.
- Technologies include efficient processors, smart cooling methods, and optimized designs.

More Energy-Efficient Processors

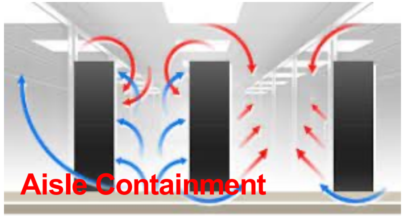
- Over the last 20 years, significant improvements have been made in developing more energy-efficient leveraging (among others):
  - **Process Technology:** Advancements in semiconductor manufacturing processes, including the transition to smaller nanometer process nodes (e.g., 7nm, 5nm), have improved energy efficiency.
    - **Smaller transistors** are generally more power-efficient because they have lower leakage currents and reduced capacitance.
  - **Multi-Core and Many-Core Architectures:** Increasing the number of processor cores on a chip allows for better workload distribution and energy efficiency for parallelizable tasks.
  - **Heterogeneous Computing**: accelerators are optimized for specific workloads and can significantly improve energy efficiency for parallel and specialized tasks.



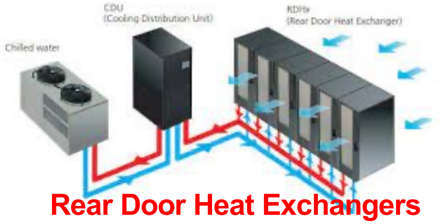
Courtesy:https://cmte.ieee.org/futuredirections/2017/06/08/5nm-transistors/

Cooling Methods

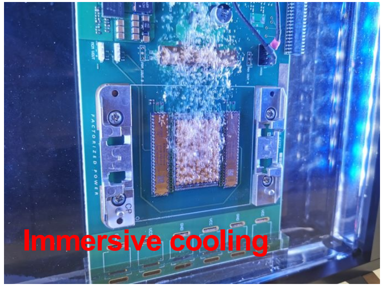
- **Air Cooling**:
  - **Air Conditioning:** Traditional air conditioning systems are used to cool data centers and supercomputing facilities. They remove heat by circulating chilled air through the facility.
  - **Hot/Cold Aisle Containment:** In this approach, hot and cold aisles are separated within the data center.
- **Liquid Cooling (Water-based, Mineral Oils, …):**
  - **Direct-to-Chip Liquid Cooling:** Liquid-cooled systems circulate coolant directly through or around the processors and other high-heat components.
  - **Rear Door Heat Exchangers:** Rear door heat exchangers are attached to the back of server racks and use liquid cooling to remove heat from the servers.
  - **Immersion Cooling:** In immersion cooling, servers and components are submerged in a non-conductive coolant.



Courtesy :https://cool-shield.com/aisle-containment-faq/



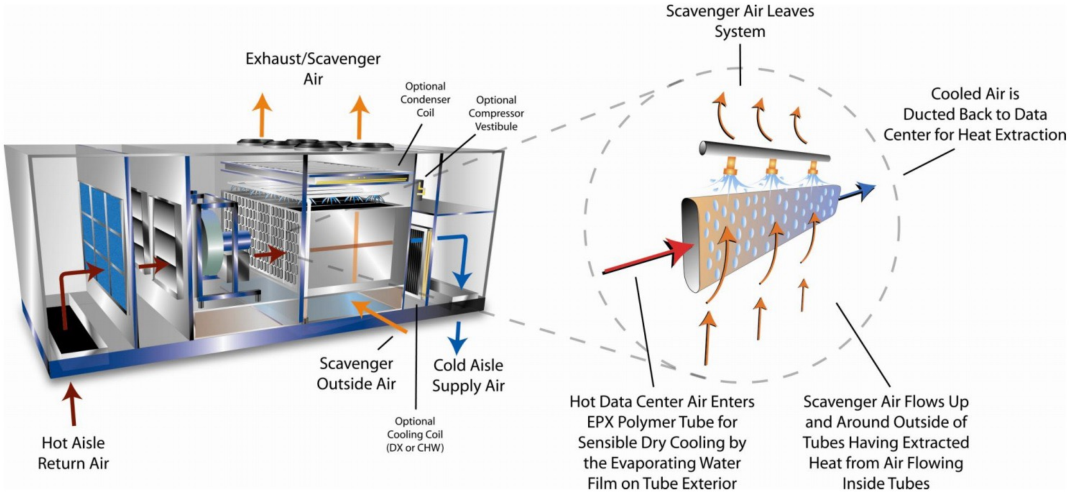
Courtesy: https://www.akcp.com/articles/cooling-with-rear-doo heat-exchanger-to-optimize-data-center/



Courtesy: https://www.anandtech.com/show/15166/two-phase-immersion-liquid-cooling-at-supercomputing-2019

Free Cooling

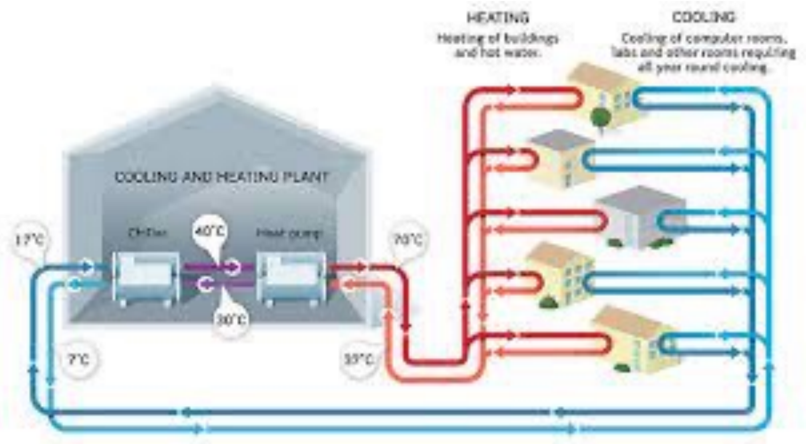
- **Outside Air Cooling**: In regions with a suitable climate, outside air can be used for cooling during cooler months.
- Airside economizers draw in outside air to cool the data center, reducing the need for mechanical cooling.



Courtesy: https://engineeringbyjorgen.wordpress.com/2014/08/18/data-centre-cooling-simplified/

Sustainability - Heat Reuse

Heat from supercomputers can be used to heat other buildings



The custom made hood and attached piping on top of Lindgren made it possible to re-use the heat

Renewable & Clean Energies to Feed Energy into Computers

- Using **renewable energy sources** to power supercomputers could help reduce their environmental impact.
- Examples:
    - Swiss National Supercomputing Centre (CSCS) - Switzerland:
        - The center is powered by a combination of energy sources, including hydropower, wind, and solar energy.
    - Finnish IT Center for Science (CSC) - Finland:
        - Finland has made a concerted effort to use renewable energy sources for its HPC facilities, and much of the energy comes from wind and hydropower.
    - National Computational Infrastructure (NCI) - Australia:
        - Australia's extensive solar resources have prompted NCI to invest in solar energy to power its computing infrastructure.
- …

Conclusion

- Balancing costs and sustainability is a significant challenge in supercomputing.
- The Green500 list and ongoing industry efforts show a path towards responsible and efficient supercomputing.