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Research and Innovation SERI
EU Framework Programmes

H O R I Z O N E U R O P E

The HEATWISE project

Attila Mórotz

Project coordinator
H1 Systems Ltd.

Lulea, 19th March 2026
www.heatwise.eu



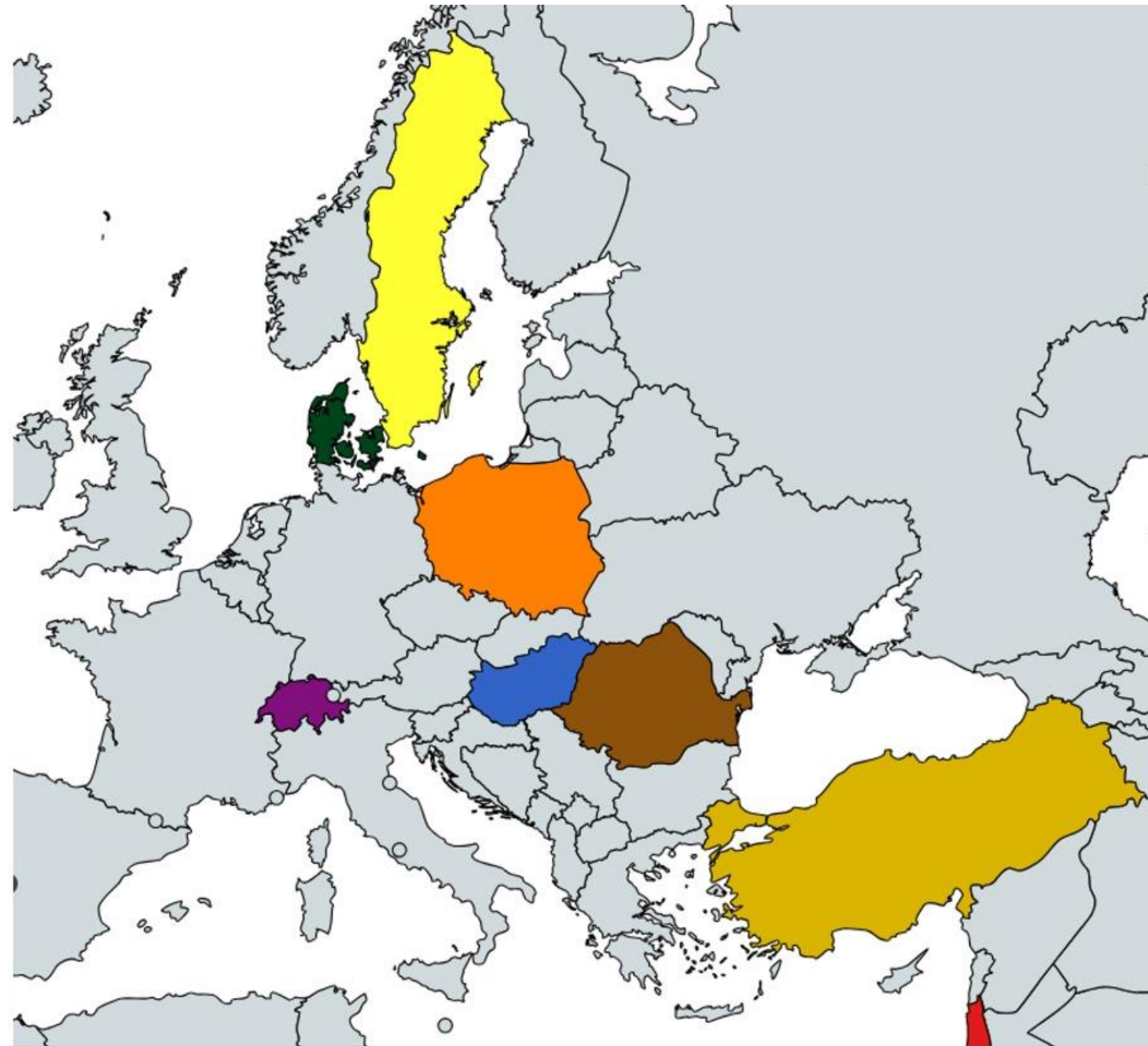
Thermal integration and optimisation of buildings and data centres



Project partners



HU	
SE	  
DK	
PL	
CH	
RO	
TR	  
IL	



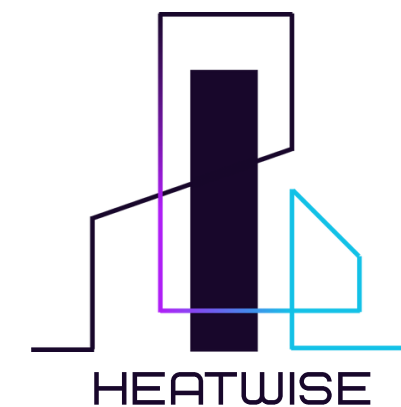
2024-2026

4.5 MEUR total budget

• 3.2 MEUR



• 1.3 MER



Drivers



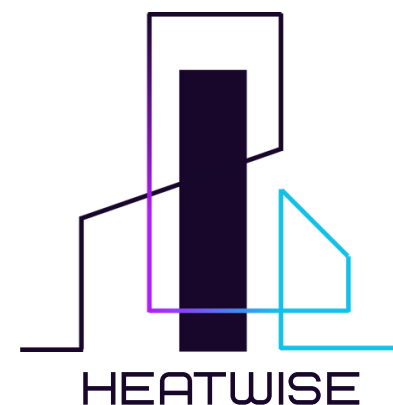
- Cost saving
- New revenue stream
- Compliance



- Cost saving
- Compliance



- EU directives
- National policies
- Standards, certifications





Renewable Energy Directive

- Increase of renewables by 2030 = 49% in building sector
- National, sectoral energy strategies
- Promotes reuse of waste heat from **DCs**, industry, WWTP

EPBD

- From **2030 all new buildings** zero-emission: no fossil-fuel-based heating systems
- By **2030/2033 renovation** of worst-performing buildings (offices, schools, hospitals, retail spaces): insulation, heating, renewables
- By 2024/2029 mandatory Building Automation and Control System installation (>70kW)
- Mandatory Energy Performance Certificate and optional Smart Readiness Indicator



EED on district heating

- Encouraging waste heat reuse in district heating and cooling
- Member States have to assess potential and include in national strategy
- Promote efficient district heating using waste heat of DCs, industry, etc.



EED on DCs

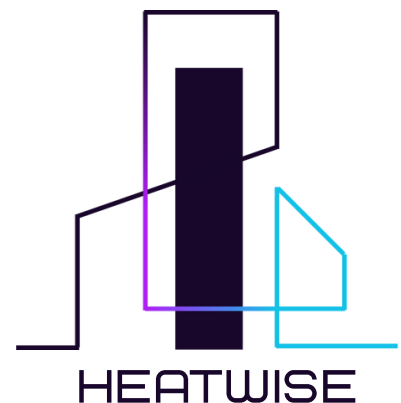
- Reporting on KPIs >500 kW DC
- Labeling is being developed
- PUE, Waste heat targets in GER, SPA, FRA



EED on DCs



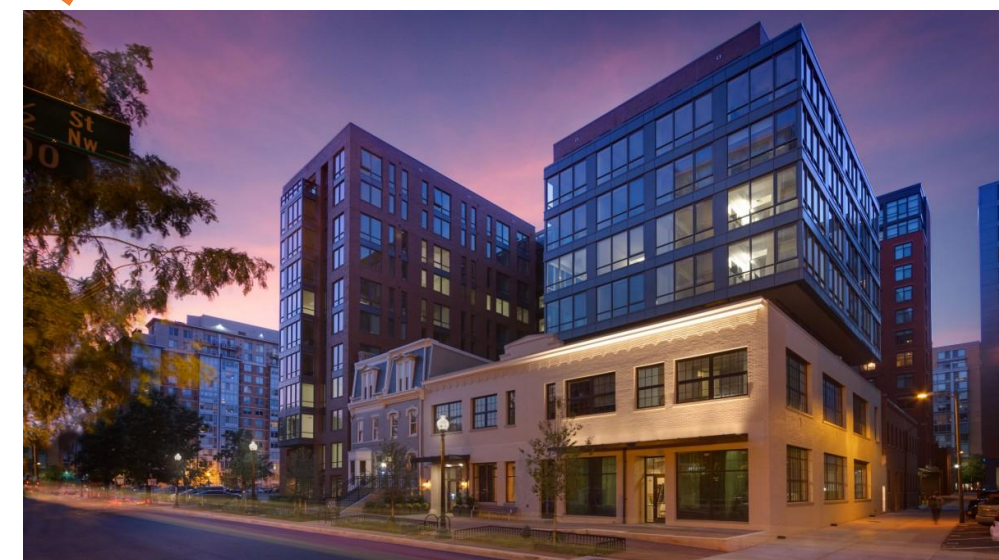
 EEA: minimum performance requirements			
Operating condition	Data center operational date	Requirement	Additional notes
Power usage effectiveness (PUE)	Before July 2026	PUE ≤ 1.5 by 1 July 2027 PUE ≤ 1.3 by 1 July 2030	
	During or after July 2026	PUE ≤ 1.2	Achieve as annual average within 2 years of commissioning
Heat reuse percentage	During or after July 2026	Energy reuse factor ≥ 10%	Heat reuse opt-out conditions specified in EEA
	During or after July 2027	Energy reuse factor ≥ 15%	
	During or after July 2028	Energy reuse factor ≥ 20%	
Renewable energy consumption	During or after 1 January 2024	50% unsubsidized renewable energy	Requirement can be met by a combination of direct consumption and application of Guarantees of Origin
	During or after 1 January 2027	100% unsubsidized renewable energy	
<i>Above requirements waived if data center closes by 1 January 2027. Some details on opt-outs and exclusions are omitted. Read the regulation to understand the full requirements.</i>			
UPTIME INTELLIGENCE 2023			



HEATWISE target values



PUE <1.05
ERF >95%
PES 20%



The research road to HEATWISE



BodenType DC (Horizon2020)

- 2017-2020
- PUE 1.028
- Birth of holistic cooling control



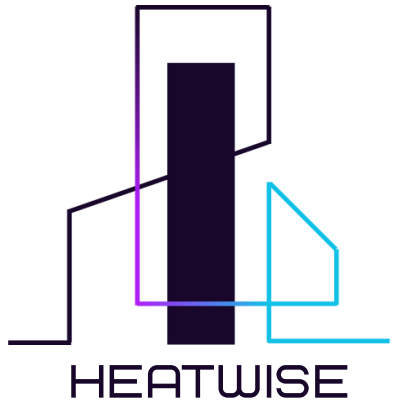
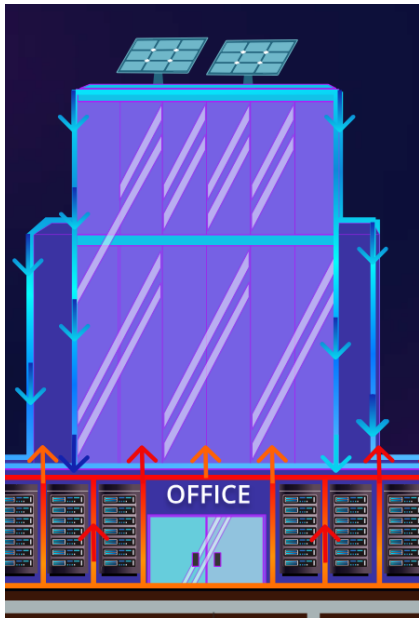
EcoQube (Horizon2020)

- 2020-2024
- AI-augmented cooling
- Zonal heat management

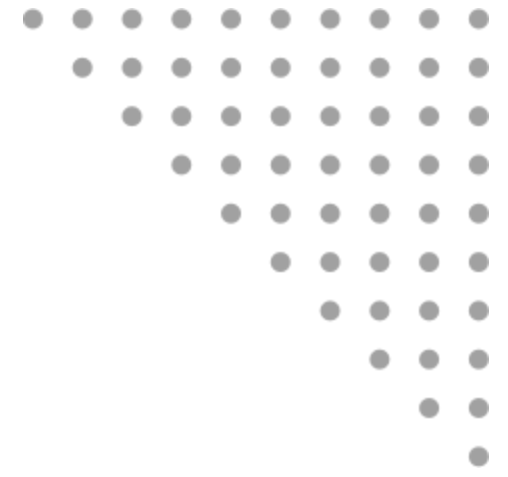


HEATWISE (Horizon Europe)

- 2024-2026
- Waste heat reuse in buildings
- Heat maximization, energy-cost optimisation



Pilots and use cases



AAU (DK)
university campus



PSNC (PL)
supercomputing centre



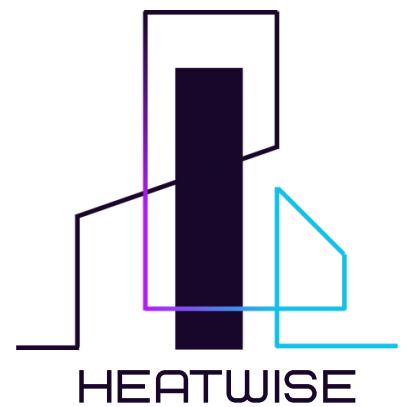
TOFAS (TR)
smart factory



EMPA (CH)
mixed use building



RISE (SE)
industrial warehouse



Value proposition



Performance

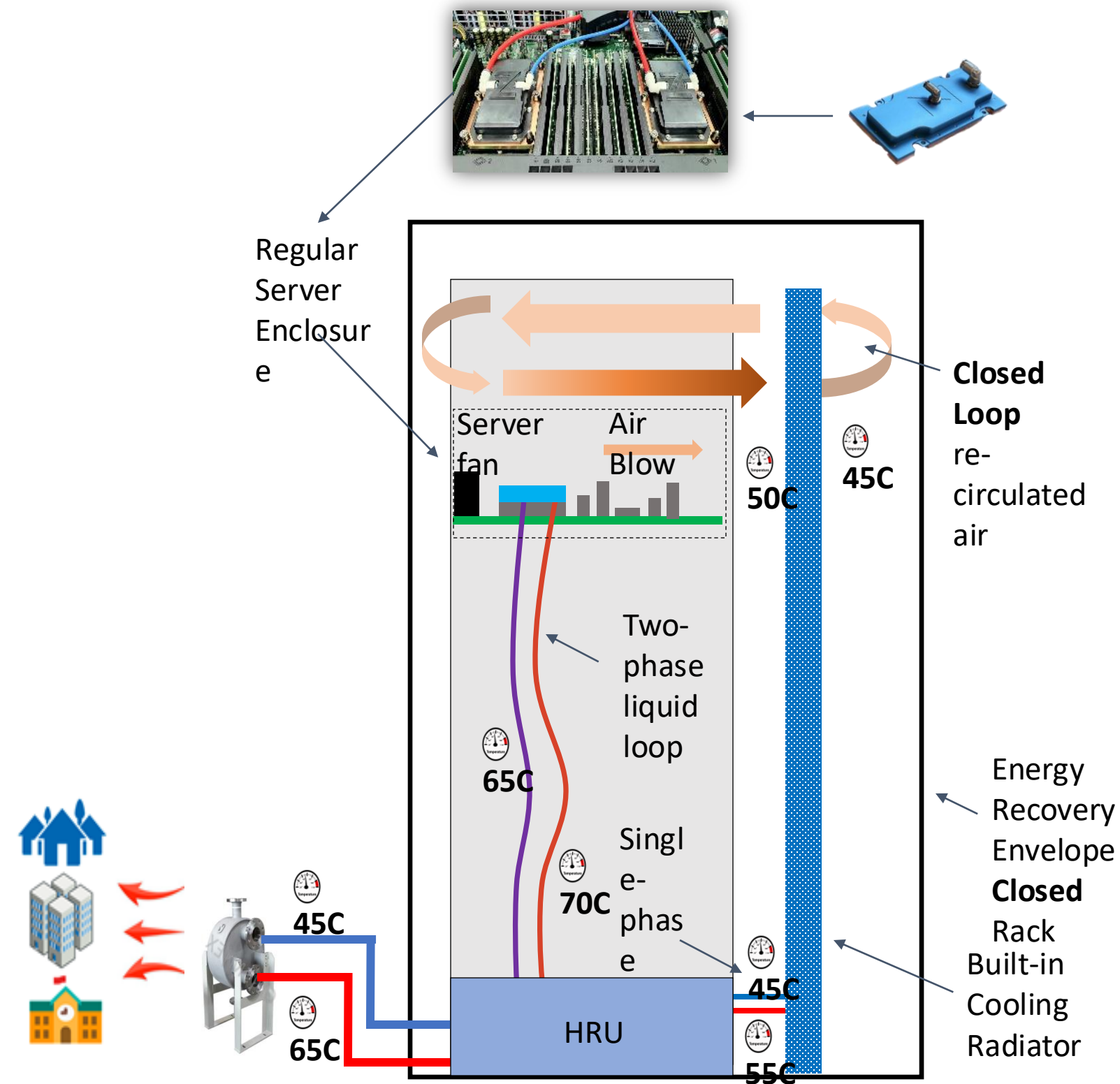
- Higher IT work
- High quality heat
- Lower capex and opex

Compliance

- EU directives
- National strategies

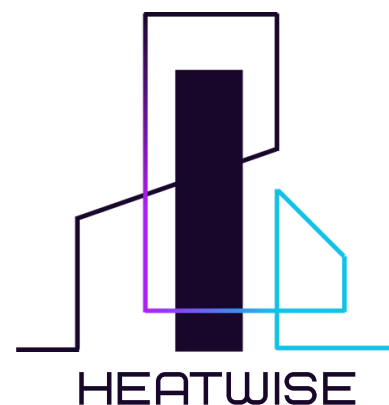
Decarbonisation

- Energy saving
- Green energy



Technology

- Hybrid cooling
- Closed rack
- Holistic cooling control
- Building integration
- Self-optimisation
- Self assessment



CONTACT

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www.heatwise.eu

**THANK
YOU**



Bridging the past and the Future: A brief Summary of Sustainable Digitalisation.

Dr Jon Summers

Scientific Lead in Data Centers

Data Center Systems Unit

Digital Systems Division

RISE Research Institutes of Sweden

Chair of FTS at Open Compute

Adjunct Professor in Fluid Mechanics

Lulea Technical University Sweden

Visiting Professor in Thermofluids

University of Leeds, UK



HeatWise Pilot Event 19th March 2026

OUTLINE

- Focus on 3 projects funded by the EU that includes heat recovery and thermal management.
- Air cooling with fresh air leading to efficient thermal management -
- - followed by heat recovery from air.
- Introduce a biogas powered liquid cooled edge style containerised DC
- - with heat recovery from high temperature fuel cells.



The effectiveness of the computational process.

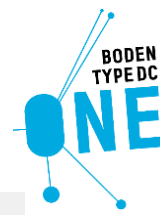


Based on:
Rolf Landauer, "Irreversibility and Heat Generation in the Computing Process," **IBM J Res. Dev. 5, 183 (1961)**.
<http://dx.doi.org/10.1147/rd.53.0183>

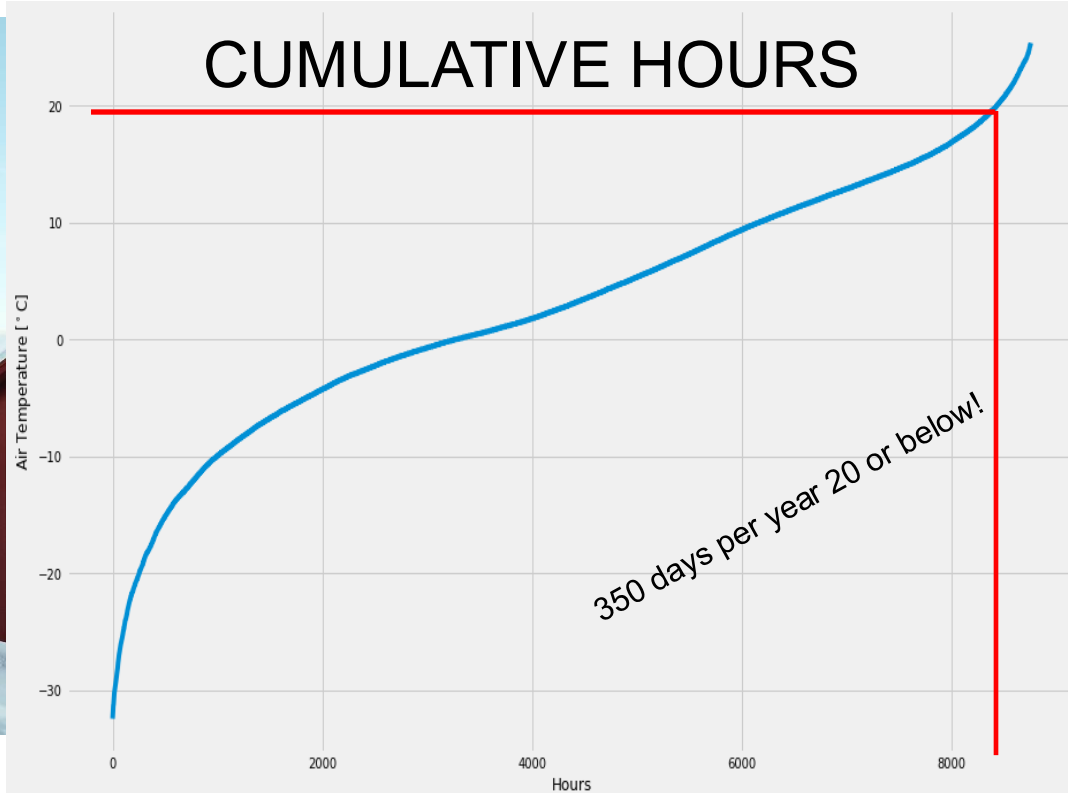
Today 99.97% of input power is in the thermal stream.

IT IS NOT EFFICIENT!!

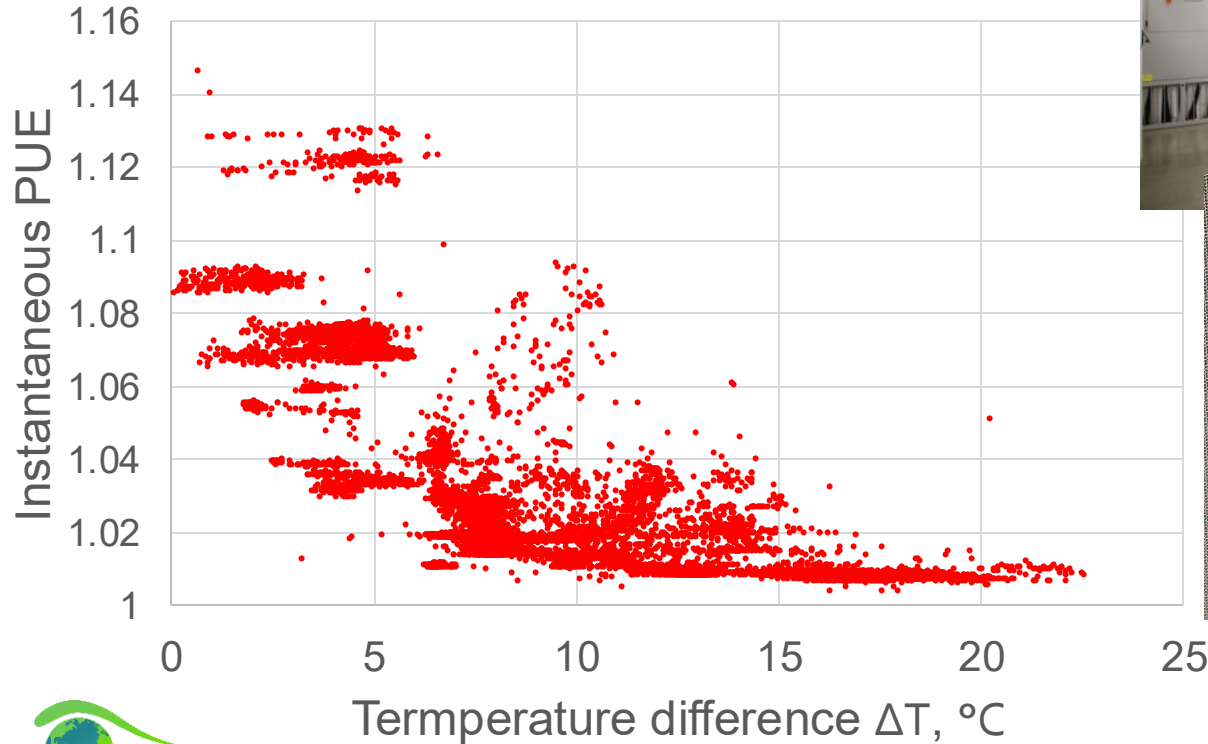
The BodenType DC – an EU funded project for efficient and low cost DC.



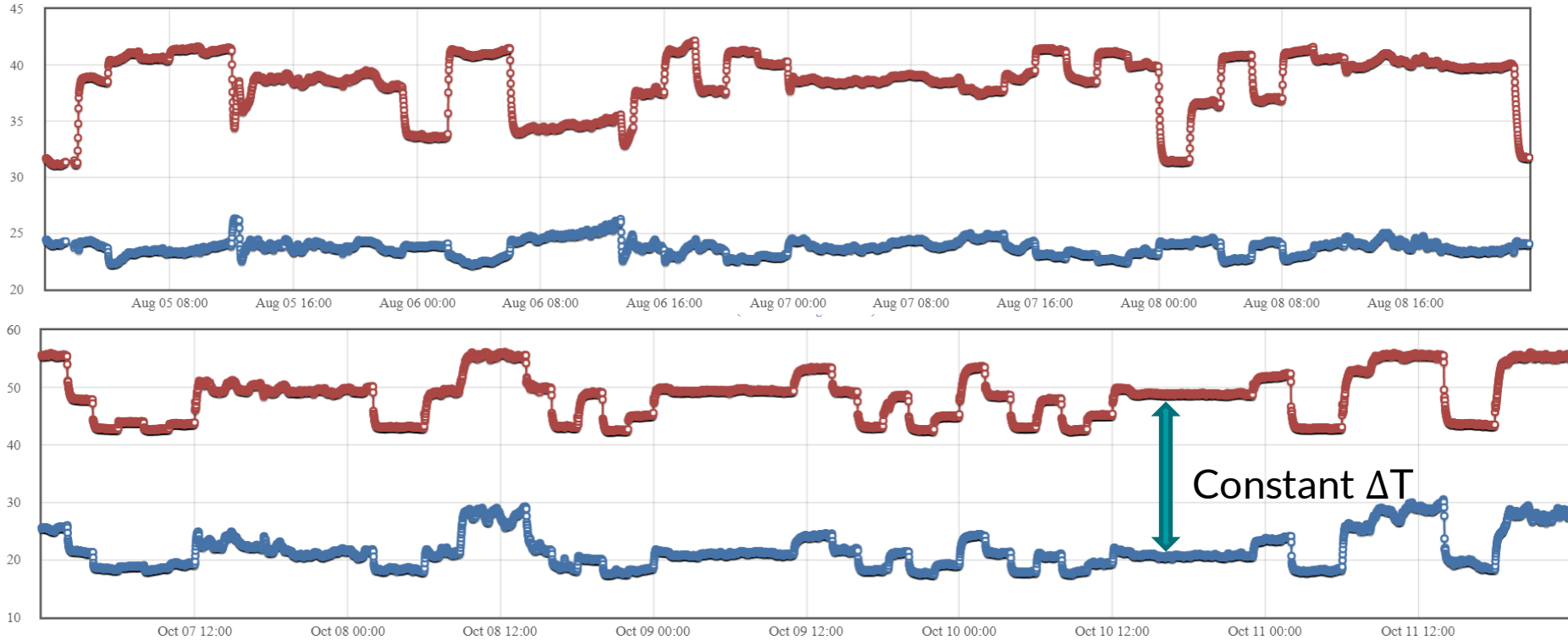
GA 768875



OCP CPU based systems (150kW)

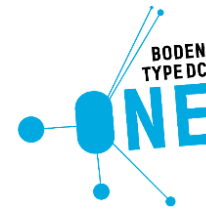


Results of targeted air flow thermal management.

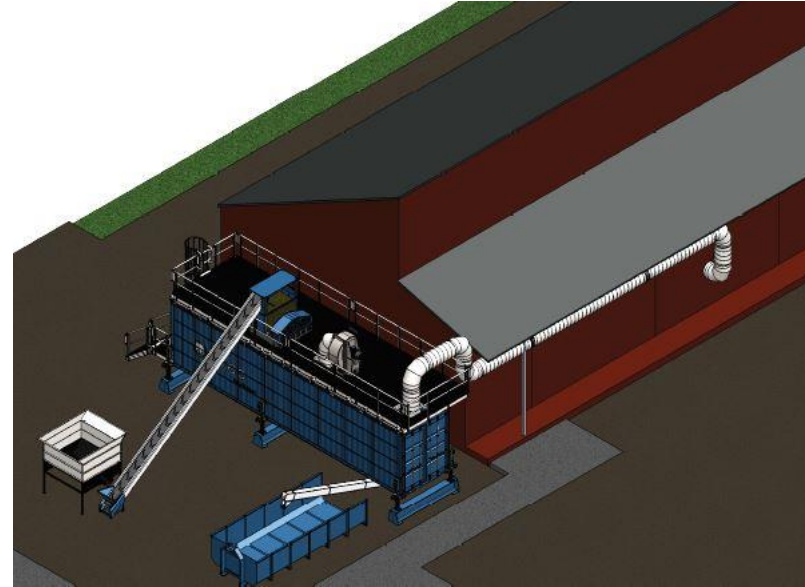


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°768875.

Assessing a use of DC waste heat.



GA 768875



Interreg
Nord
Europeiska regionala utvecklingsfonden



RI
SE

GPUs in POD2 used for biomass drying.

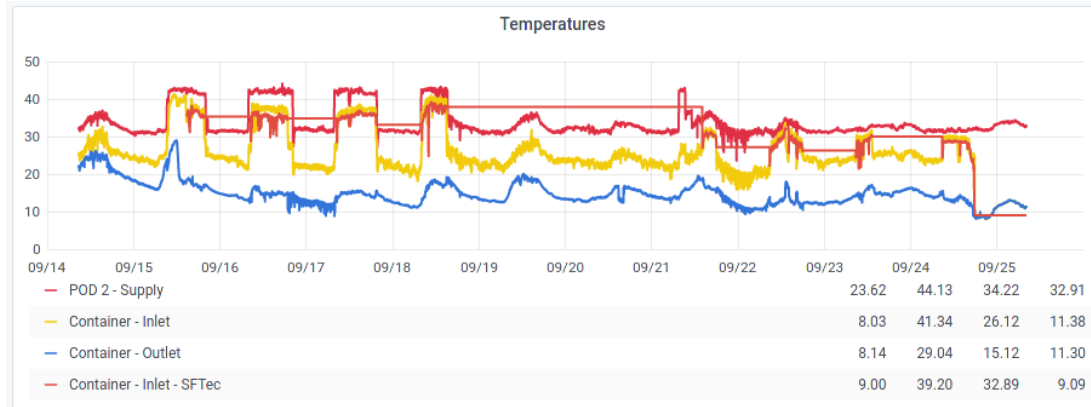


GA 768875



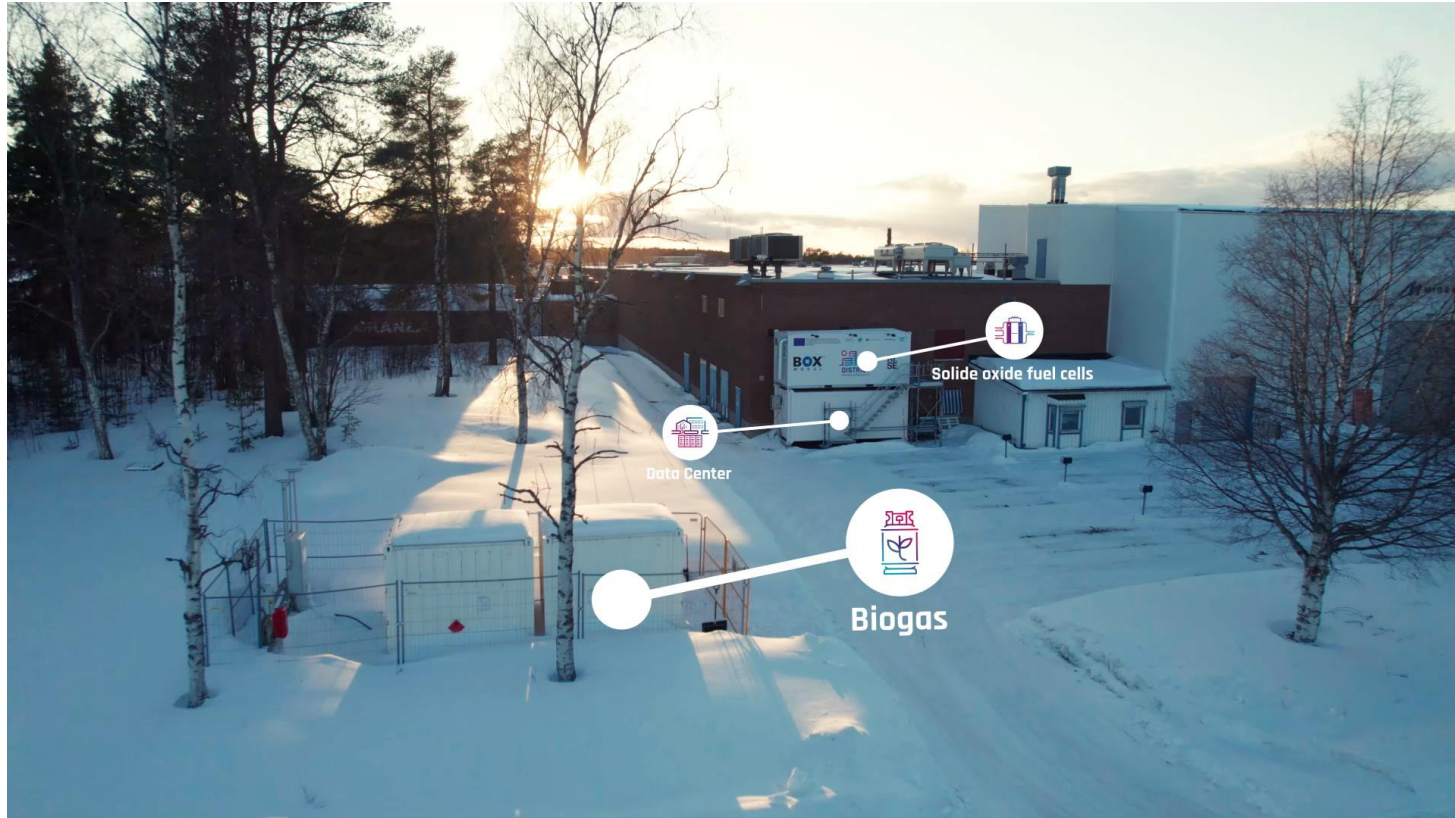
Conclusions

- 8% reduction of moisture content
- 42 % **ERF** (Energy Reuse Factor)
- 8 year for return of investment



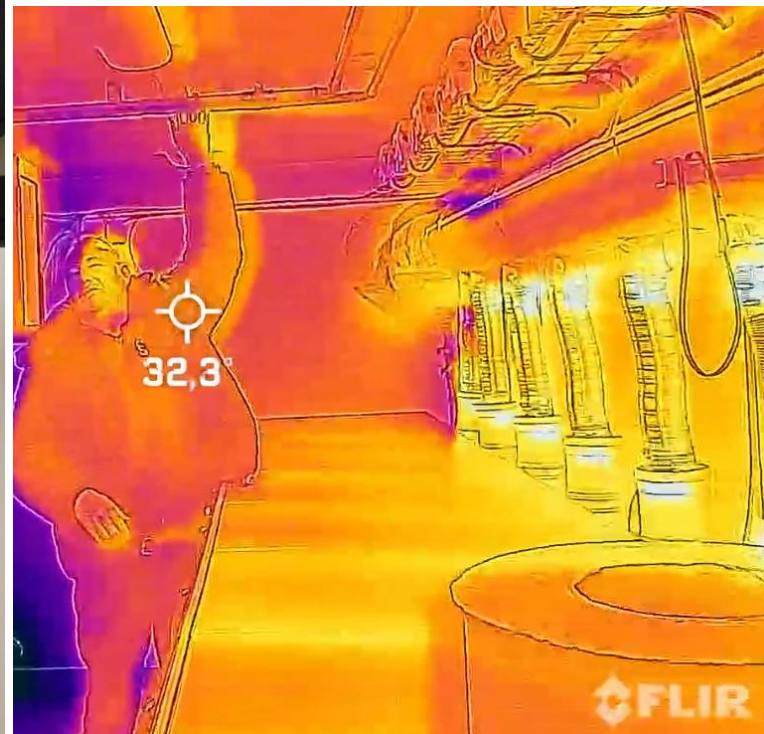
Demonstration site

LULEÅ (Sweden)

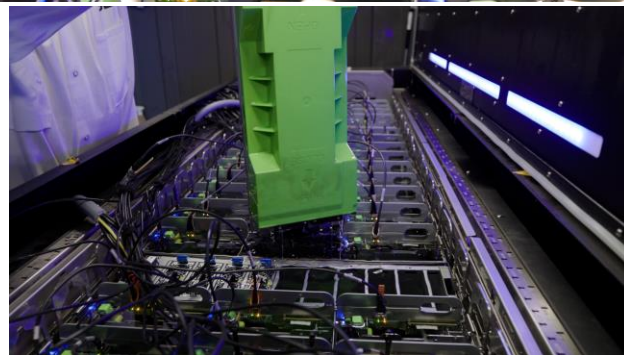
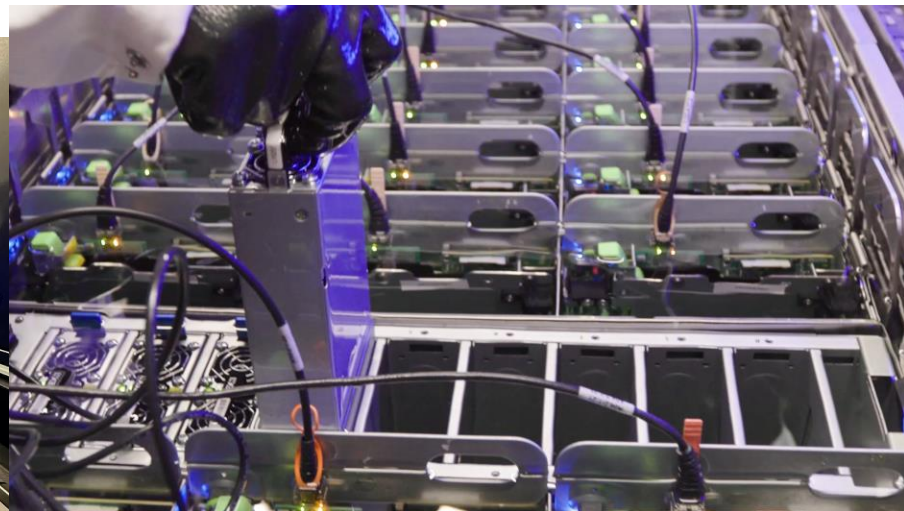
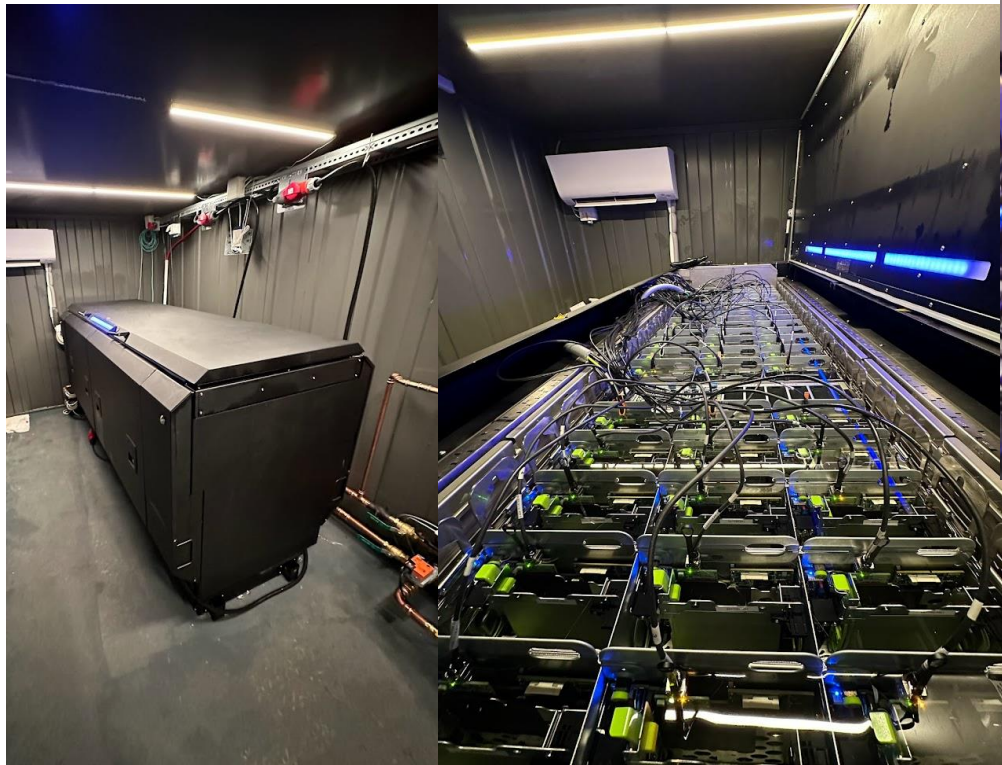


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°857801

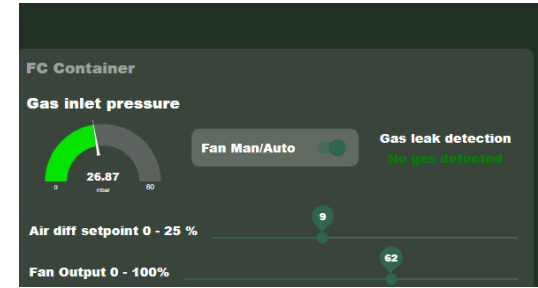
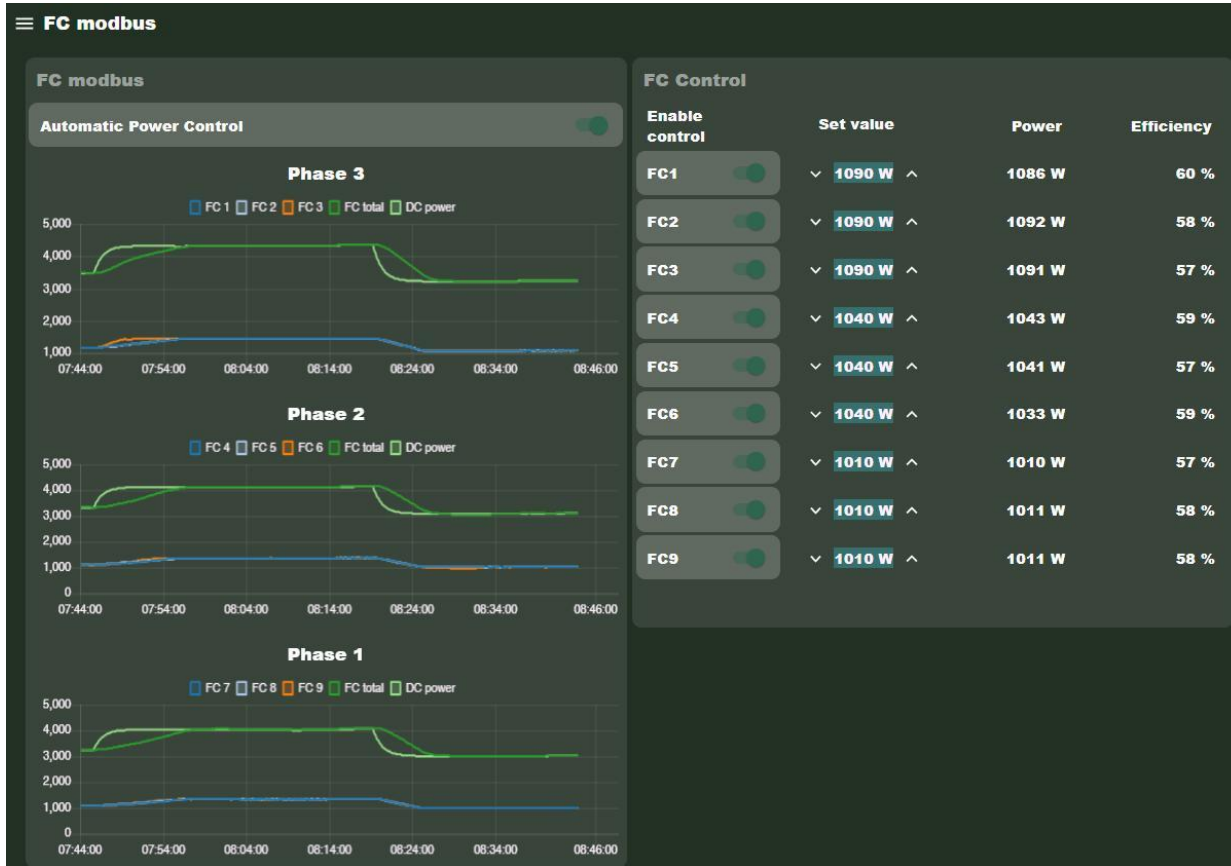
Inside the Fuel Cell container



Inside the Data Center container

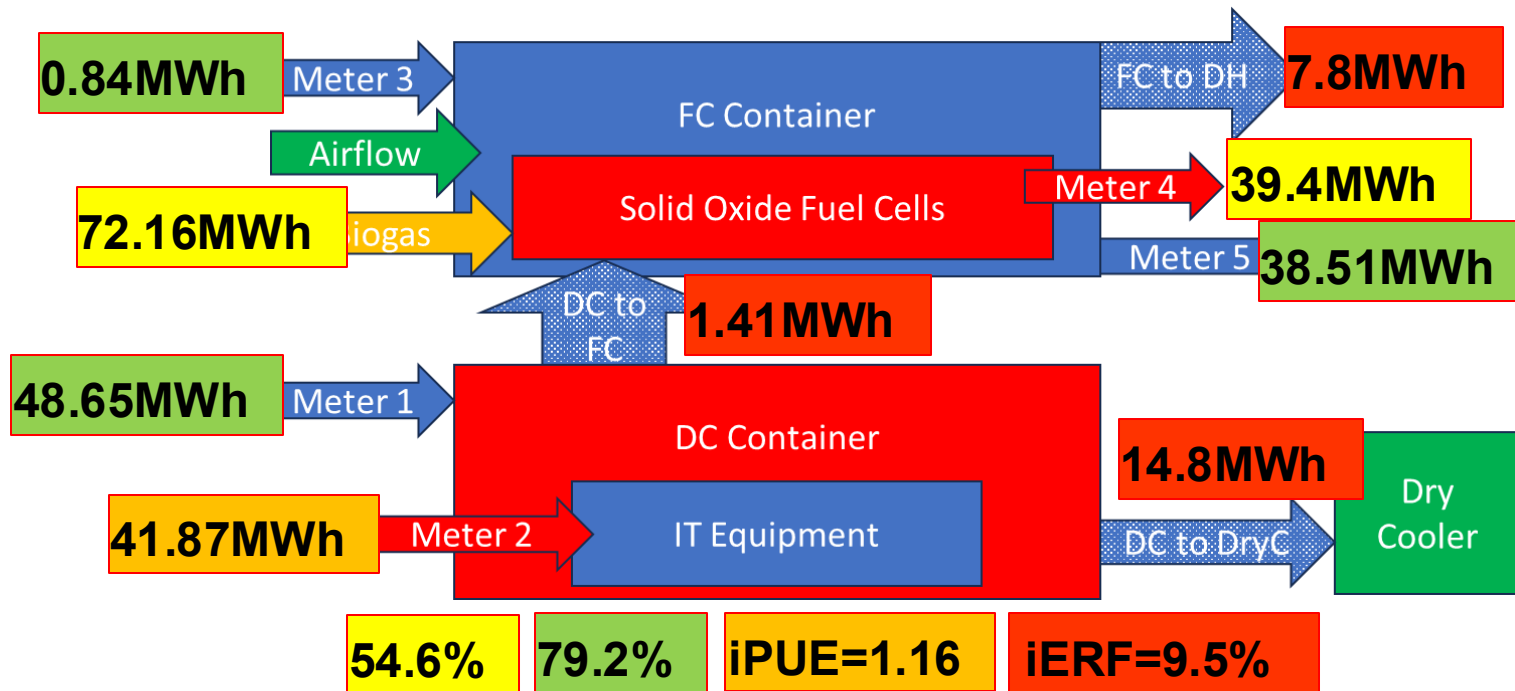


Fuel cells control (using node red)



Energy flows during monitored period.

Complete operational datasets from 11/01/2023 to 16/06/2023



Some points of discussion

- Holistic air-cooling control can slow all fans down and take advantage of the cube law for their energy consumption. Use outside air to supply servers at the lower end of ASHRAE temperature if available.
- Taking control of server fans centrally is now more possible with developments of openBMC and the ability to create bespoke BIOS settings.
- Immersion systems can reject heat to supply at temperatures of up to 40°C (after losses) for low density with air-cooled heat sinks operating with a tank setpoint of 45°C.
- Solid oxide fuel cells can operate at >55% electrical efficiency with biogas. Sweet spot of operation around 1200-1300W per FC for nearly 60% efficiency, but heat recovery reduced, but can still recover heat at over 60 °C.
- **General discussion points for the containerised demo:** edge, island mode, partial hydrogen solution, noise levels, urban deployment, reduced load on electrical grid in urban areas.

Thanks for listening.

Dr Jon Summers
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Thanks also to my colleagues at the RISE ICE datacenter and partners on the WEDISTRICK project.

Future District Heating: The Role of Data Centers in Luleå's Energy Mix

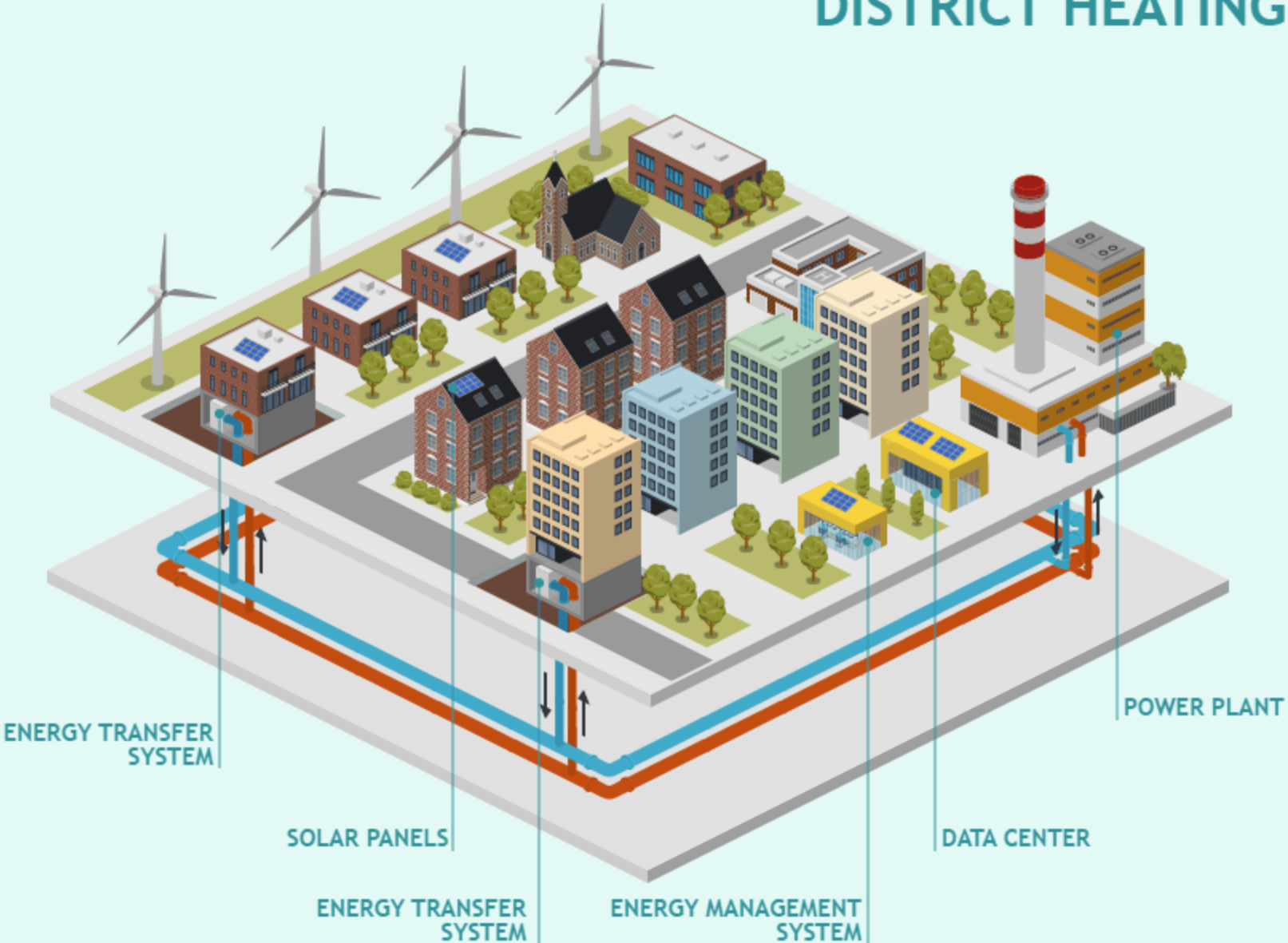


FREDRIK ENGSTRÖM, PhD



BUSINESS AREA MANAGER
DISTRICT HEATING AND COOLING, LULEÅ ENERGI AB

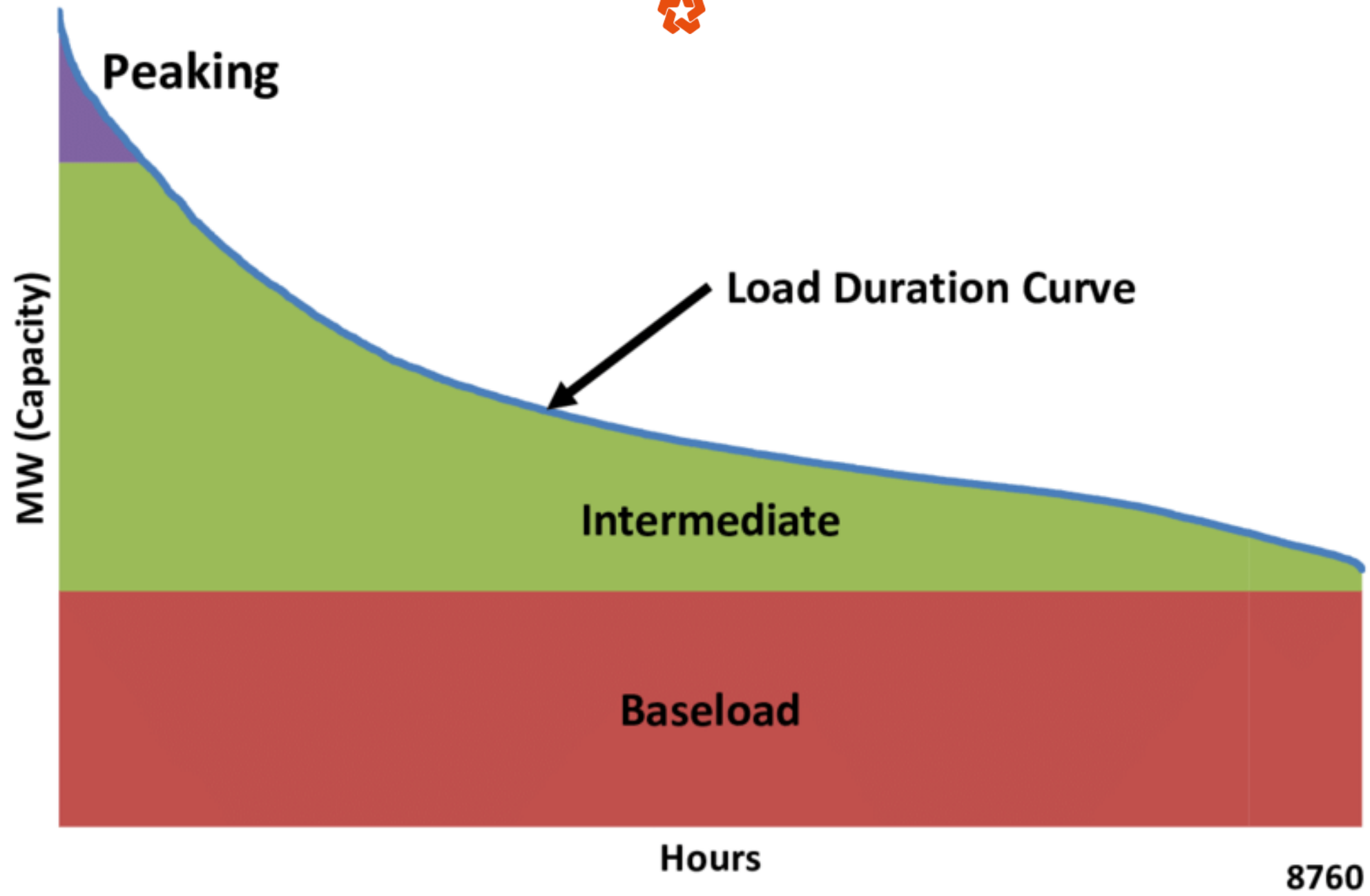
DISTRICT HEATING





900 GWh - 90 % 74-99 °C
30-300 MW 40-55 °C







The Green Transition

TALGA - ANODFABRIK FÖR BATTERIER



UNIPER - VÄTGASHUB BOTHNIALÄNKEN H2



DATA CENTERS

- Supply temp?
- Heat pump?
- Duration curve – hours and price?
- Position in grid?
- Return heat?

SSAB/VATTENFALL - HYBRIT TESTANLÄGGNING



LKAB MINERALS - CIRKULÄR INDUSTRIPARK



SSAB - ELEKTROSTÅLVERK



An aerial night photograph of Luleå, Sweden, showing a dense urban area with illuminated buildings and a large body of water in the background. A full moon is visible in the dark blue sky. The word 'Tack!' is written in a large, white, elegant script font across the center of the image.

Tack!

FREDRIK ENGSTRÖM • LULEÅ ENERGI

E STADSHOTELLET LULEÅ

Waste to Value: Heat Transfer Innovations for the AI Era

Gemma Reeves; Alfa Laval

Alfa Laval at a glance

Founded in

1883

140 years of experience in engineering and innovation

Key technologies

3

- Heat transfer
- Separation
- Fluid handling

Employees

22,300+

Operating in over 100 countries

Patents

4,200+

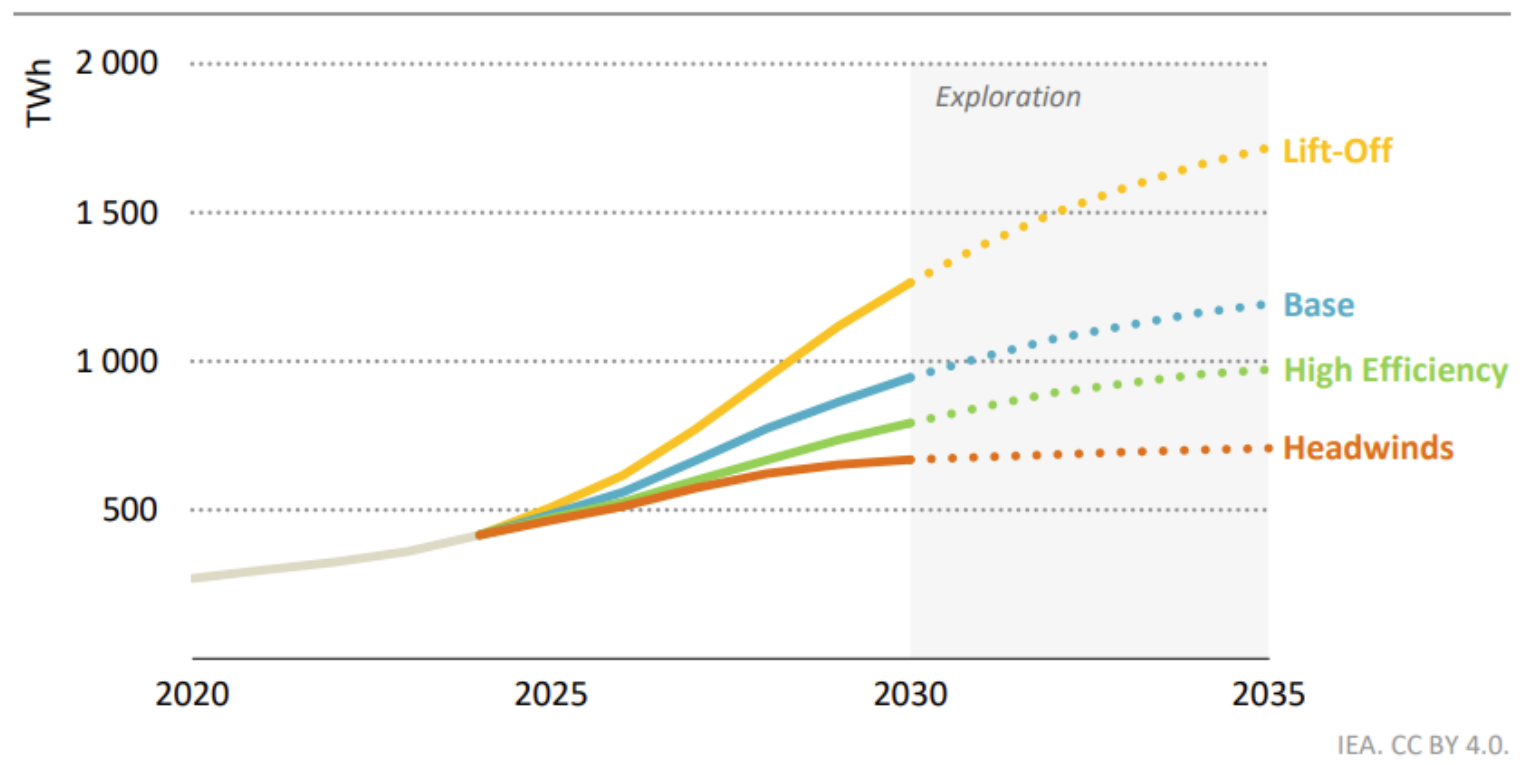
Continuous investment in R&D



Core Development and R&D are Key

AI is Reshaping Energy Demand

Figure 2.14 ▶ Global data centre electricity consumption by sensitivity case, 2020-2035



The outlook for data centre electricity demand is highly uncertain, driven by factors including efficiency improvements, AI uptake and potential energy sector bottlenecks

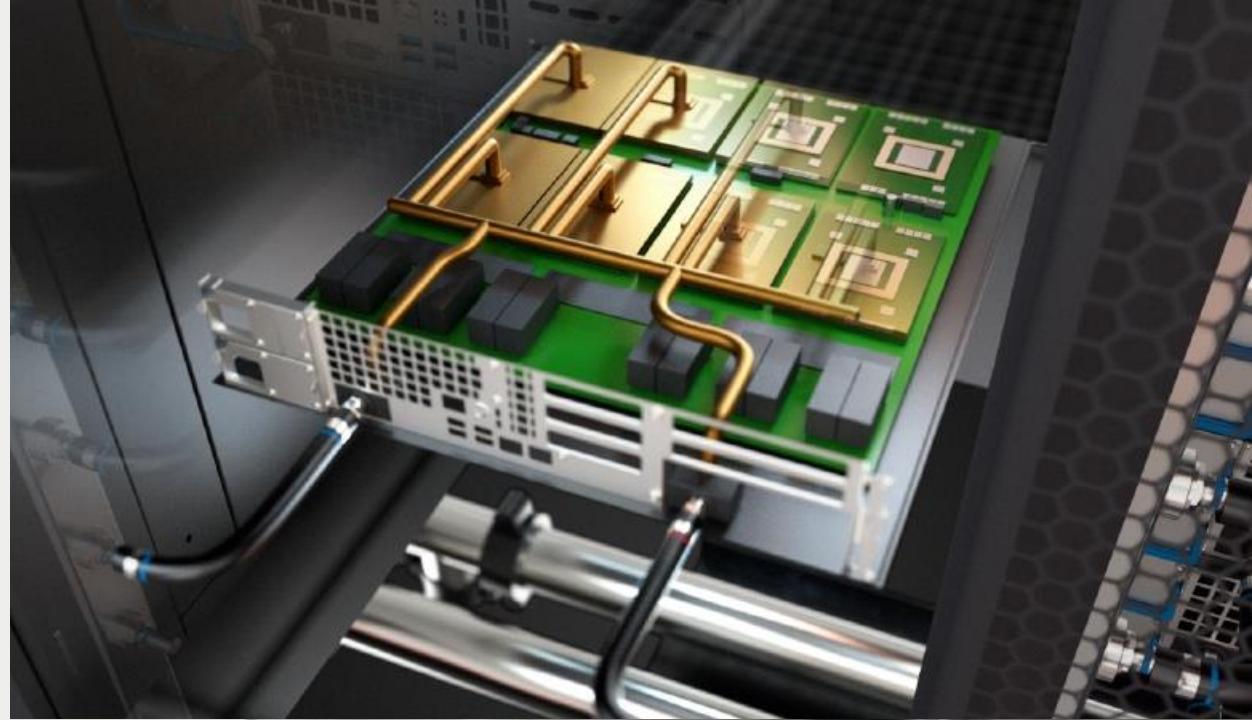
AI workloads are driving exponential heat generation in data centres

Source: IEA, Report "Energy and AI" from April 2025

Liquid Cooling Enables Heat Reuse

Direct-to-chip, immersion, and hybrid architectures

- 3–4× more efficient heat capture than air cooling.
- Higher outlet temperatures (40–60°C) = usable waste heat.
- Lowers PUE, WUE, and operating costs
- Accelerates compliance with sustainability mandates.
- Heat Transfer technology no barrier



Overview of Alfa Laval positions



- Plate heat exchanger as interchanger with an open or closed cooling tower
- Plate heat exchanger, pump and filter for sea water/lake/river cooling
- Dry coolers and hybrid coolers for heat rejection
- Plate heat exchangers for heat reuse connection and in heat pumps
- Plate heat exchangers in CDUs

Heat Transfer Technologies for the AI era

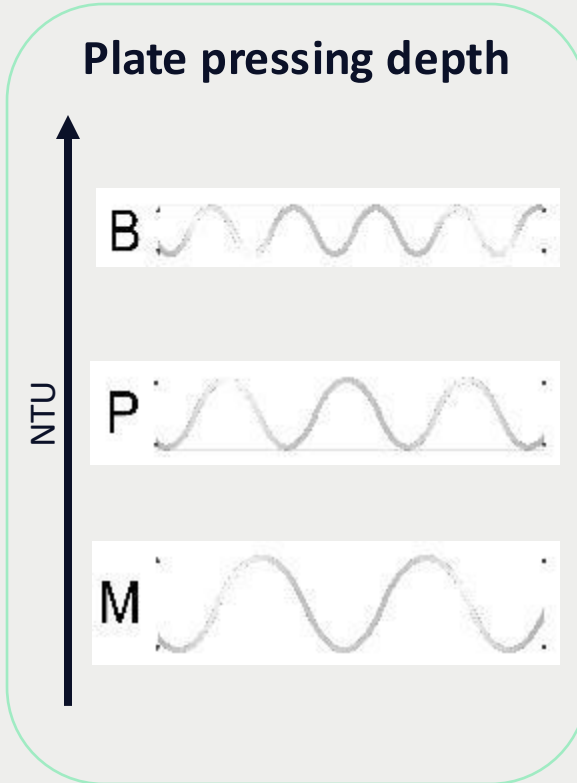
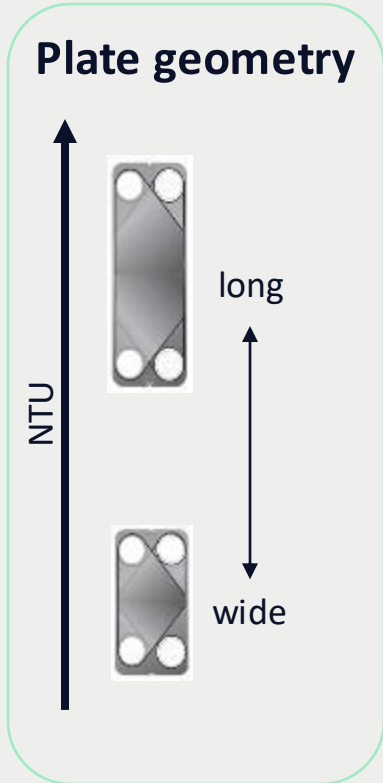
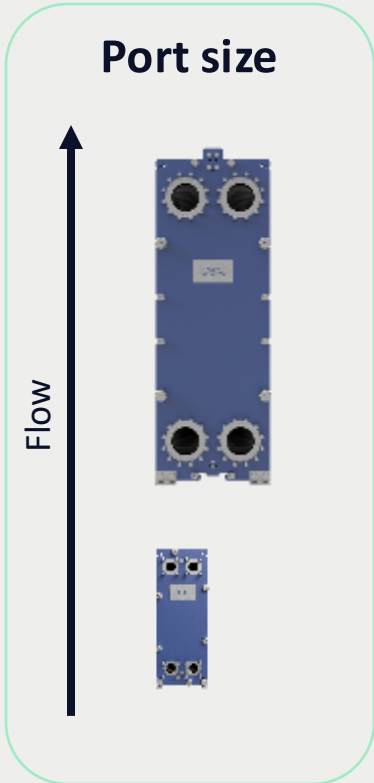




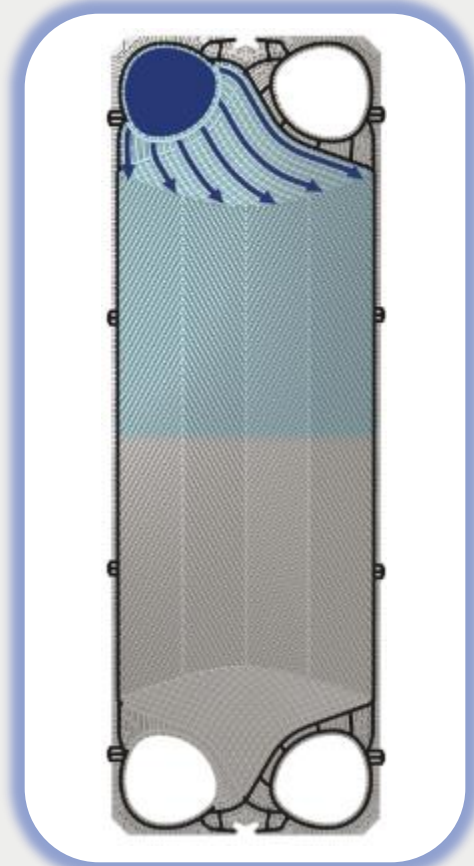


Plate design

-  **Asymmetric Channels**
Optimises efficiency with varying liquid flow/media
-  **Curve-flow Distribution**
Improves media flow and minimizes risk of fouling
-  **Omega Ports**
Enhances media flow and thermal efficiency
-  **Offset gasket grooves**
Ensures plate utilization for maximum heat transfer efficiency

For increased heat transfer efficiency



- ✓ Minimising the Pressure drop lost in the ports and connections.
- ✓ Less fouling in the plates.
- ✓ Improved K value resulting in less material - less carbon.
- ✓ Smaller footprint.
- ✓ Sustainable performance throughout the lifecycle
- ✓ Patented Efficiency design features



Innovations Specific to Liquid Cooling

DtC and Immersion; One phase and two phase



General Innovations



Asymmetric
Wide/narrow channel to optimise efficiency

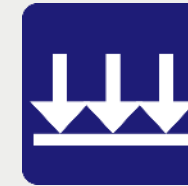


ValuePlus
The flexibility to alter the connections and channels to a client's unique needs



AlfaNova
Option for units in 100% Stainless steel

Specific Two Phase Benefits



PressureSecure
Unparalleled strength for demand duties



REFuture
A future-proof investment in tomorrow refrigerants



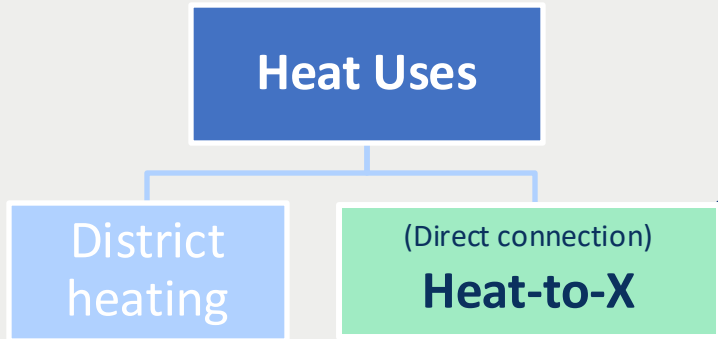
IceSafe
Controlled non-destructive freezing

Value Creation Through Heat Reuse

- Sell or donate heat to district networks or nearby industry
- Support local communities and reduce grid pressure
- Lower Total Cost of Ownership through energy recapture
- Strengthen ESG profile and brand



Heat Applications Beyond District Heating



District heating is considered the default option for heat reuse BUT..

That is possible only in 13% of Europe today. The main design parameter for district heating are

- **Temperature**
- **Distance** to connection point
- Heat competitive **price**.

In this case a dedicated connection to the heat user is implemented. The heat user can be the data center and/or a user in its proximity.

The main parameter to verify if there is a business case is the **price** of the heat delivered from the data center compared to alternative solutions for the user.

Application	Description
Heat-to-Power	Stirling ORC Thermoelectric generators Thermo-acoustic engine Evaporative Salinity Gradient Absorption Ammonia-CO2 with Turbines Phase Change Materials (PCME)
Heat-to-Cooling	Liquid desiccant system Heat Ejector cycles Thermoacoustic refrigeration Absorption Refrigeration Cycle (ARC)
Heat-to-Dehumidification	Dehumidification, Adsorption Dehumidifier Solid Desiccant Dehumidification Liquid desiccant
Heat-to-Carbon capture	Carbon Capture (Adsorption Based) Carbon Capture Absorption based (MEA) Water Harvest Ads. Solid desiccant (HVAC+Water)
Heat-to-Biomass	Drying of seaweed Drying of wood chips Algae Growth Drying sewage sludge
Heat-to-Food	Fish Farming Food processing: Acting as a heat source or cool source Algae Growth: Cosmetics or agri-food Greenhouses
Heat-to-Water Treatment	Waste water treatment plants: Processing Waste water treatment plants: Drying (cake) Desalination

Cooling -

- > Heat ejectors
- > Absorption/Adsorption
- > ~0.7 COP
- > Cost ~200% equivalent thermal chiller

Power -

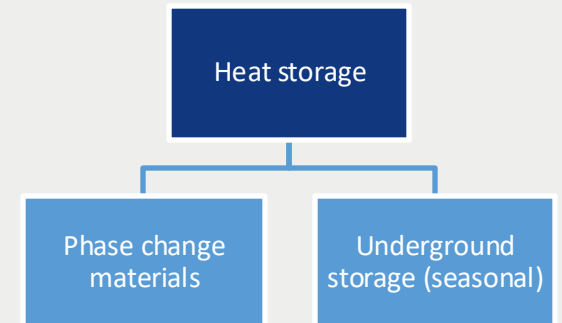
- > **Thermo-Electric Generator**
- > 0.01 COP at DC temps
- > + recovered lower-grade heat
- > Cost ~100 €/kW
- > **ORC** - 0.03 COP at DC temps
- > + recovered lower-grade heat
- > Cost ~200% equivalent thermal chiller

Dehumidification / Water Gener. / Carbon Capture -

- > Dessicant - Relatively inexpensive
- > Adsorption - 0.7 COP
- > Cost - Relatively low (to be detailed)

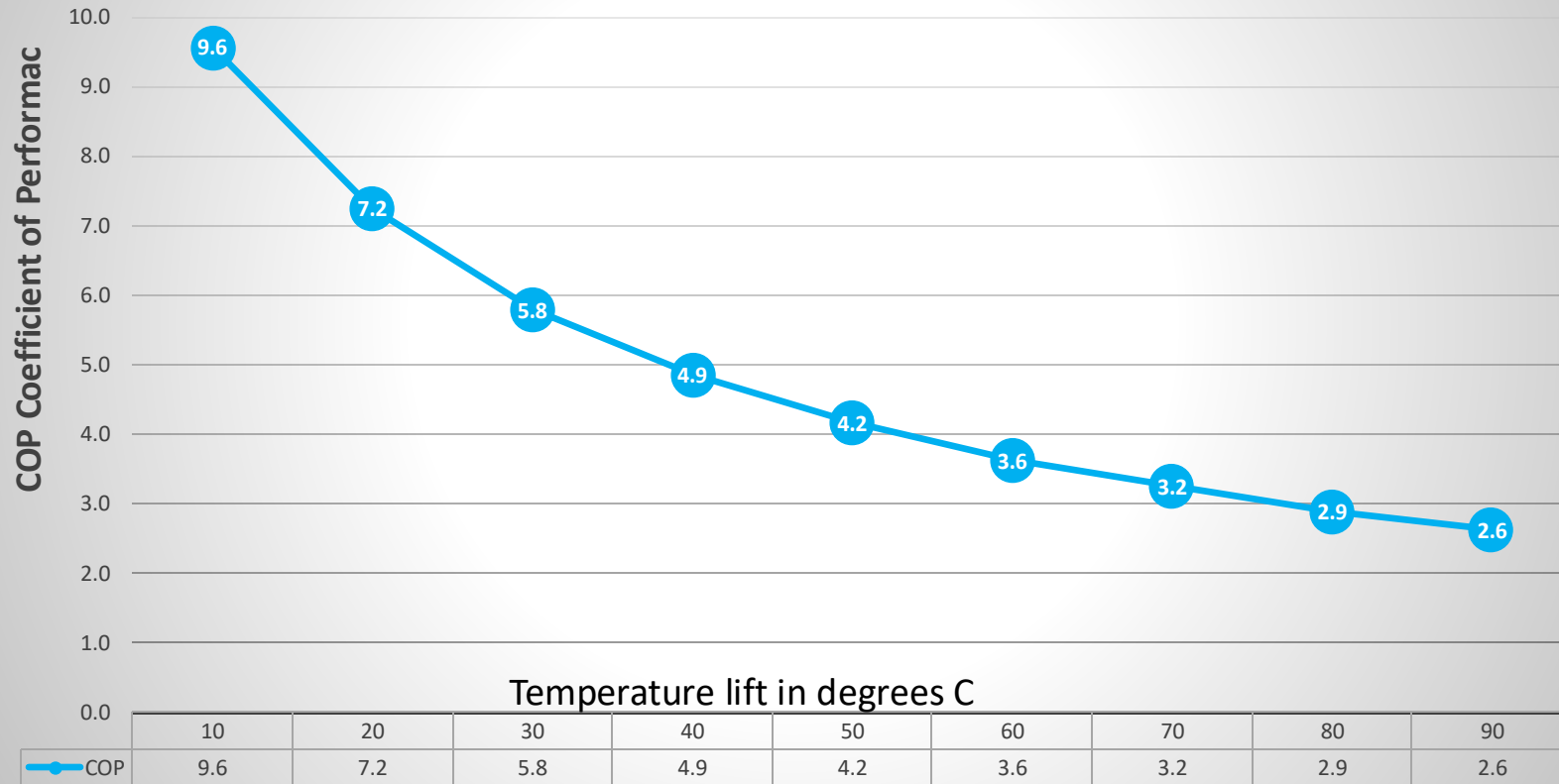
Heat Storage

Heat demand is often variable. The options for heat storage, short term or seasonal.



Heat reuse-COP

Temperature lift from waste heat source to demanded temperature



Why is heat capture and re-use so important?

Heat Source-to-Heat demand:
1K lift reduction = 2% efficiency increase

Data Centres as Energy Hubs

- AI-ready infrastructure that is circular, efficient, and connected
- Waste heat becomes a resource, not a problem
- Heat transfer technology plays a central role in enabling this shift



Pioneering Positive Impact

The European Landscape for Data Centre Cooling & Sustainability

Raúl Álvarez

OCP European Market Development Manager

HEATWISE Pilot Event

19/3/2026

Meeting the Market and Shaping the Future

INTERNATIONAL COMMUNITY

Hyperscale Centric



OPEN INNOVATION

- Hyperscale-proven designs
- Trusted IP model
- Specs, best practices
- Rapid technology adoption
- Multi-vendor ecosystems
- Future technologies

The OCP Open Data Center Ecosystem Vision

Strategic Domains: **AI DCs, Cloud DCs, and the AI Computing Continuum**



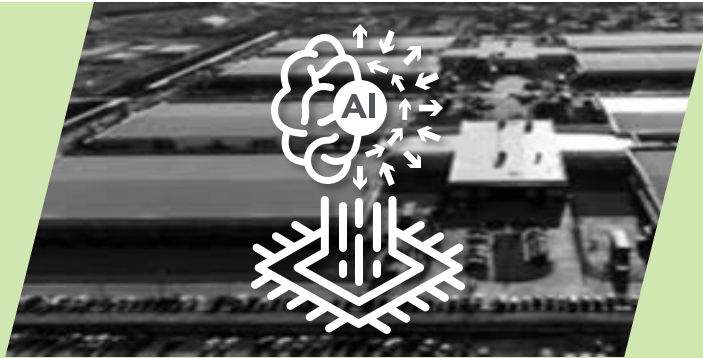
From Hyperscale to Regional

Technology Scope: **Facilities & Physical Infrastructure, IT Infrastructure, and Systems Management**



From Grid to Chip

Strategic OCP Domains



AI DCs

- GW-scale AI Factories
- Neocloud AI DCs
- Wholesale Colo Provider
- Power Co-Generation

- Large Scale Training
- High Density Clusters
- Fungible DCs



Cloud DCs

- Hyperscale Centralized Cloud
- Other T1/T2 Cloud DCs
- Colocation Provider

- Efficiency of Scale
- Integrate AI
- Automation



AI Computing Continuum

- Regional Cloud Sites
- Colocation Providers
- Enterprise sites
- Industrial sites
- Telco Points of Presence

- Efficient Inference
- AI Sovereignty
- Smaller Scale Architectures

OCP's 15+ Year Journey



2011

- 5 founding members
- 200+ people at first summit
- Facebook open-sources initial hardware specs



2014

- 150+ members
- 2500+ at all Summits
- Adds: DC full stack, network, storage, rack, silicon/GPUs
- Facebook claims saving \$2B over 3y thanks to OCP open source



2018

- 200+ members
- 3800+ at all Summits
- Adds to physical facilities, cooling environments, security FTS, OCP Ready
- ~ \$11B OCP-recognized equipment revenue



2022

- 300+ members
- 3500+ at OCP Summit
- Adds: Open Chiplet Economy, photonics, OCP Experience Centers, FTI
- ~\$27B OCP-recognized equipment revenue



2025

- 500+ members
- 17,500+ est. at all Summits
- ~ \$132B OCP-recognized equipment revenue
- Open Systems for AI strategic initiative growing OCP as the premiere AI infra community

Sample of OCP's Diverse Membership

Cloud   Microsoft  Google  Alibaba Group  Uber  Tencent 腾讯  Baidu 百度  amazon  ORACLE  YAHOO! JAPAN  ByteDance 

Neocloud / AI  OpenAI  Scaleway  DENVR  NEBIUS  OVHcloud  FarmGPU  Lambda  Crusoe

Co-location  VANTAGE DATA CENTERS  Aligned  STELLIUM  CONAPTO COLOCATION MADE IN SWEDEN  DataVita  maincubes  Global Switch  Princeton DG  Start Campus  edged  Borealis DATA CENTER  KAO DATA

System Integrators  STORDIS  vesper  QARNOT  hyve solutions  CircleB  Parler Cloud Technologies  CTC  DELTA  RACK RENEW high performance, low carbon  CELERIS

DC Equipment  DELTA  FATON  VERTIV  Schneider Electric  legrand  ABB  RITTAL  Advanced Energy  HARTING  Danfoss

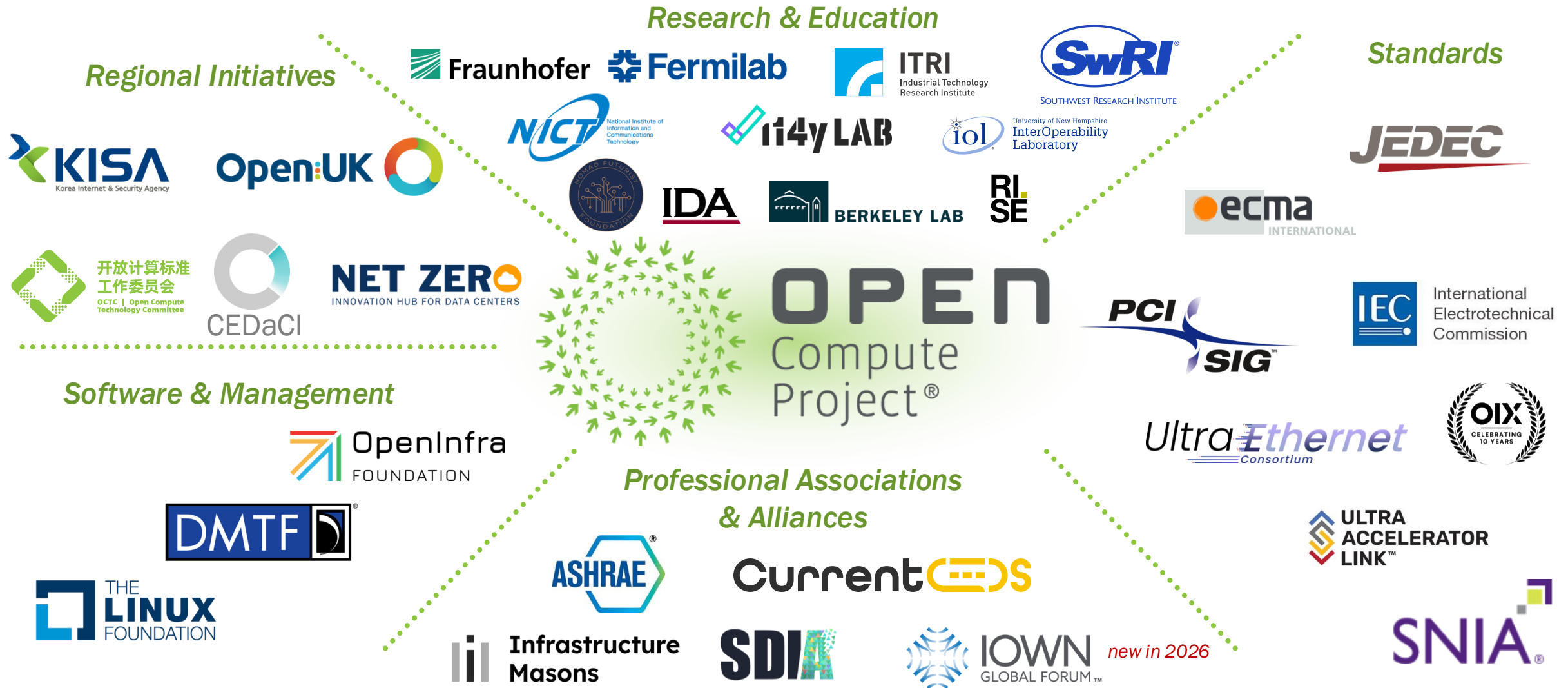
DC Cooling  Dow  Castrol  Shell  Valvoline  Parker  CoolIT systems  liquidstack  Auras  LiquidCool SOLUTIONS  EJN  SOLTEXT  submer

IT Systems  MITAC  wiwynn  SUPERMICRO  Hewlett Packard Enterprise  Accton  DELL  IEIT SYSTEMS  Celestica  FOXCONN  flex  ARISTA  CISCO

IT Component  NVIDIA  arm  AMPERE  SAMSUNG  SK hynix  intel  AMD  MARVELL  Micron  AsteraLabs  NOKIA  SEAGATE  BROADCOM  ami

Startups  ACCELSIUS  baya Systems  ZUTACORE  SUNRISE memory  MemVerge  SEGUENTE  LIGHTELLIGENCE  WOODEN DATA CENTER  XSCAPE PHOTONICS  SAPEON

Amplifying OCP Reach Through Alliances



OCP: A Collaborative Community Effort

INCUBATOR

COMMUNITY PROJECTS

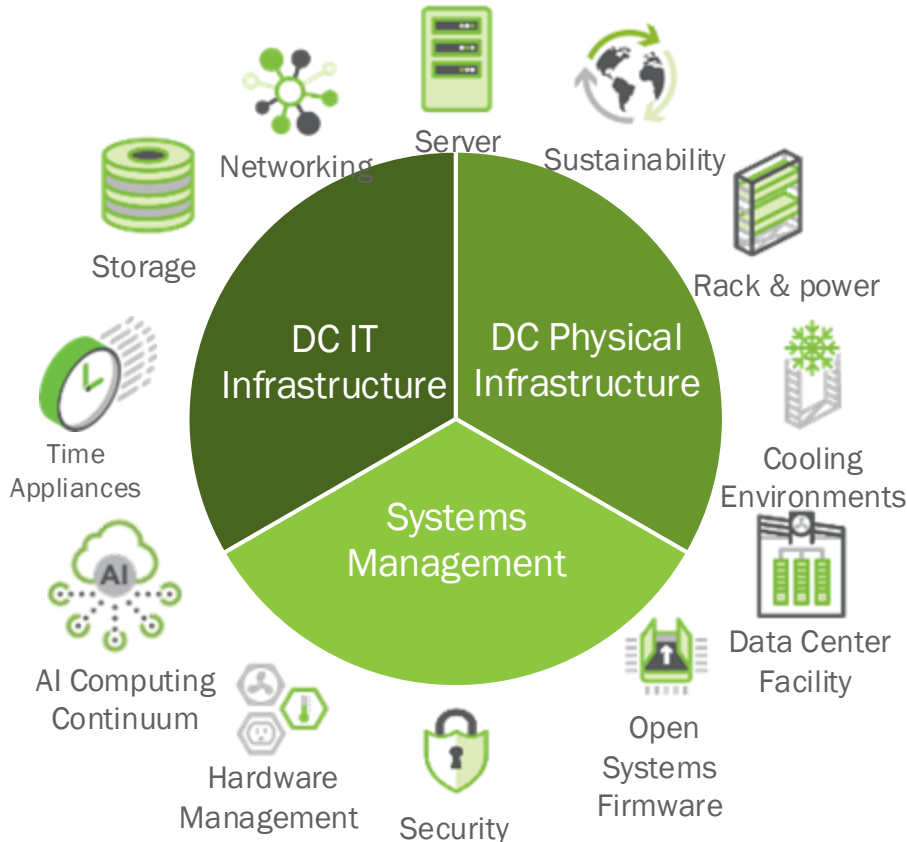
NEW INITIATIVES

EMERGING MARKETS

Open Systems for AI “umbrella” Strategic Initiative

Open DC for AI

Open Cluster Designs for AI



TECHNOLOGY



Power Distribution



AI Networking

MARKETS



Quantum



Neocloud



Photonics



Chiplets

OCP MARKETPLACE

Marketplace

The OCP Marketplace is a dynamic ecosystem where members from across the OCP Community converge to offer a diverse variety of hardware products, solutions, facilities and services that address the unique needs of OCP. The collaborative nature of the OCP Marketplace ensures access to a wide range of options, allowing potential buyers to tailor their infrastructure to meet their specific needs and preferences.

EXPLORE OUR MARKETPLACE SEGMENTS



RECOGNITION PROGRAMS

Security | Facilities



OCP S.A.F.E.



OCP READY™

Product

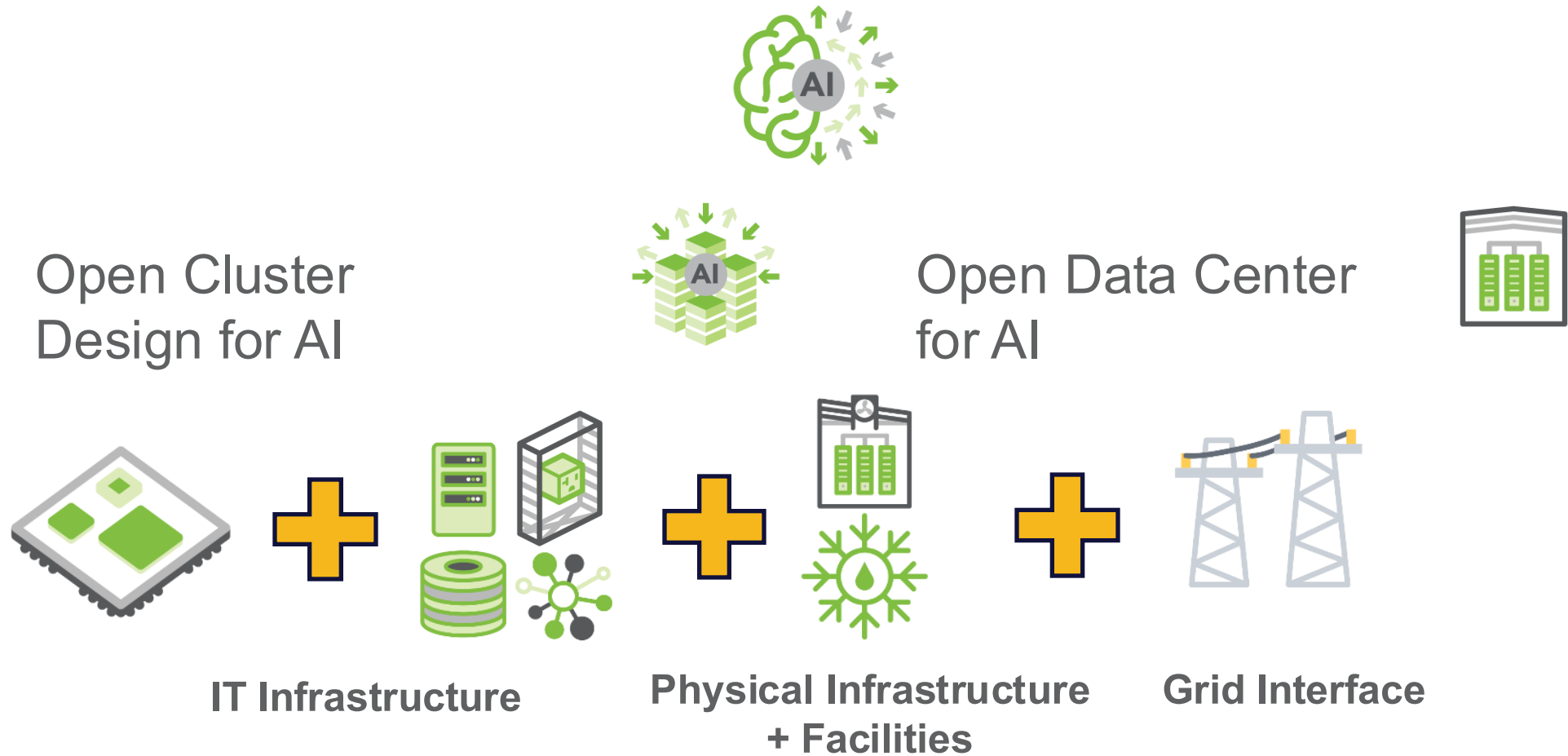


OCP ACCEPTED



OCP INSPIRED™

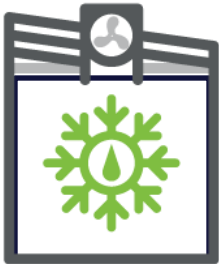
Open Systems For AI Umbrella Initiative



Open Data Center for AI Strategic Initiative



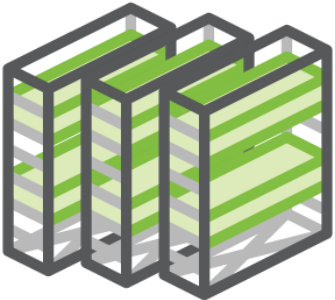
Power



Cooling



Grid

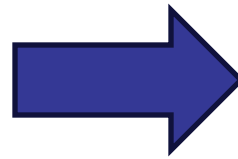
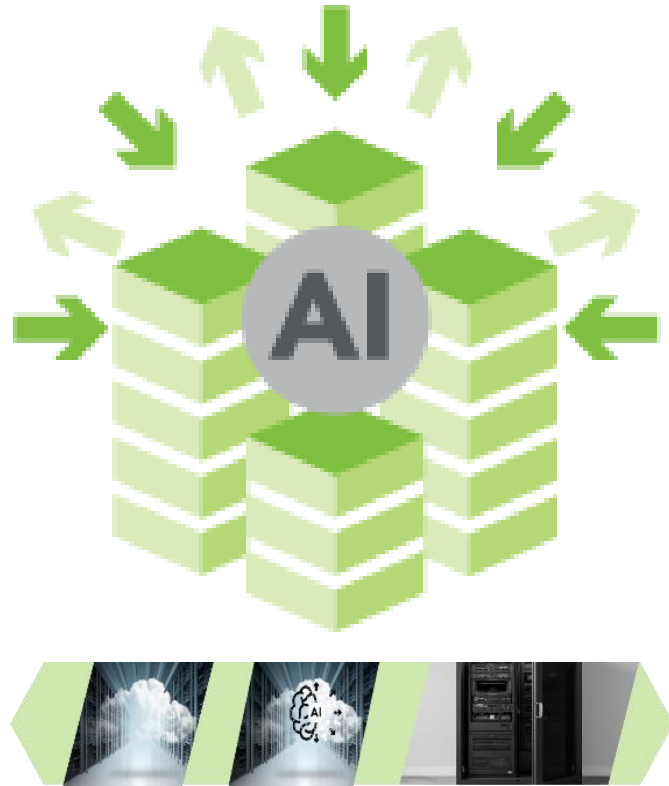
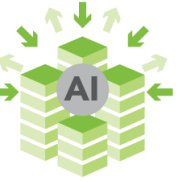


Mechanical



Management
Telemetry

Open Cluster Design for AI Strategic Initiative



Designs

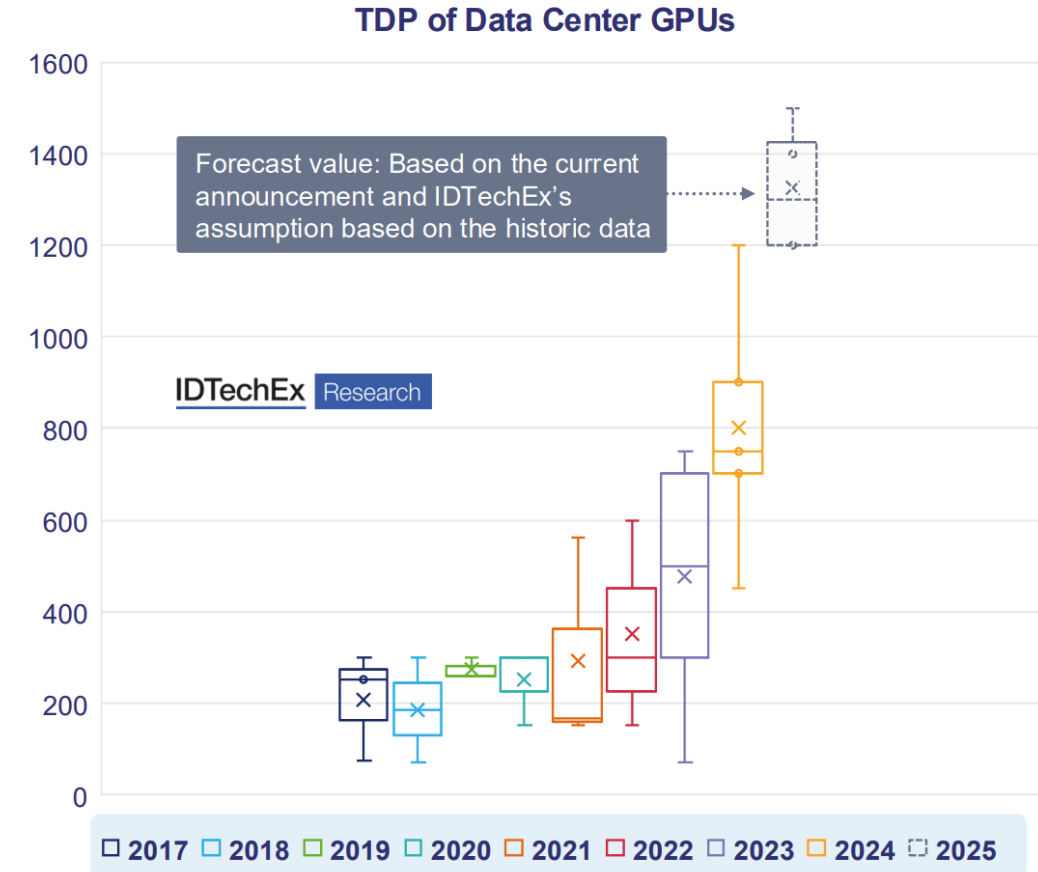
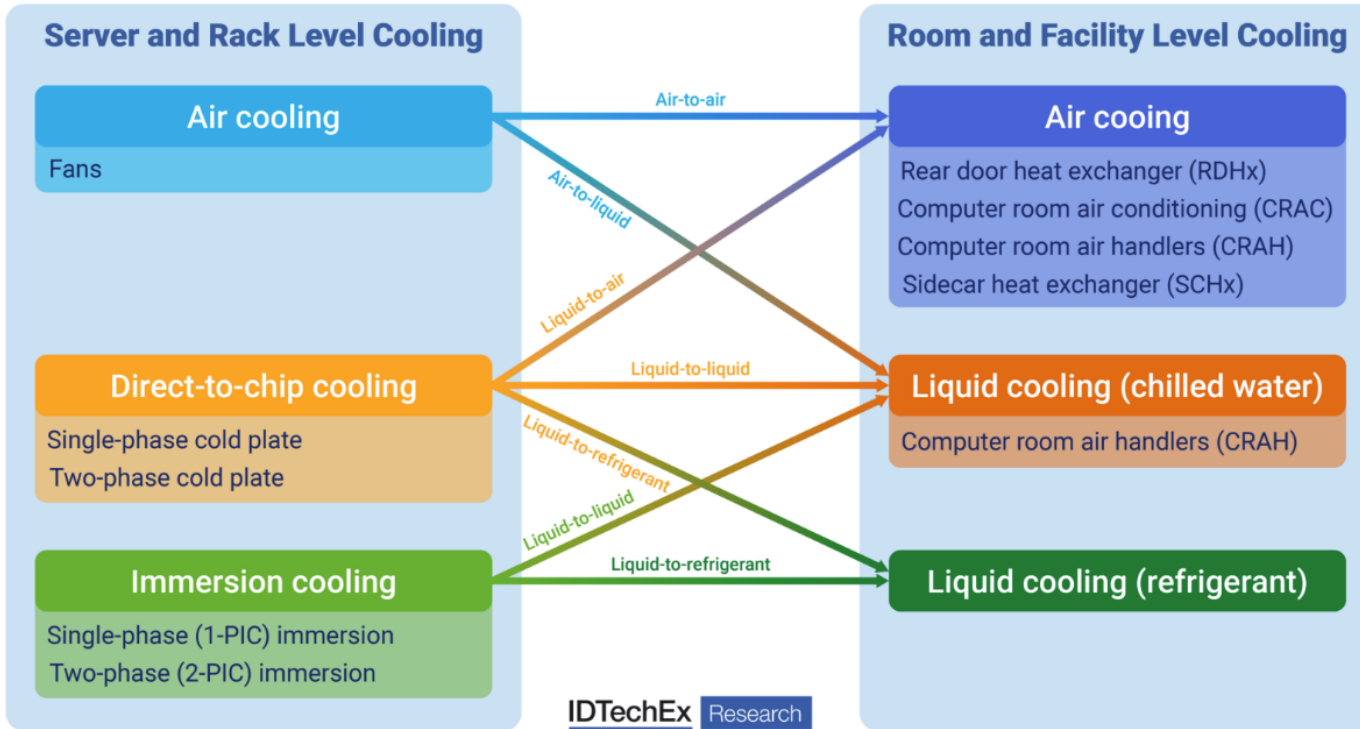


Guidelines

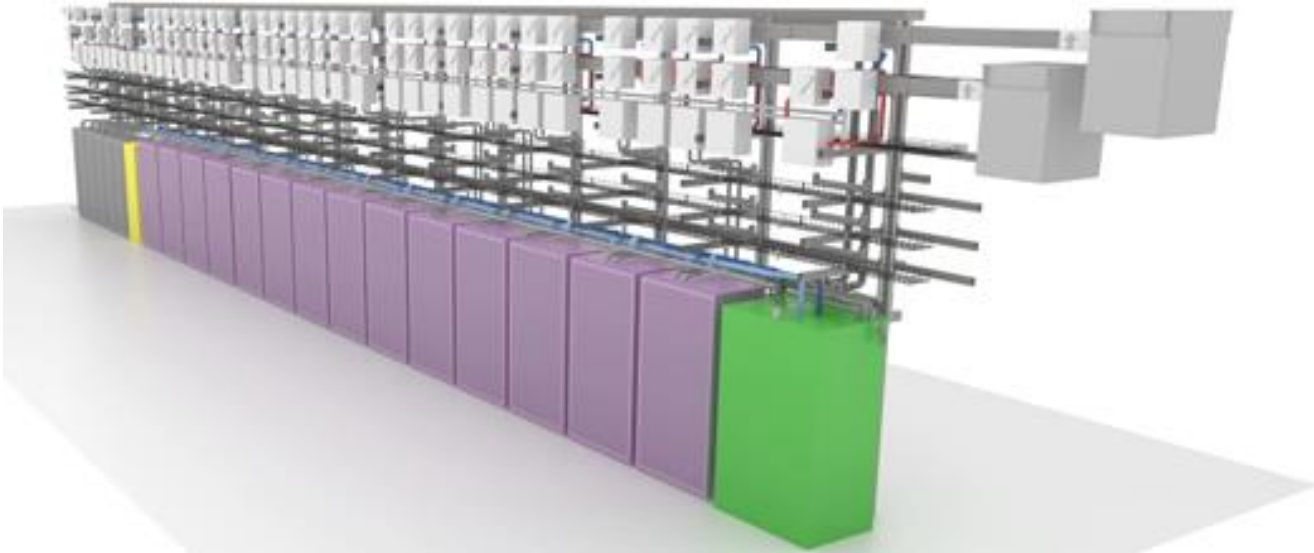
Enabling Liquid Cooling

Following the industry trends

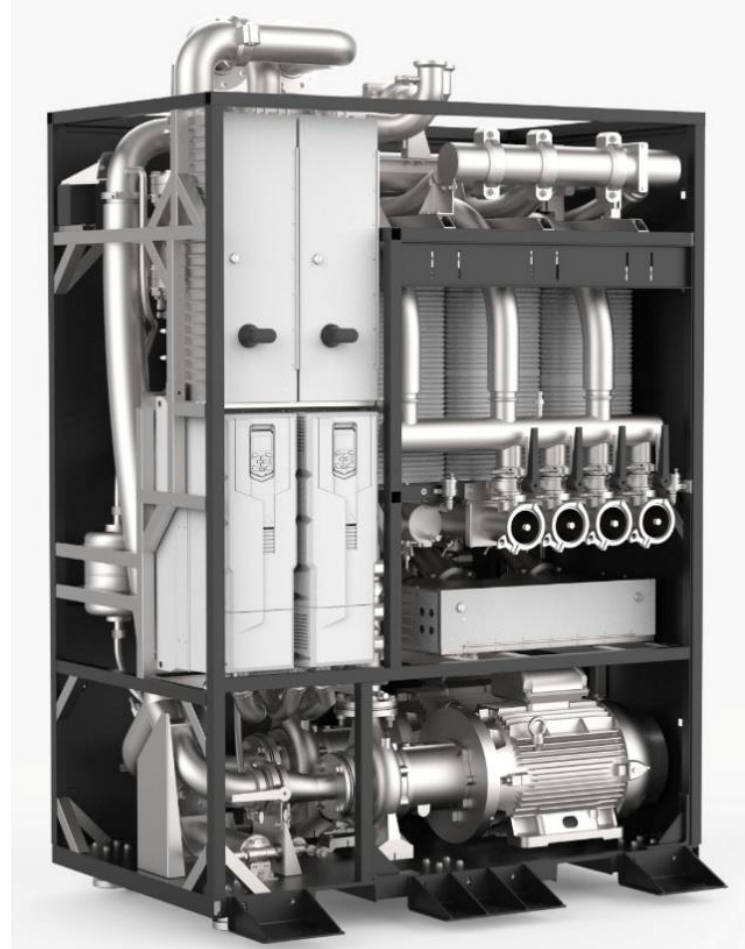
Trends Towards Liquid cooling



Established Industry trend: DLC w/End of Row CDU



Deschutes an OCP Specification From



Enabled a Multi-Vendor Supply Chain

Envicool - Deschutes 5 CDU

Envicool's CDU is based on the Google Deschutes 5 CDU spec. Key Technical Highlights: 2MW @3°C ATD 500 GPM (1890 LPM) | 80 PSI ...

Solution Provider: Envicool

Model #: Envicool - Deschutes 5 CDU

[Associated Approved OCP Contributions](#)



Vertiv CoolChip CDU - Project Deschutes 5

Vertiv™ CoolChip CDU for open standards is built to Google's Project Deschutes 5th-generation OCP specification delivering up to 2MW coolin...

Solution Provider: Vertiv

Model #: Vertiv CoolChip CDU - Project Deschutes 5

[Associated Approved OCP Contributions](#)



Boyd ROL4000-48U65 Deschutes CDU

Boyd's ROL4000-48U65 in-row liquid-to-liquid coolant distribution unit enables cooling for the next generation of AI processors in high density d...

Solution Provider: Boyd

Model #: ROL4000-48U65

[Associated Approved OCP Contributions](#)



nVent Project Deschutes Open CDU

Based on Google Deschutes 5.0 CDU Specification 2MW @ 3°C ATD 500 GPM (1890 LPM) 80 PSI Available Pressure N+1 Sealless Pumps ...

Solution Provider: nVent

Model #: nVent Project Deschutes Open CDU

[Associated Approved OCP Contributions](#)



Nidec - Project Deschutes 5 CDU

Nidec's In-Row CDU for open standards is built to Google's Project Deschutes 5 OCP-compliant specification, delivering 2MW of cooling cap...

Solution Provider: Nidec

Model #: Nidec - OCP 2MW CDU

[Associated Approved OCP Contributions](#)



Delta 2MW Deschutes 5 CDU

Delta 2MW In-Row CDU is built on Google Project Deschutes 5 Open CDU specification Key Technical Highlights: 2MW @3°C ATD 500 GPM (1...

Solution Provider: Delta Electronics

Model #: Delta 2MW Deschutes 5 CDU

[Associated Approved OCP Contributions](#)



STULZ Deschutes CDU – CyberCool Liquid Cooling Distribution Unit

Based on Google Deschutes 5.0 CDU Specification 2MW @ 3°C ATD 500 GPM (1890 LPM) 80 PSI Available Pressure N+1 Sealless Pumps ...

Solution Provider: STULZ

Model #: STULZ Deschutes CDU – CyberCool Liquid Cooling Distribution Unit

[Associated Approved OCP Contributions](#)



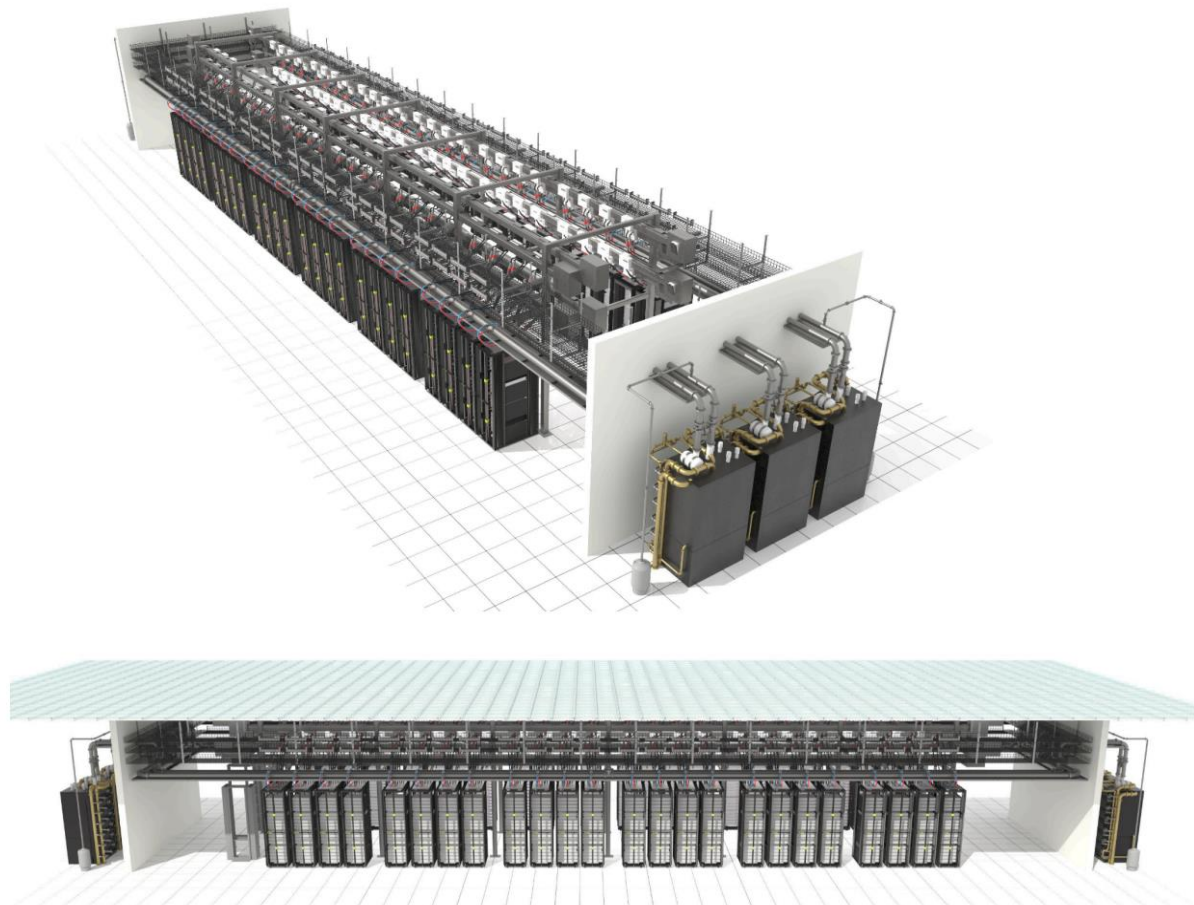
The Fungible Data Center

Open Data Centers for AI



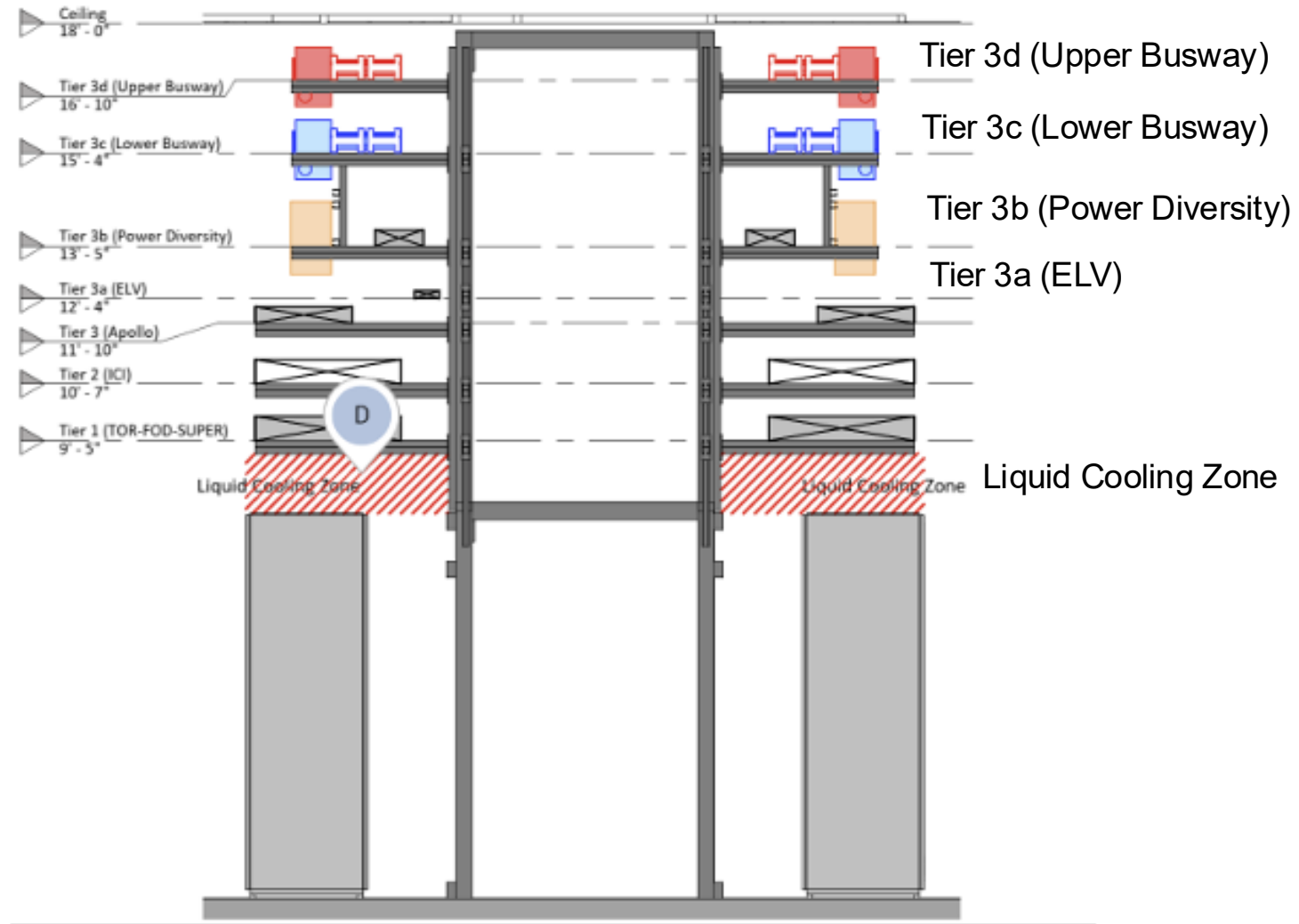
Community-driven hyperscale innovation for all

3D Renderings of "Small" Scale DC Designs

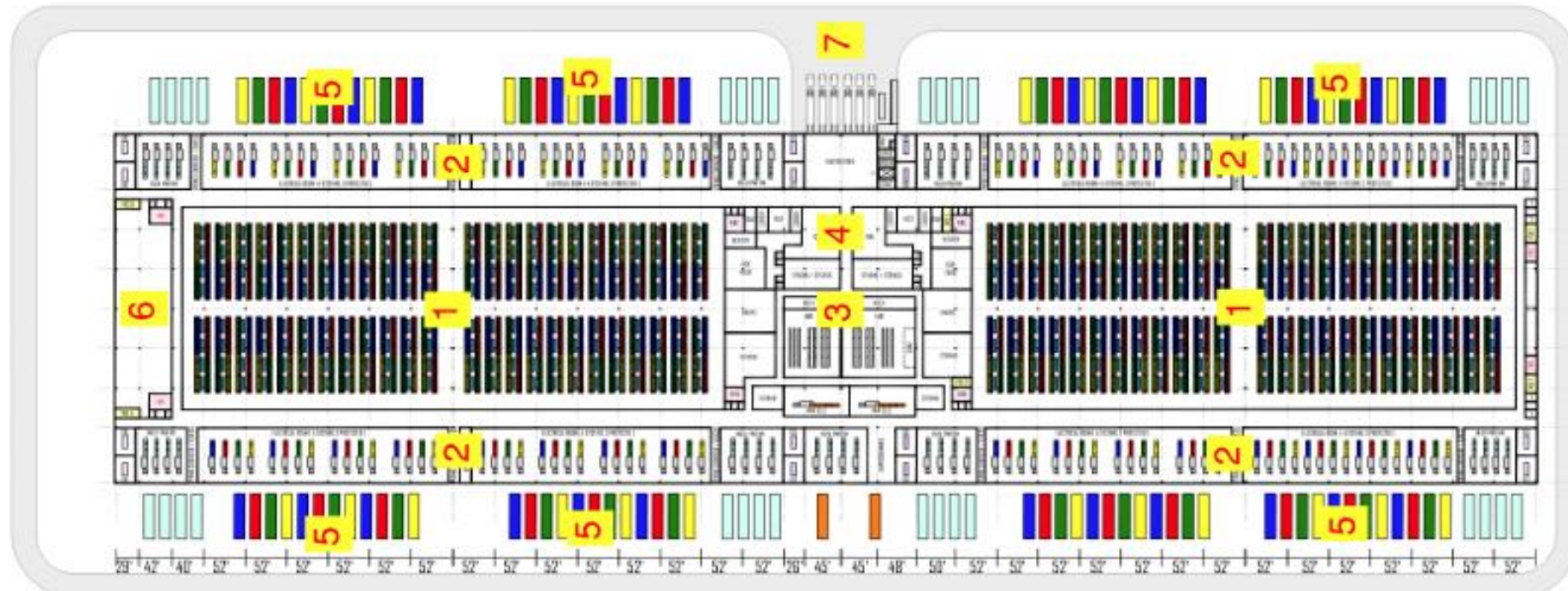


Example 3D rendering of the "Small" scale DC design, showing the capability to enable high dense ML deployments in constrained spaces.

HAC cross section for the “Large” Datacenters



Common Data Hall Designs



Enabling Sustainability and Heat Reuse

Community, industry and alliances collaboration

OCP & iMasons Deliver on Carbon Disclosure



Carbon Disclosure Standardizations

- **Objective:** Establish a standardized format for disclosing embodied carbon data across the data center supply chain.
- **Why?** Addresses inconsistent reporting, high supplier overhead, and difficulty in data aggregation/comparison.
- **Scope:** Covers ICT equipment, MEP systems, and construction materials (cradle-to-gate, A1-A3 life cycle stages).
- **Flexibility:** Does not mandate specific calculation methodologies; focuses on standardized disclosure.



Carbon Disclosure Standardizations

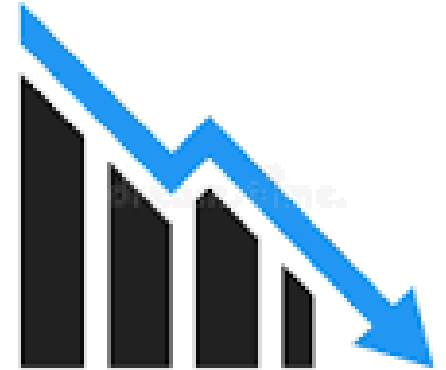
Example disclosure (Fictional UPS System)

Section	Example Data
Respondent	Acme Power Solutions Inc., Jane Smith (Sustainability Manager), J.Smith@acme.com
Product	EverUPS 500kW Module, MEP/UPS Systems and Batteries, Part #EUPS-500M-LI
Embodied Carbon	750 kg CO ₂ e per 500kW Module (A1-A3), [Link to EPD]
Methodology	LCA/EPD, Verified by GreenCert Ltd., GaBi Software, Ecoinvent v3.8 Database, PCR 2019:14

Carbon Disclosure Standardizations

Why adopt?

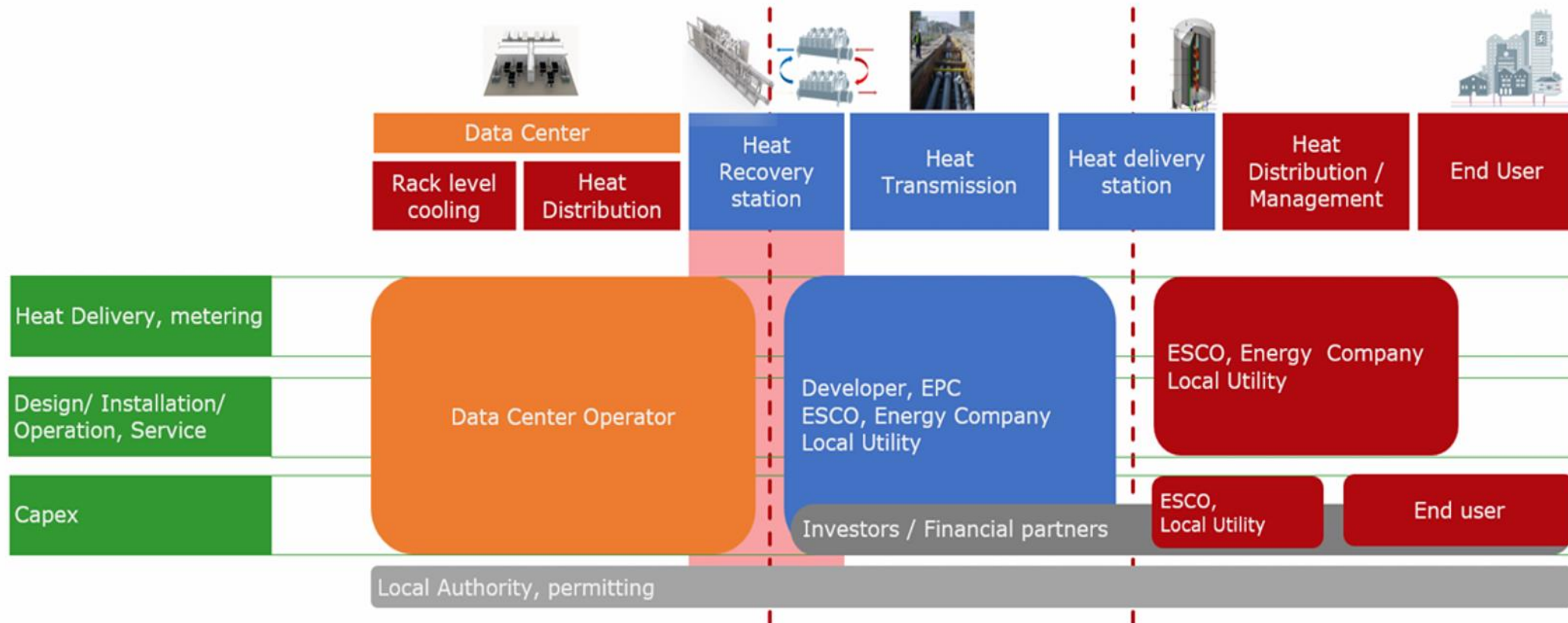
- **Suppliers:** Streamlined reporting, meet customer demands efficiently.
- **Customers:** Comparable data, informed procurement, align with sustainability goals.
- **Industry:** Accelerates transparency, supports net-zero targets.



Call to Action

- Adopt the specification in procurement processes.
- Provide feedback for continuous improvement.

Reference Designs - NZIH



Heat Reuse Policy and Regulation

5.7 Reuse of Data Centre Waste Heat

8.1 Data Centre Building Physical layout

8.2 Data Centre Building Geographic Location



5.7 Reuse of Data Centre Waste Heat

Data Centres produce significant quantities of waste heat, whilst this is typically at a relatively low temperature there are some applications for reuse of this energy. As IT equipment utilisation is increased through consolidation and virtualisation the exhaust temperature is likely to increase which will provide greater opportunity for waste heat to be re-used. Data Centres should therefore consider the potential for the reuse of the 'waste' heat that they produce. Directly liquid cooled IT equipment is likely to provide a further improvement in the return temperature of coolant.

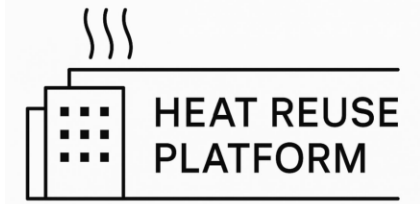
No	Name	Description	Expected	Value
5.7.1	Waste heat re-use	Evaluate the possibility of providing grade heating to industrial space or to other targets such as adjacent office space fresh air directly from heat rejected from the data centre. This does not reduce the energy consumed by the data centre itself but does offset the total energy overhead by potentially reducing energy use elsewhere.	New build or retrofit	4
5.7.2	Heat pump assisted waste heat re-use	Where it is not possible to directly re-use the waste heat from the data centre due to the temperature being too low it can still be economic to use additional heat pumps to raise the temperature to a useful point. This possibility should be evaluated and can potentially supply office, district and other heating needs.	New build or retrofit	4
5.7.3	Use data floor waste heat to warm office, generator and fuel storage areas	Evaluate reducing or eliminating the electrical preheat loads for generators and fuel storage by using warm exhaust air from the data floor to maintain temperature in the areas housing generators, fuel storage tanks and office areas.	Optional	2
5.7.4	Energy reuse metrics and reporting	The opportunity for the reuse of waste heat from data centres is referenced by ISO/IEC 30134-6 Information technology – Data centres – Key performance indicators – Part 6: Energy Reuse Factor (ERF) Note: Required for EU Commission EED reporting	Entire Data Centre	1
5.7.5	Capture Ready Infrastructure	Consider installing 'Capture Ready' Infrastructure to take advantage of, and distribute, available waste heat during new build and retrofit projects.	Optional	1

8.2 Building Geographic Location

Whilst some operators may have no choice of the geographic location for a data centre it nevertheless impacts achievable efficiency, primarily through the impact of external climate.

No	Name	Description	Expected	Value
8.2.1	Consider locating the Data Centre where waste heat can be reused	Locating the data centre where there are available uses for waste heat can save substantial energy. Heat recovery can be used to heat residential or office space, industrial spaces, hydroponic farming, swimming pools, fish farms, grain and biomass drying etc.	New build or retrofit	4
8.2.2	Locate the Data Centre in an area of low ambient temperature	Free and economised cooling technologies are more effective in areas of low ambient external temperature and or humidity. Note: Most temperature climates present significant opportunity for economised cooling and zero refrigeration.	Optional	4
8.2.3	Avoid locating the data centre in high ambient humidity areas	Free cooling is particularly impacted by high external humidity as dehumidification becomes necessary. Many economiser technologies (such as evaporative cooling) are also less effective.	Optional	1
8.2.4	Locate near a source of free cooling	Locating the data centre near a source of free ground source cooling such as a river or lake etc. subject to local environmental regulation.	Optional	1
8.2.5	Co-locate with power source	Locating the data centre close to the power generating plant can reduce transmission losses.	Optional	1
8.2.6	Consider Heat re-use	Evaluate the technical and commercial opportunities for the use of 'waste' heat produced by the data centre. This may include district heating systems of industrial process as described in 8.2.1	New build or retrofit	4

The Heat Exchange Platform a 'one-stop' commercial toolkit



Objective: streamlining partner discovery, cut negotiation times, enabling rapid project kick-off.

- An EU matchmaking portal to connect data centres with nearby DHC networks - streamlining partner discovery.
- Helpful Resources: A template contract with standard clause and business model fact sheets to cut negotiation times, enabling rapid project kick-off.
- Capacity-building tools: training modules, feasibility calculators, and best-practice workshops to empower stakeholders and de-risk early-stage project development.



Get Involved!

Join

- Project Mailing Lists
- Project Calls
- Open Systems for AI Initiative

Drive

- Project Focus
- Thought Leadership

Run

- Projects and Workstreams
- Technical Steering Committee

Contribute

- Effort
- Specifications
- Products and Facilities

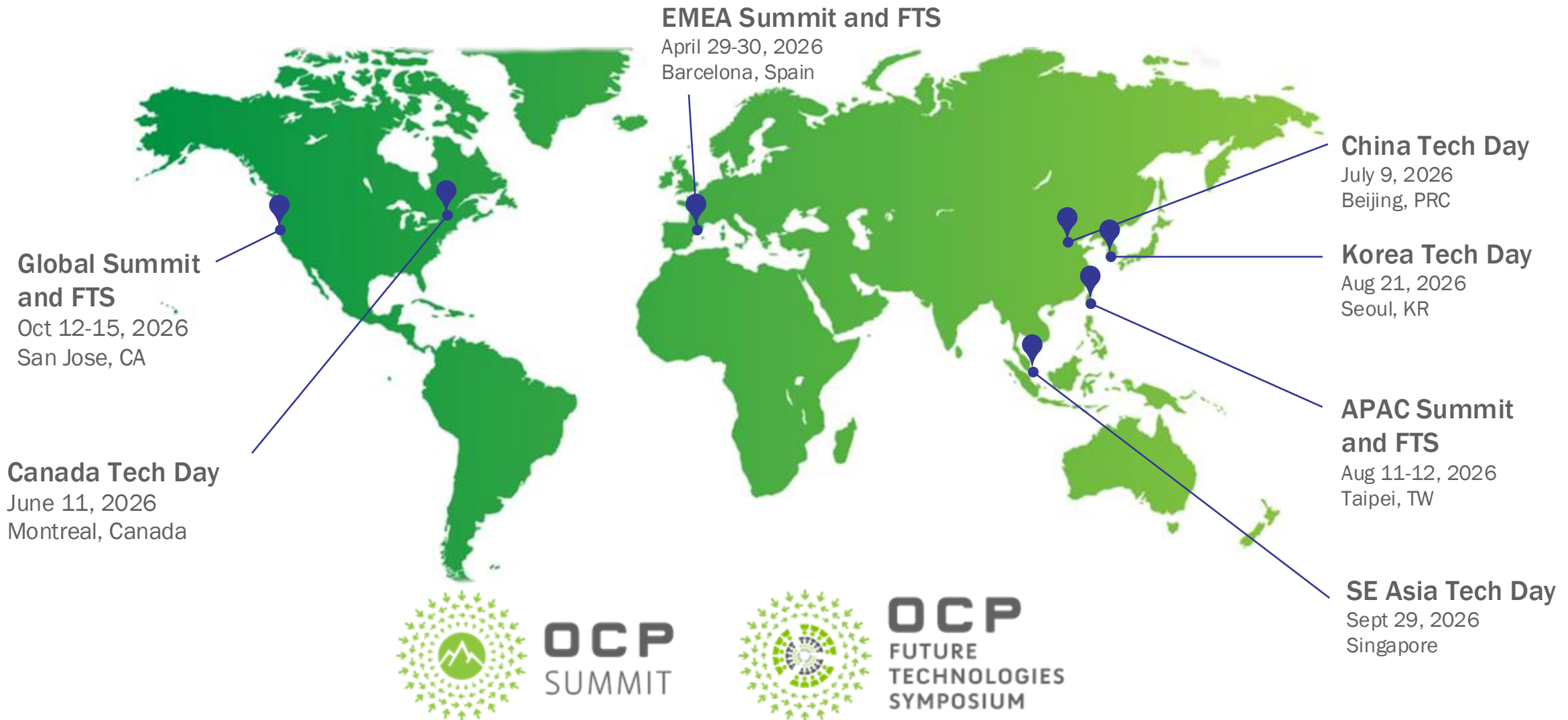
Attend

- OCP Summits
- OCP Panels
- Engineering Workshops
- OCP Webinars
- 3rd Party Events



OPEN
Compute
Project®

OCP Major Events



Learn more at
www.opencompute.org

Community-driven hyperscale innovation for all

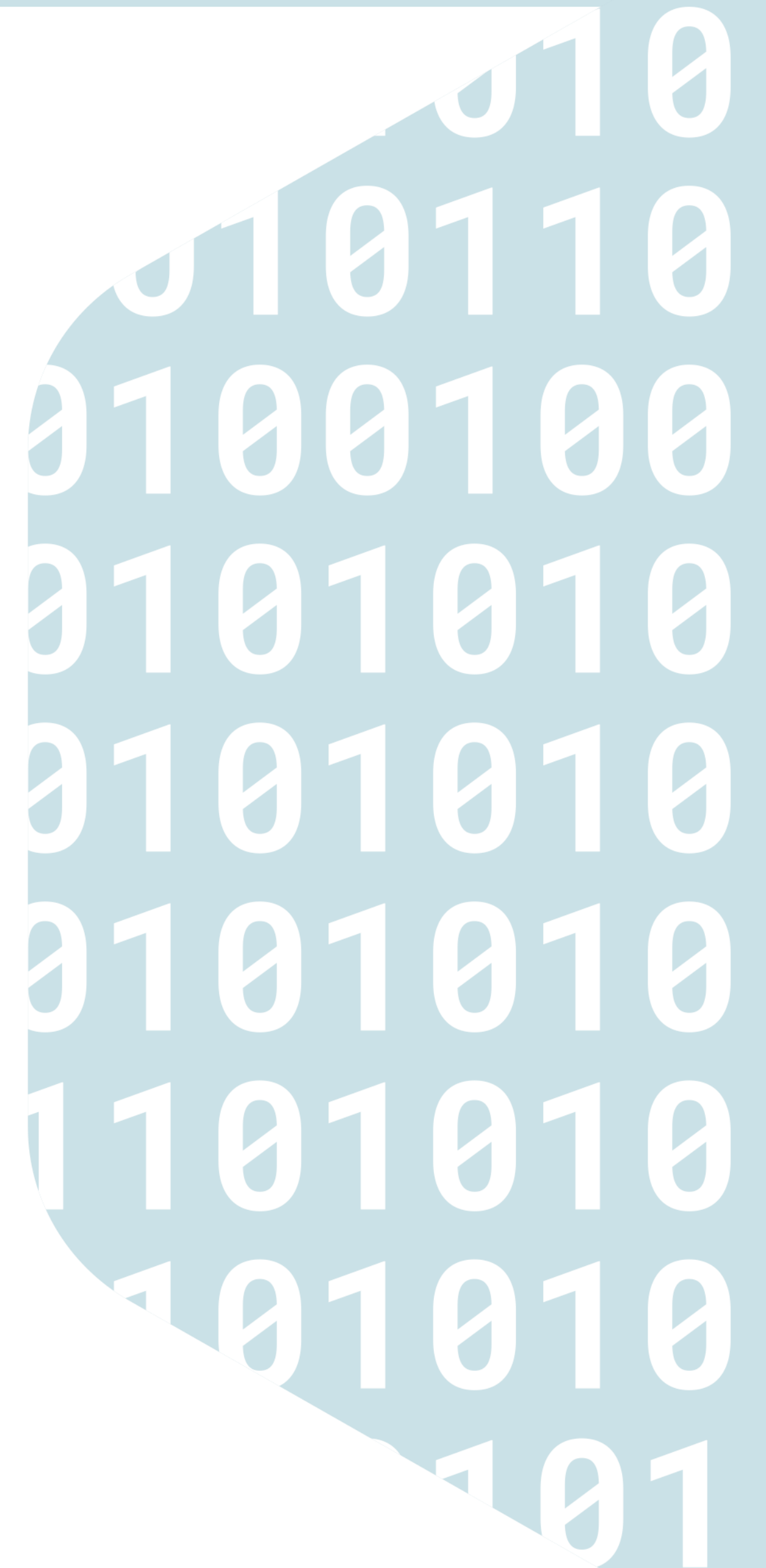


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Project®



WOMEN IN THE DATA CENTER INDUSTRY

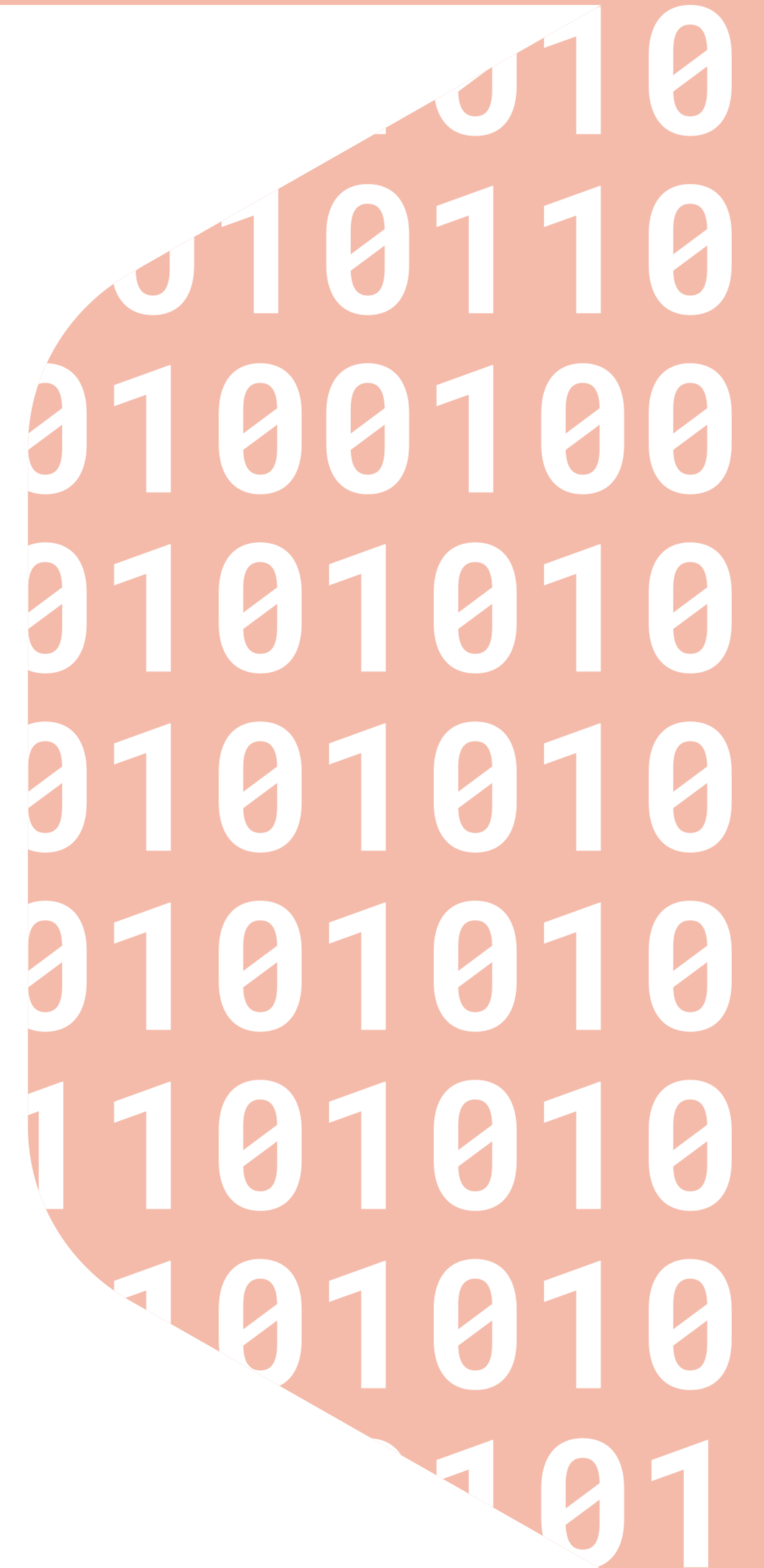
Part of SweDCI



- 📖 Only 1 in 3 researchers globally is a woman
- 📖 Just 35% of STEM graduates are women
- 📖 Women hold 22% of STEM jobs in G20 countries
- 📖 Only 1 in 10 STEM leaders is a woman

Source: UNESCO

Closing the gender gap isn't just about equity — it's about unlocking innovation and building a stronger future for our industry.





WHERE THE IDEA CAME FROM



The Data center industry is growing rapidly

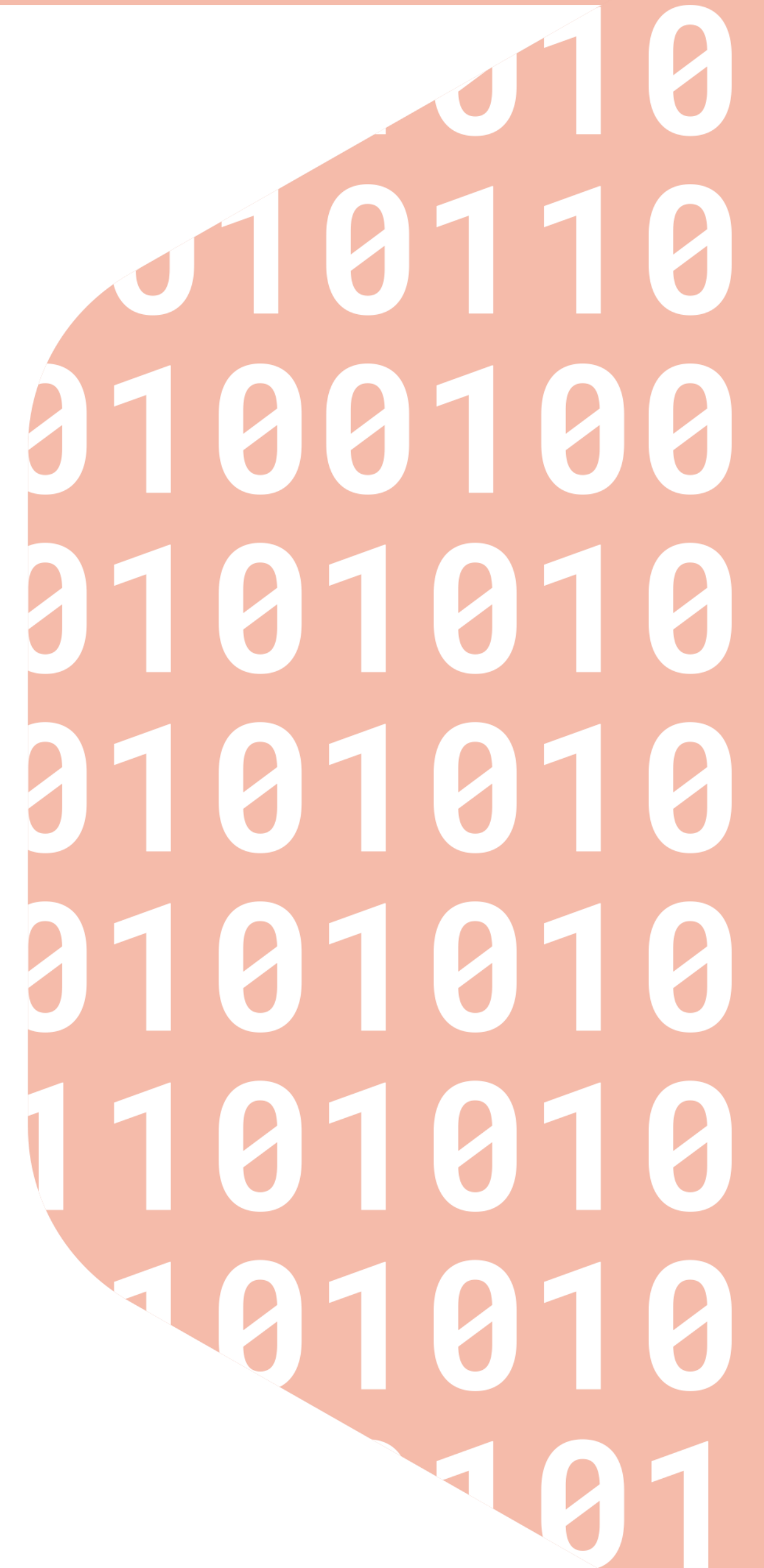


Women remain significantly under-represented



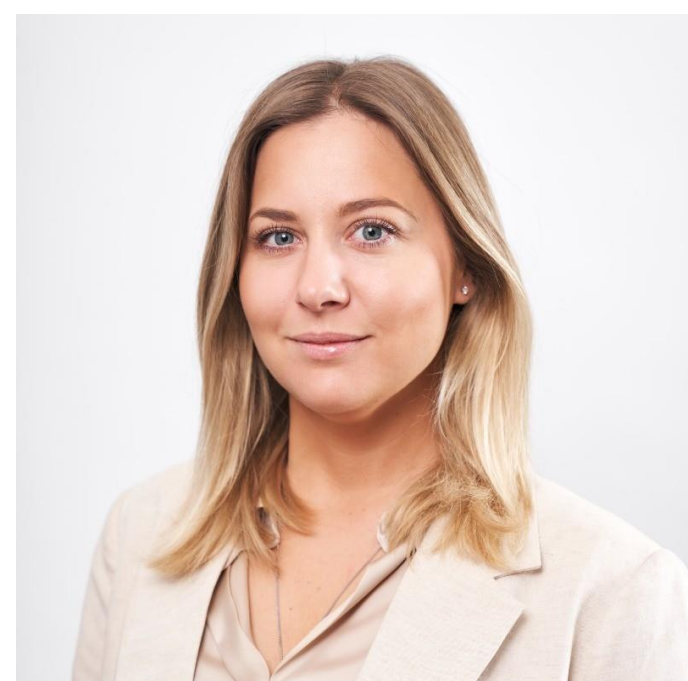
There is an opportunity for the Data center industry to strengthen diversity and attract more female talent

How can we encourage more women to join, and strengthen the position of women already established in the industry?





CORE GROUP



Anna Ekman
Head of Marketing
Conapto



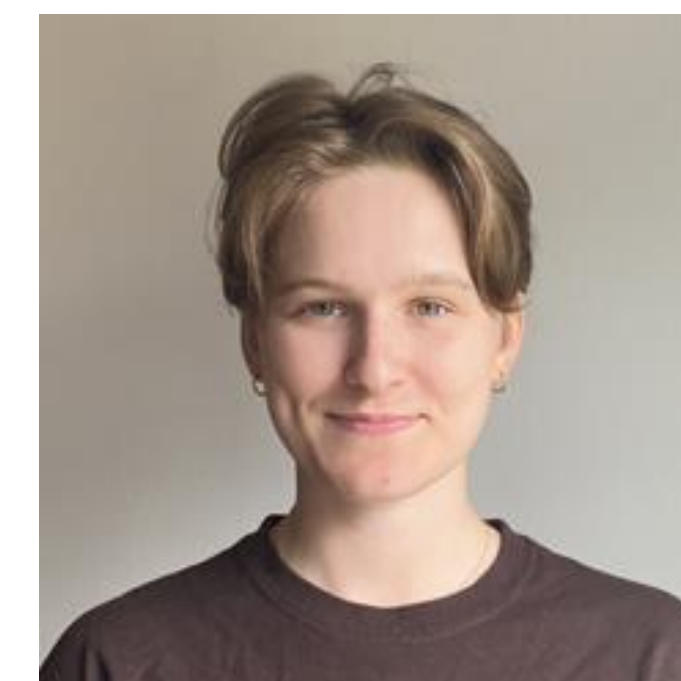
Amanda Blomberg
Data Center Engineer
Conapto



Tina Stark
R&D Engineer
RISE



Parvathi Maya Thampi
R&D Engineer
RISE



Annie Wyon
R&D Engineer
RISE

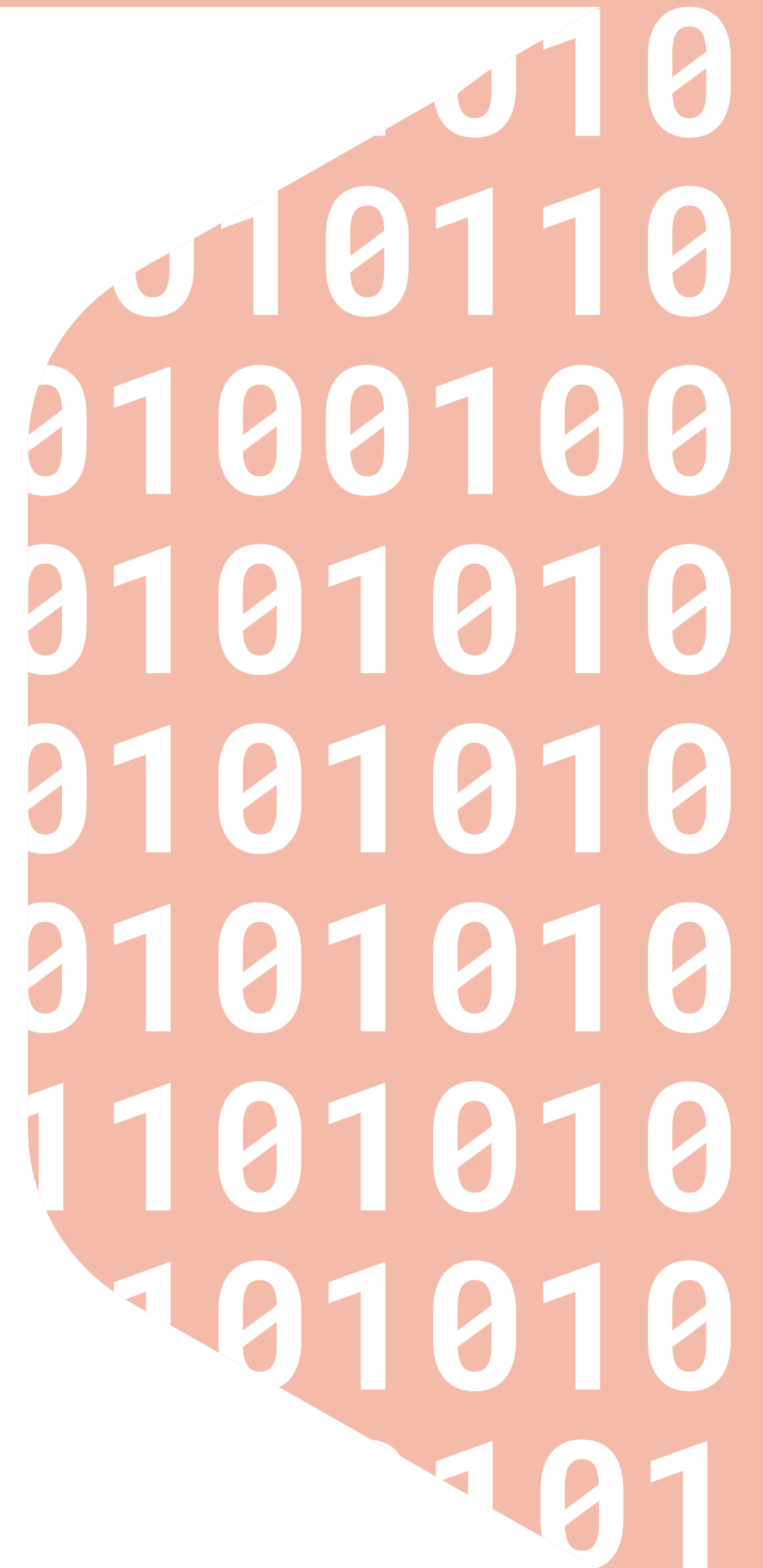




OUR VISION





To create an inclusive and empowering community that connects and inspires women in the data center industry – fostering knowledge sharing, collaboration, and supporting increased representation across the sector.

Connecting women – empowering the community





OUR MISSION

-  Reach women in the industry through SweDCI, partners, and existing industry networks
-  Establish a forum for ongoing contact and regular meet ups
-  Showcase the data center industry to young women and highlight career paths
-  Connect with international communities of women in tech





WHO IS THIS COMMUNITY FOR?

Women working
in any part of the
data center
ecosystem

Industry
ambassadors and
senior professionals
who can uplift the
initiative

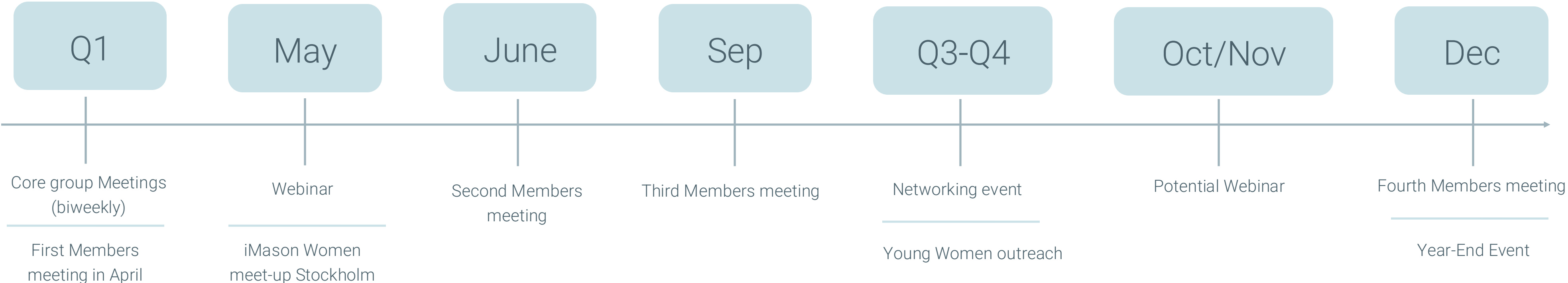
Current and
future students
in tech
education

260+
followers
on LinkedIn





PLANNED ACTIVITIES FOR 2026



Follow us on LinkedIn



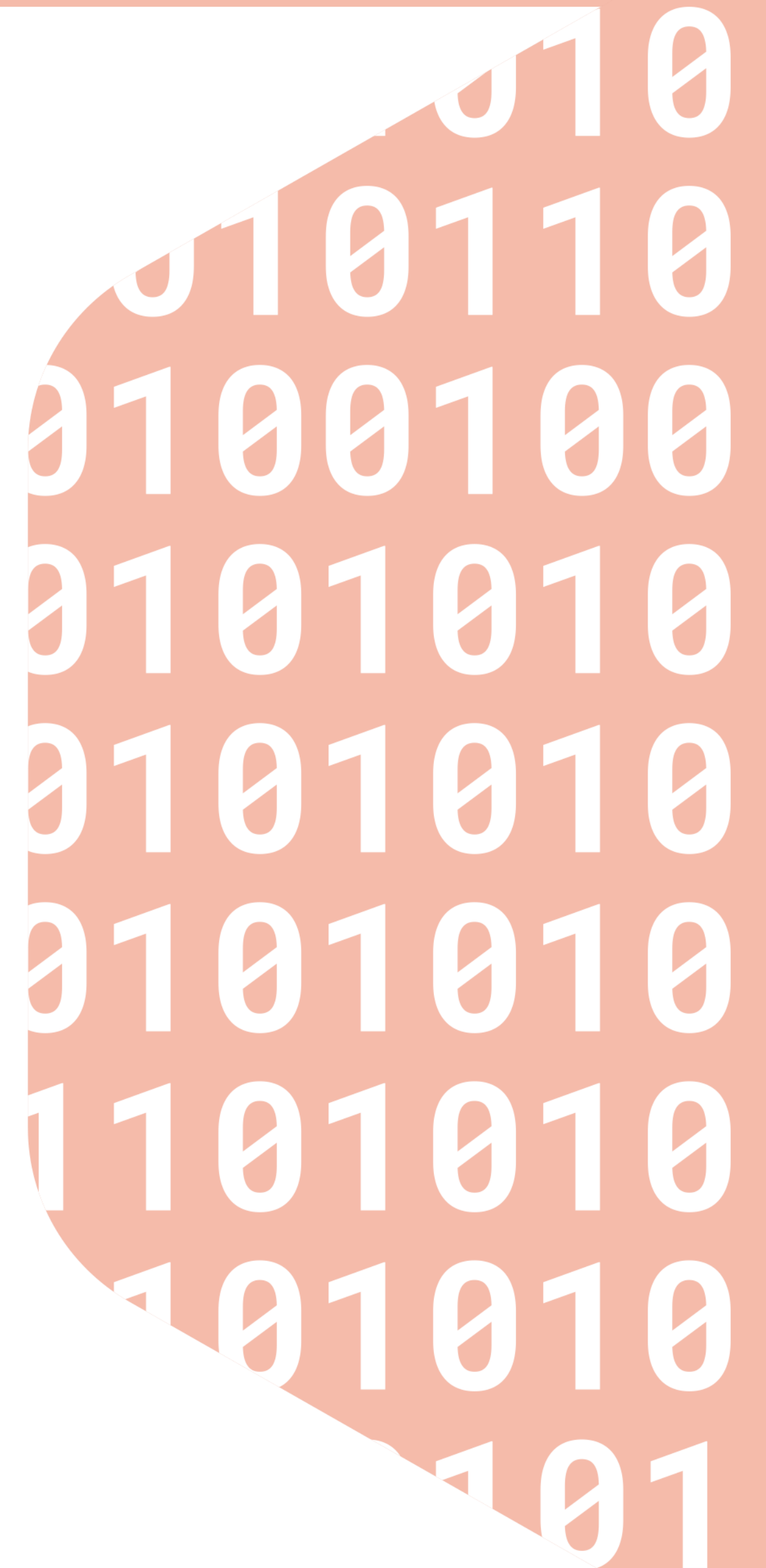


FIRST MEMBERS MEETING

14th of April

15.30-16.30 CEST

Sign up as a member on our
webpage womendci.com





WOMEN^{IN}_{THE}
DATA CENTER
INDUSTRY
Part of SweDCI

Thank you!

Follow us on
LinkedIn!





Funded by
the European Union



HEATWISE Overview & Technical Vision

Holistic Energy Management and Thermal
Waste Integrated System

Horizon Europe – GA 101138491
tamas.seres@h1systems.hu





Funded by
the European Union



Today's Presentation Overview v1

- Why Data Centres and Buildings Should Not Be Separate Systems
- The HEATWISE Concept
- Technical Challenges
- The HEATWISE Project Framework
- Current Situation in Buildings (Typical Hospital Example)
- Vision: Integrated Computing–Building Energy System
- Hospital Case Study Hungary
- System Development Phases
- KPI Evolution (Before → After HEATWISE)
- Business Model and Scalability
- Key Takeaways
- Outlook





Funded by
the European Union



Today's Presentation Overview v2

- 1 — What are the expected results?
Energy savings and EU compliance.
- 2 — Why should we believe it?
Data, modelling and validated KPIs.
- 3 — How can it be implemented?
Technology, economics and regulation.



What are the expected results?



Potential impact of the HEATWISE concept:

- Energy savings in tertiary buildings
- Significant CO₂ reduction
- Compliance with EU energy efficiency requirements (EED)
- Scalable model for e.g. hospitals

Illustrative use case (model-based estimate, HU)

- Energy savings 100 / 301 / 866 k€ per year
- CO₂ reduction 237 / 986 / 2191 t CO₂ per year

HEATWISE shows that server waste heat can cover a significant share of hospital heating demand while improving data centre efficiency and meeting EU energy efficiency targets.



The presented figures illustrate the potential impact of the HEATWISE concept based on preliminary modelling and use-case assumptions. Further analysis and validation are ongoing within the project.



How were these estimates derived?

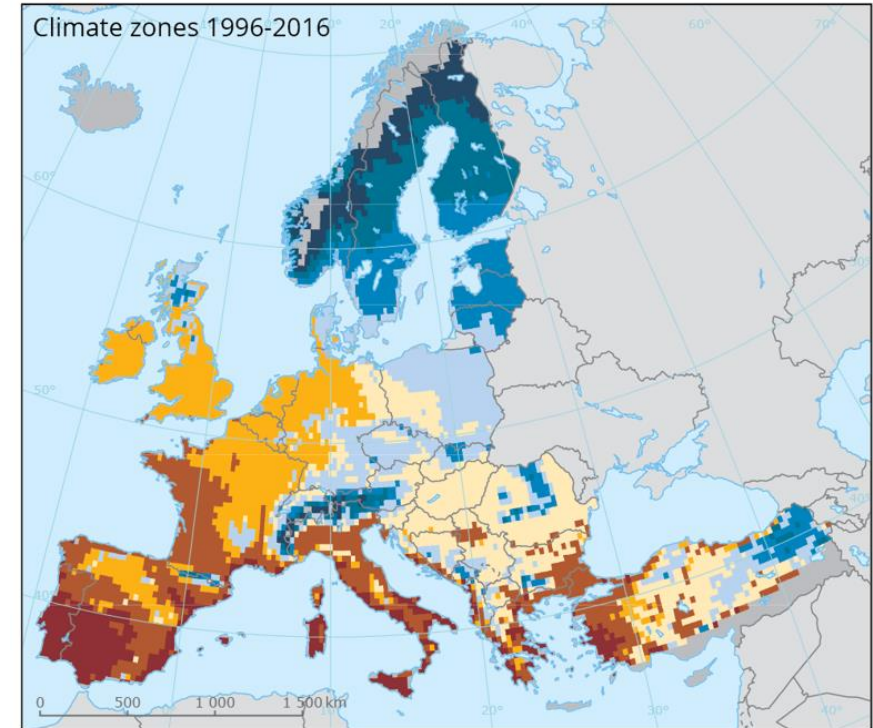
Illustrative estimates depend on several factors

- Climate conditions
- Building heat demand
- IT load and cooling technology
- Heat reuse configuration
- Energy prices

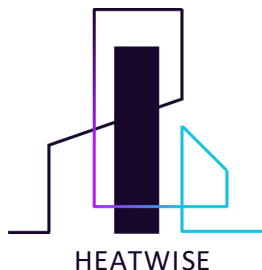
Methodology

- Real energy data analysis
- Thermal modelling
- CFD simulations
- KPI framework aligned with EU EED indicators

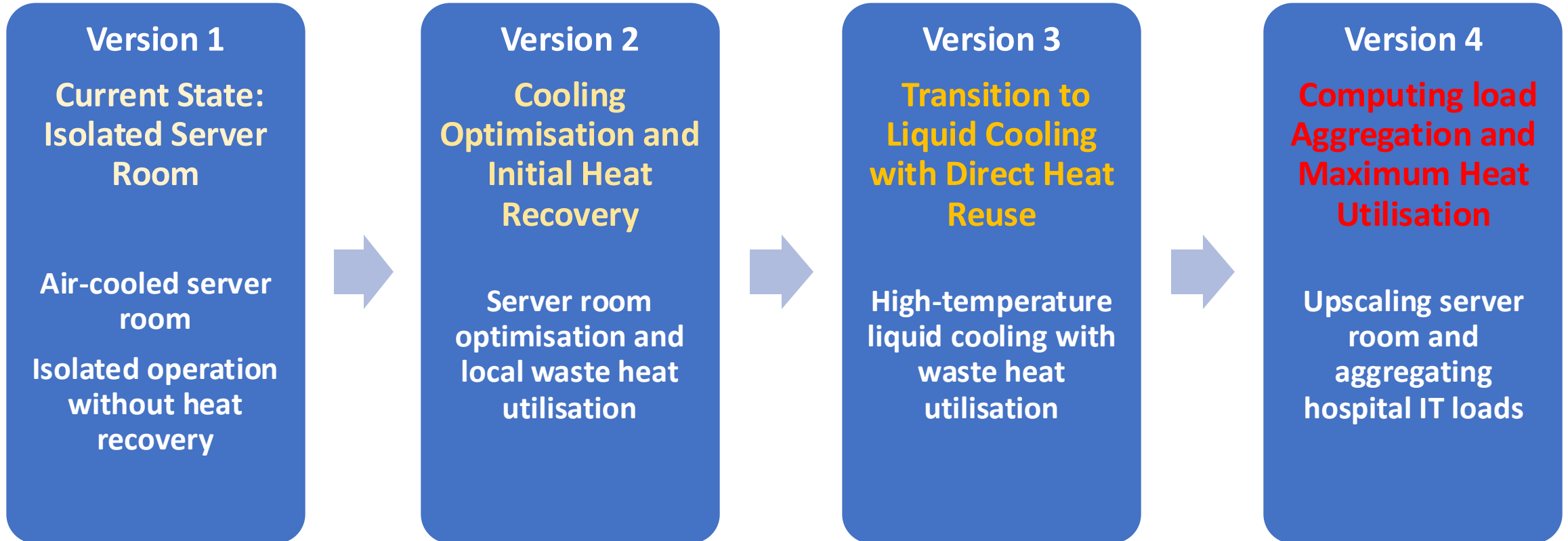
The presented use case illustrates a high-level estimate. The HEATWISE project focuses on developing and validating the detailed scientific models and methodologies required for accurate estimation.



Source: European Environment Agency (EEA)

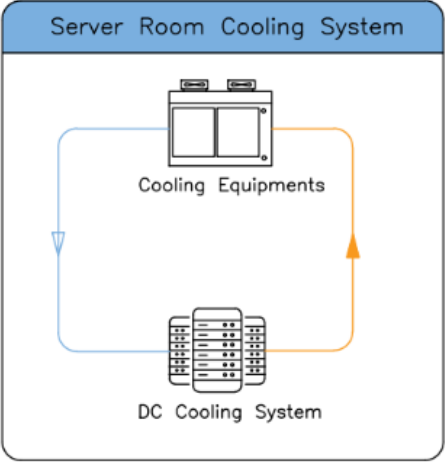


HEATWISE Value Proposition Versions

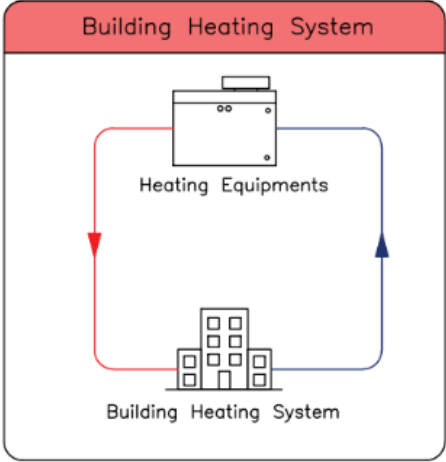


HEATWISE does not assume an instant transformation. Instead, it defines a realistic transition path from today's isolated server rooms to integrated IT–energy systems.

Version 1 — Current state: Isolated operation in one building



- Hospital Key Characteristics:**
- **Gross floor area:** ~70,000 m²
 - **Bed capacity:** ~700 beds
 - **Operating theatres:** 14
 - **ICU capacity:** 40 beds
 - **Building concept:** modern or deeply renovated hospital complex
 - **Heating system:** low-temperature heating
 - **Primary energy source:** natural gas (baseline)
 - **Operation profile:** continuous
 - **Annual heat demand:** 14,000 MWh_{th}/year
 - **On-site computing capacity:** ~200 kW



Version 1
Current State:
Isolated Server Room

Isolated operation without heat recovery

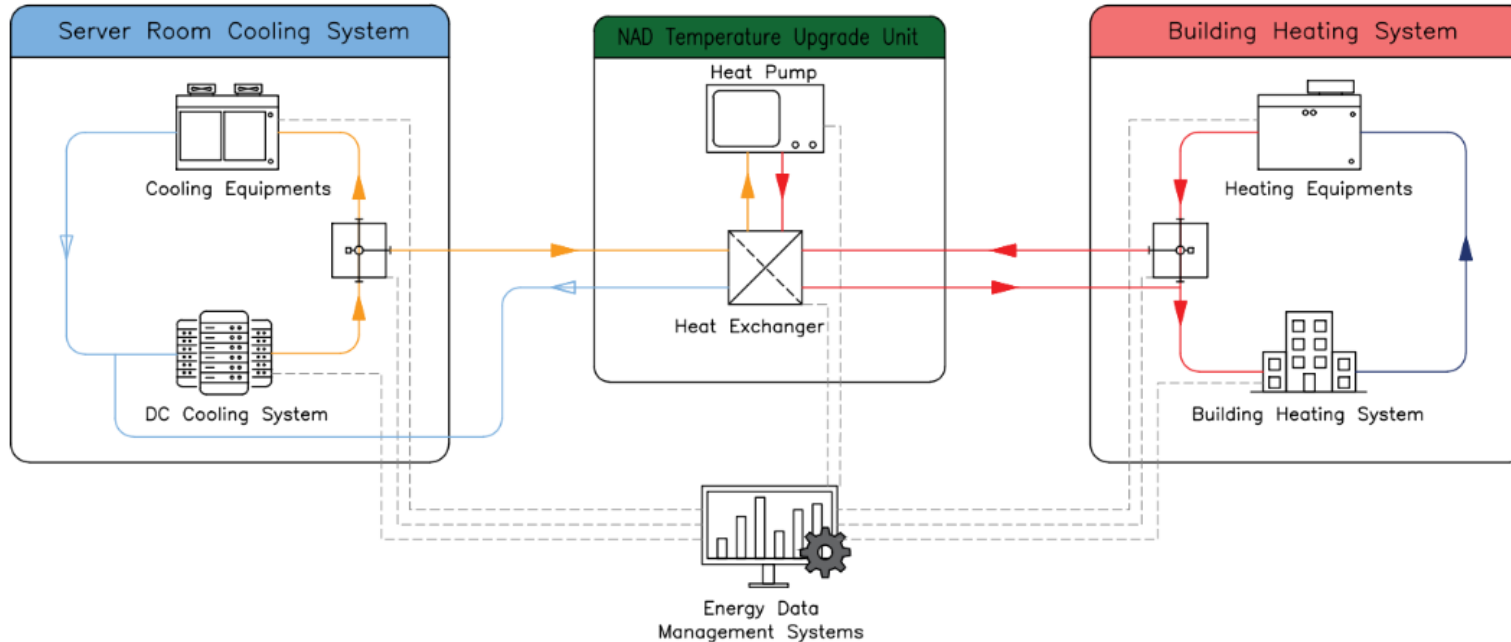
- Air-cooled server room
- IT operates independently from the building energy system
- Waste heat is rejected to the environment
- No waste heat utilisation

Typical hospital configuration in Hungary today.

Version	Energy savings	CO ₂ reduction	PUE	ERF	PES	Cooling	Waste heat Resuse
Version 1	0k/year	0 t/year	1,8	0 %	0 %	Air	No



Version 2 — Cooling optimisation and initial heat reuse



Version 2
Cooling Optimisation and Initial Heat Recovery

Server room optimisation and local waste heat utilisation

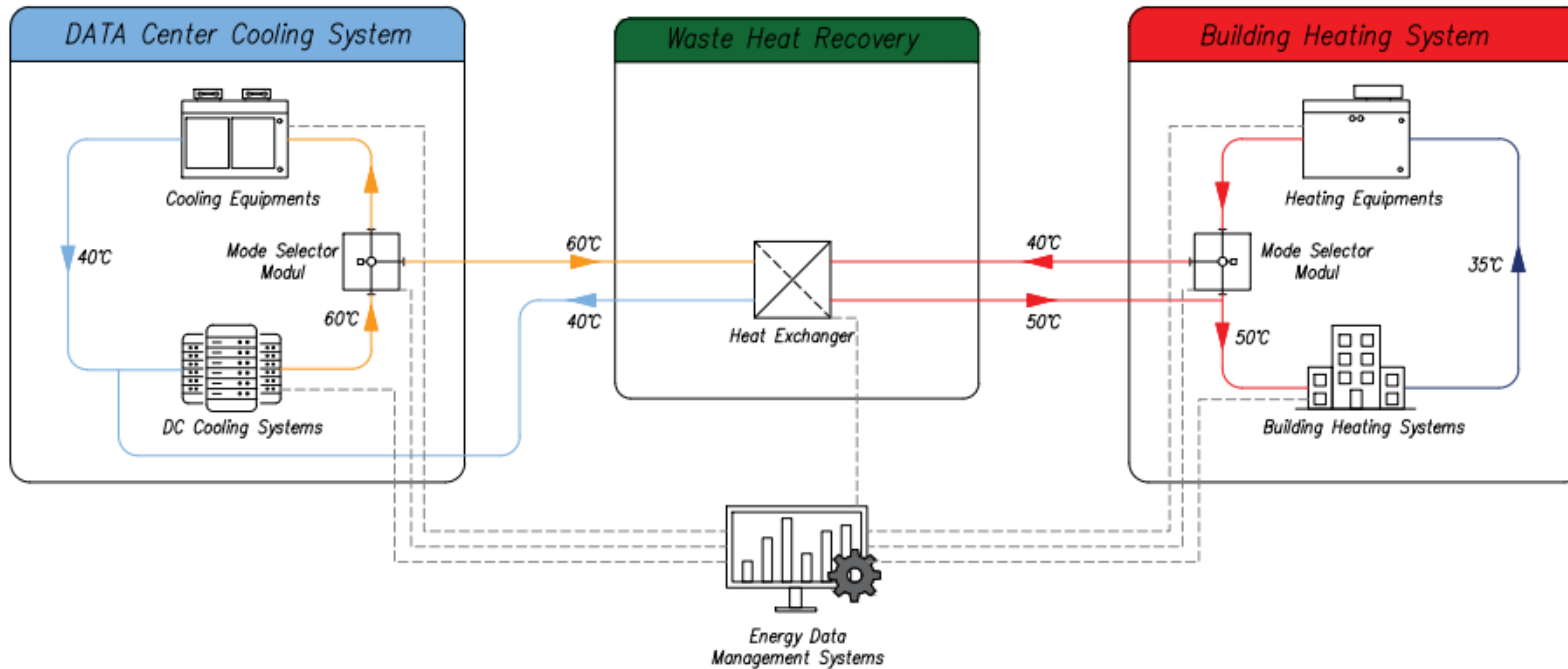
- Optimisation of server room cooling (CFD, airflow management)
- Integration of waste heat into the building energy system
- Heat pump likely required to raise temperature level

Even with air cooling, partial heat recovery is possible.

Versions	Energy savings	CO ₂ reduction	PUE	ERF	PES	Cooling	Waste Heat Resuse
Version 1	0k/year	0 t/year	1,8	0 %	0 %	Air	No
Version 2	€100k/year	237 t/year	1,5	27%	6,5 %	Air	Yes



Version 3 — Transition to liquid cooling



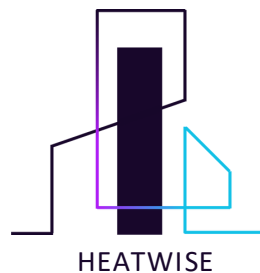
Version 3
Transition to Liquid Cooling with Direct Heat Reuse

High-temperature liquid cooling

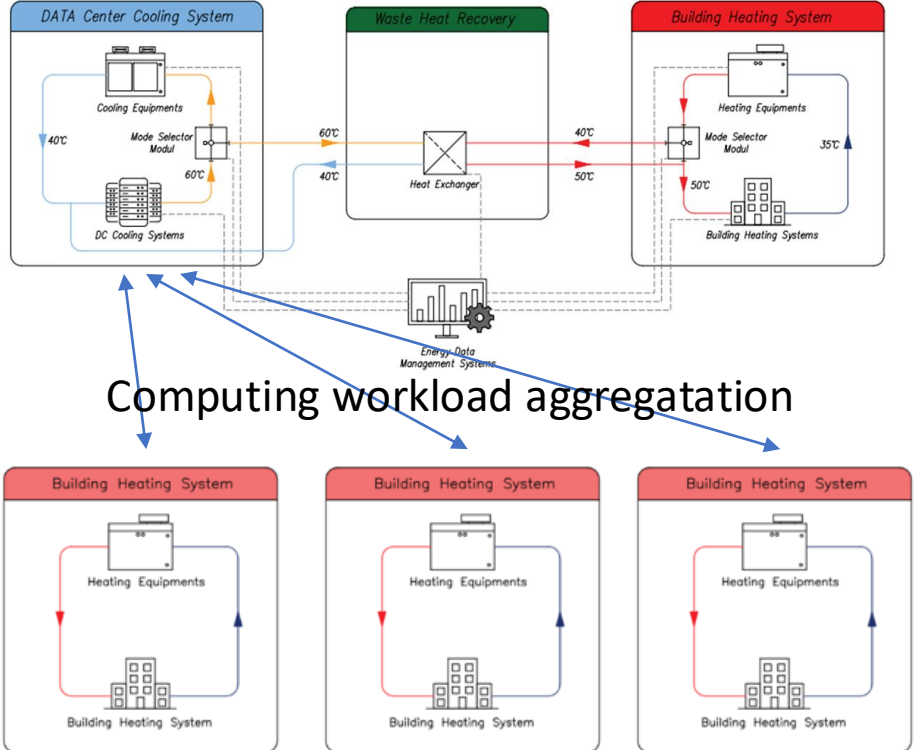
- Transition from air cooling to direct liquid cooling
- Waste heat temperature ~50–60 °C
- Heat is reused directly in the building
- Heat pump typically no longer required

Liquid cooling fundamentally changes the heat recovery potential.

Versions	Energy savings	CO ₂ reduction	PUE	ERF	PES	Cooling	Waste heat Resuse
Version 1	0k/year	0 t/year	1,8	0 %	0 %	Air	No
Version 2	€100k/year	237 t/year	1,5	27%	6,5 %	Air	Yes
Version 3	€301k/year	684 t/year	1,1	88 %	19,6 %	Liquid	Yes



Version 4 — Maximum heat utilisation



Hospital case:

- Upscaling of server room capacity to the Maximum waste heat utilisation
- Aggregation of hospitals computing workloads

Version 4
Upscaling
Computing load Aggregation and Maximum Heat Utilisation

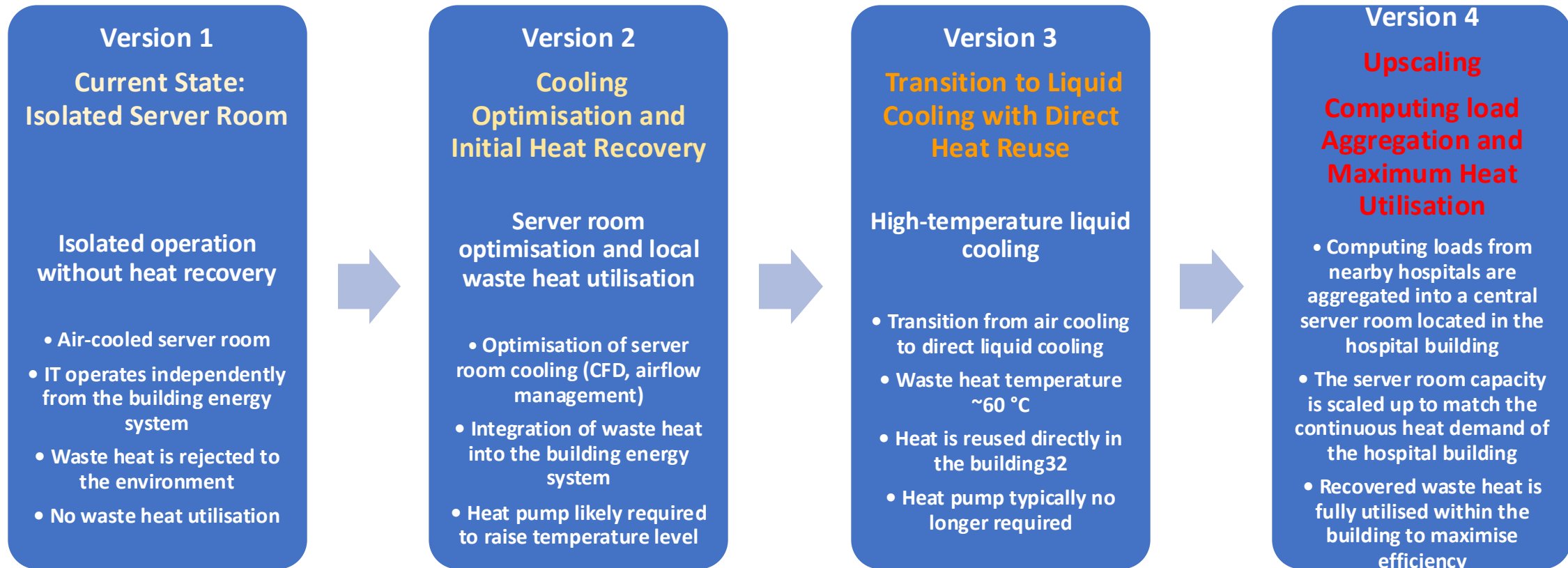
- Computing loads from nearby hospitals are aggregated into a central server room located in the hospital building
- The server room capacity is scaled up to match the continuous heat demand of the hospital building
- Recovered waste heat is fully utilised within the building to maximise efficiency

IT capacity can be aligned with available heat demand

PUE: 1,1 (1.05)
 ERF: 88 % (90%)
 PES: 46.6% (20%)



HEATWISE Value Proposition Versions – Towards Computing Load Aggregation



Hospital clusters operate as orchestrated edge computing nodes where IT capacity grows only as long as the generated waste heat can be fully utilised.

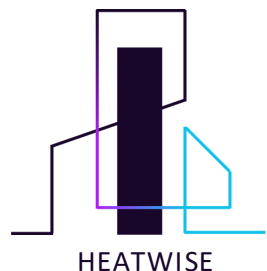
Summary of Estimated Results – Hospital case (HU)



Version	Energy savings	CO ₂ reduction	PUE	ERF	PES	Cooling	Waste heat reuse
Version 1	0k/year	0 t/year	1,8	0 %	0 %	Air	No
Version 2	€100k/year	237 t/year	1,5	27 %	6,5 %	Air	Yes
Version 3	€301k/year	684 t/year	1,1	88 %	19,6 %	Liquid	Yes
Version 4	€866k/year	2.191 t/year	1,1	88 %	46,3 %	Liquid	Yes

The largest impact is achieved when server room capacity is sized to the hospital's continuous heat demand, using pure liquid cooling and orchestrating the computing load from surrounding hospitals.

The presented figures illustrate the potential impact of the HEATWISE concept based on preliminary modelling and use-case assumptions. Further analysis and validation are ongoing within the project.

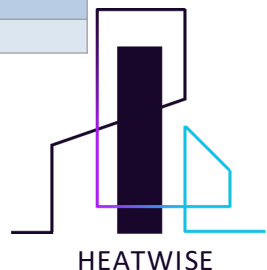


Estimation - HEATWISE KPI Calculation for Hospital (HU)



KPI	Phase 1	Phase 2	Phase 3	Phase 4
Phase definition	Current state	Cooling optimisation + initial heat reuse	Transition to liquid cooling	Upscaling + regional IT aggregation
Cooling type	Air	Air + CFD	Liquid (ZutaCore 60°C)	Liquid (ZutaCore 60°C)
IT power (kW)	200	200	200	200 local + 800 hosted
PUE	1.80	1.50	1.10	1.10
Total DC electricity – physical site (MWh/yr)	3,154	2,628	1,927	9,636
DC electricity paid by hospital (MWh/yr)	3,154	2,628	1,927	1,927
DC electricity billed externally (MWh/yr)	0	0	0	7,709
Heat pump electricity (MWh/yr)	0	200	0	0
IT energy (MWh/yr)	1,752	1,752	1,752	8,760
Waste heat supply temperature	Low	Low, HP-assisted	~60 °C	~60 °C
Waste heat reused (MWh_th/yr)	0	700	1,700	8,480
Annual building heat demand (MWh_th/yr)	14,000	14,000	14,000	14,000
Building heat from waste heat (MWh_th/yr)	0	700	1,700	8,480
Building heat from gas (MWh_th/yr)	14,000	13,300	12,300	5,520
Gas replaced (MWh_gas/yr)	0	778	1,889	9,422
ERF (site level)	0.00	0.27	0.88	0.88
Heat pump COP	"-"	3.5	"Not required"	"Not required"
REF	0.20	0.20	0.20	0.20
PES_DC	0.0%	16.7%	38.9%	38.9%
PES_SYS (site-level, DC + building)	0.0%	6.5%	19.6%	46.3%
Annual CO2 reduction – hospital (t/yr)	0	237	684	2,191
Annual hospital energy savings (EUR)	€0	€100,661	€301,099	€866,072

The presented figures illustrate the potential impact of the HEATWISE concept based on preliminary modelling and use-case assumptions. Further analysis and validation are ongoing within the project.



Scientific and Technical foundation



The following presentations illustrate selected examples of the work carried out within the project.

HEATWISE results are based on multiple validated components

- **High-temperature waste heat availability**
Liquid cooling technologies enabling heat recovery at **50–65 °C**
- **Building heat demand modelling**
Quantifying how much waste heat buildings can actually utilise
- **Efficiency evaluation framework**
KPI-based assessment of data centre performance
- **Thermal prediction and optimisation models**
Determining optimal waste heat reuse configurations
- **Digital twin-based operational optimisation**
Integrated management of IT infrastructure and energy systems

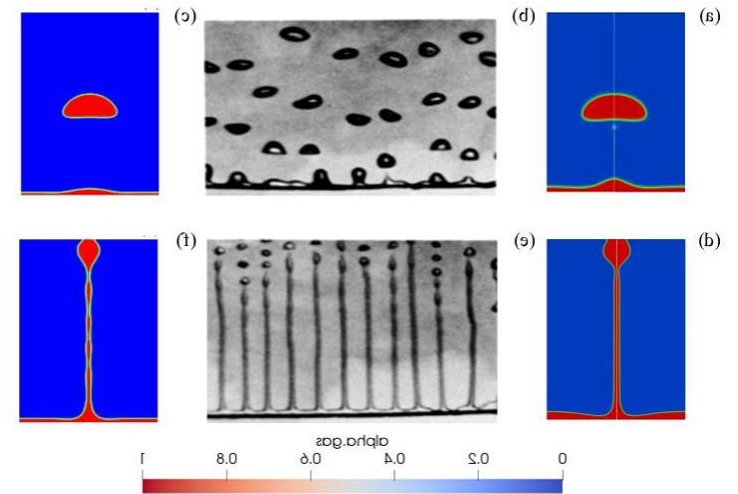
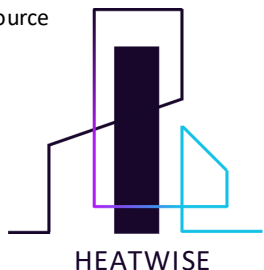


Figure 3.7: Comparison of vapor-liquid interface shapes for $\Delta T_{\text{sub}} = 10 \text{ K}$ (a, d) and $\Delta T_{\text{sub}} = 30 \text{ K}$ (b, e) present (c) experimental and (f) numerical. (e) and (f) present (e) experimental and (f) numerical.

Source: Development and validation of opensource CFD model for thermal analyses of IT systems
Project ID: 101138491 Prepared by: **DSTECH**



What will HEATWISE deliver?



A decision and design framework for deploying waste heat recovery

- **Investment logic**
Economic conditions for viable waste heat reuse.
- **Design patterns and planning tools**
Reference system architectures and assessment tools for real deployments.
- **Operational model**
How IT workloads and heat demand can be orchestrated across sites.
- **Risks and constraints**
Technical, economic and organisational limitations.
- **Regulatory guidance and policy recommendations for standardisation**
Identification of the need for standardization and development in the future.

HEATWISE develops a comprehensive framework—including investment logic, design patterns, operational models, risk assessment, and regulatory guidance—to support the large-scale deployment of waste heat recovery solutions





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Research and Innovation SERI**
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Thank you for attention

For more and current information visit our website:
www.heatwise.eu





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State Secretariat for Education,
Research and Innovation SERI
EU Framework Programmes

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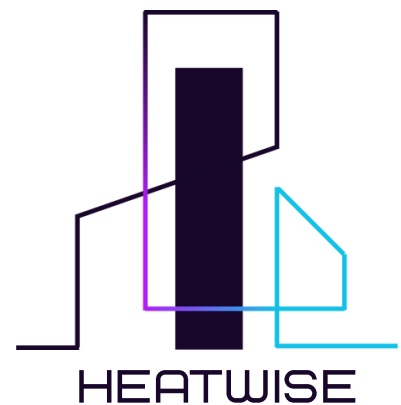
Luleå March 2026





Waste heat potential of buildings

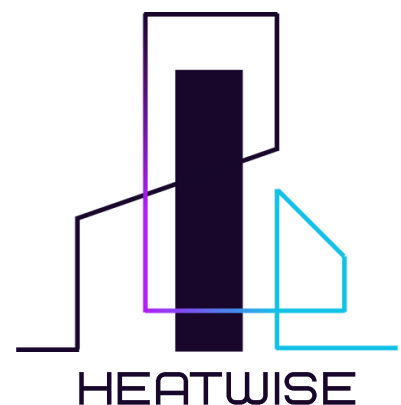
Rasmus Lund Jensen & Simon Melgaard
Aalborg University (AAU), Denmark





AAU pilot building 2016

- University building with laboratories, offices for staff, lecture rooms, student group rooms
- Houses roughly 150 employees and 600 students
- Total area of approximately 9.000 m²
- HVAC systems
 - 9 ventilation units with heat recovery
 - 5 heating systems
 - DHW production by heat exchangers
 - 3 cooling units
 - Schneider BMS system





No two buildings are alike

Buildings have:

- Very different energy need
- Very different insulation level
- Very different HVAC systems
- Very different use profile
- Designed for very different heating supply system

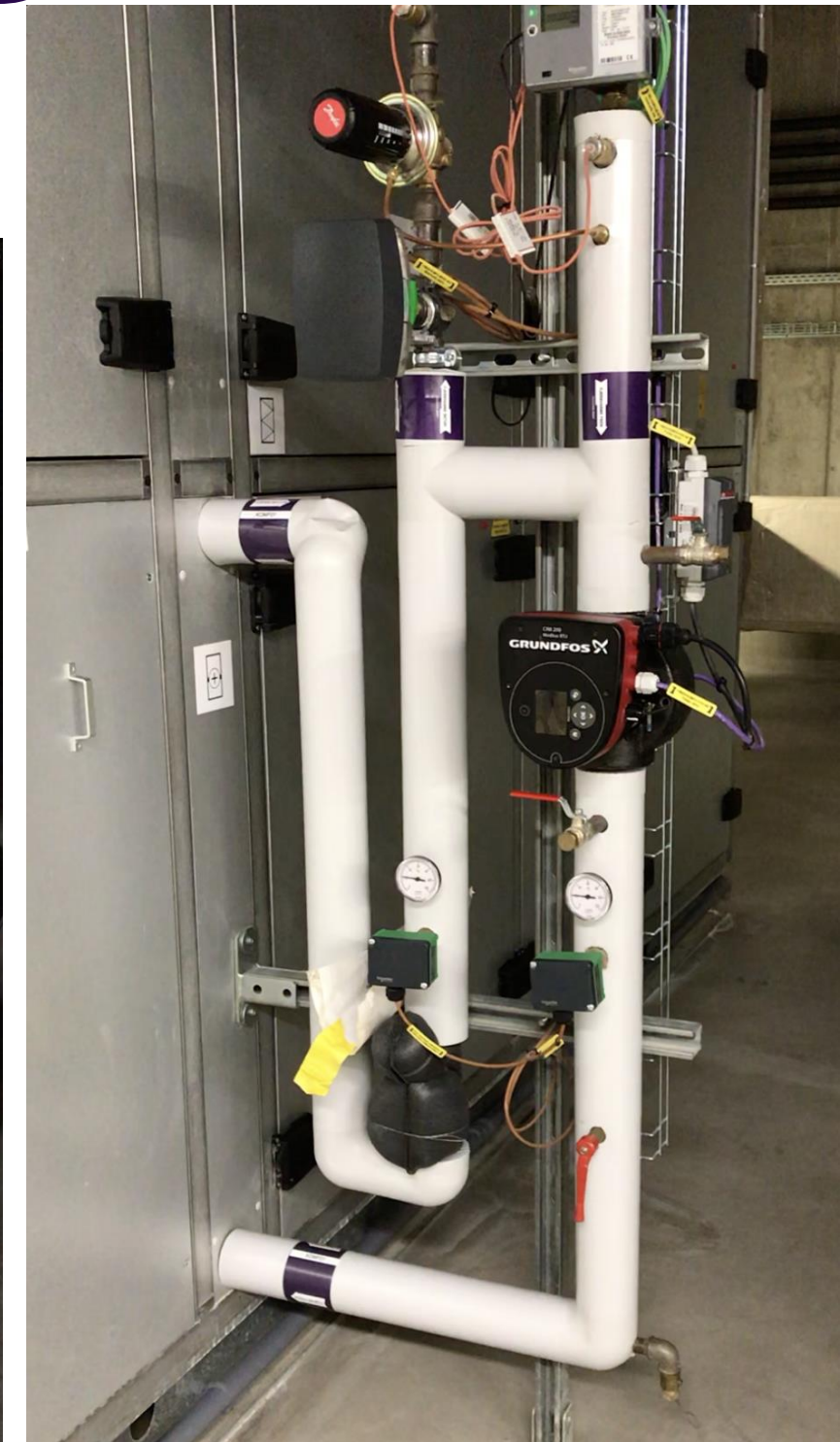
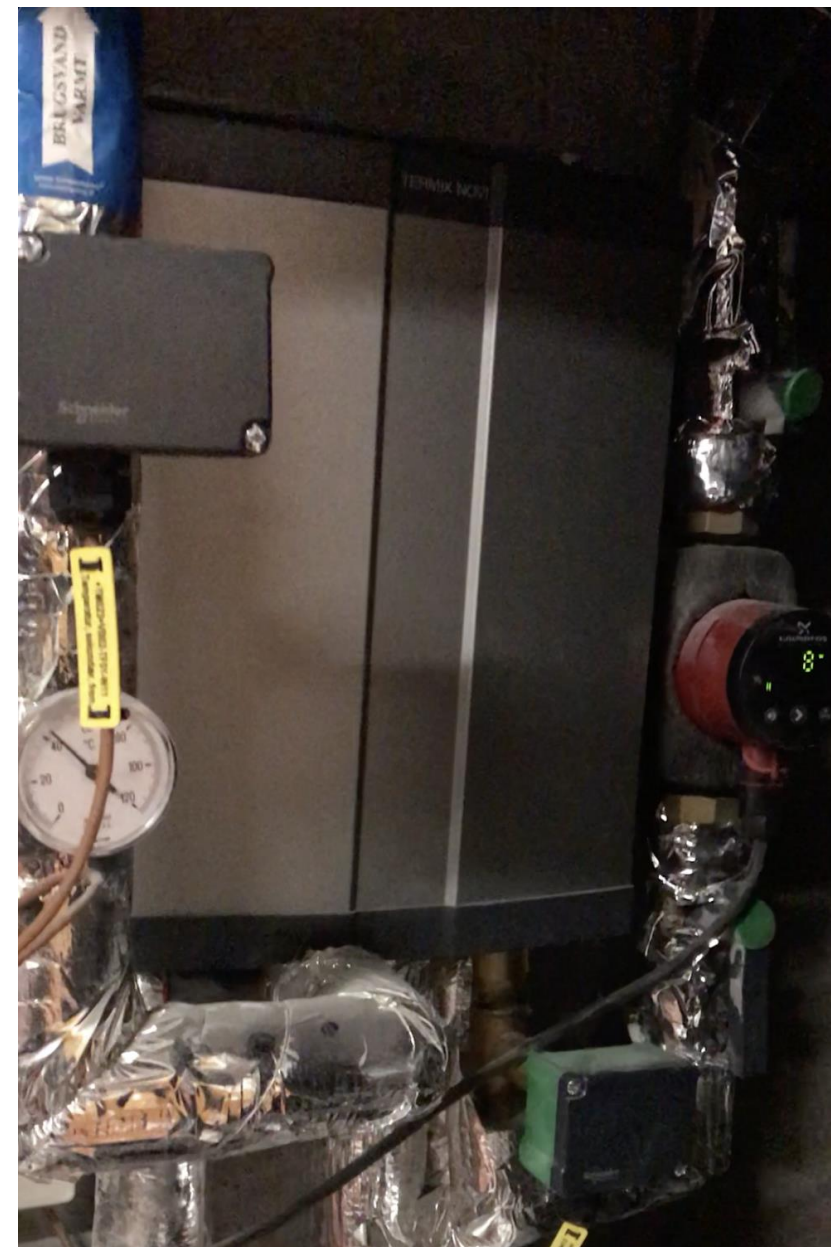




Waste heat potential of a building depends on how we connect it

Temperature demands for waste heat heavily depends on if we connect:

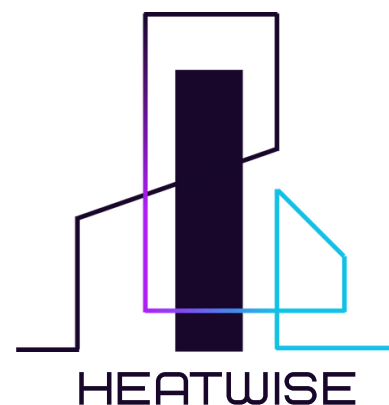
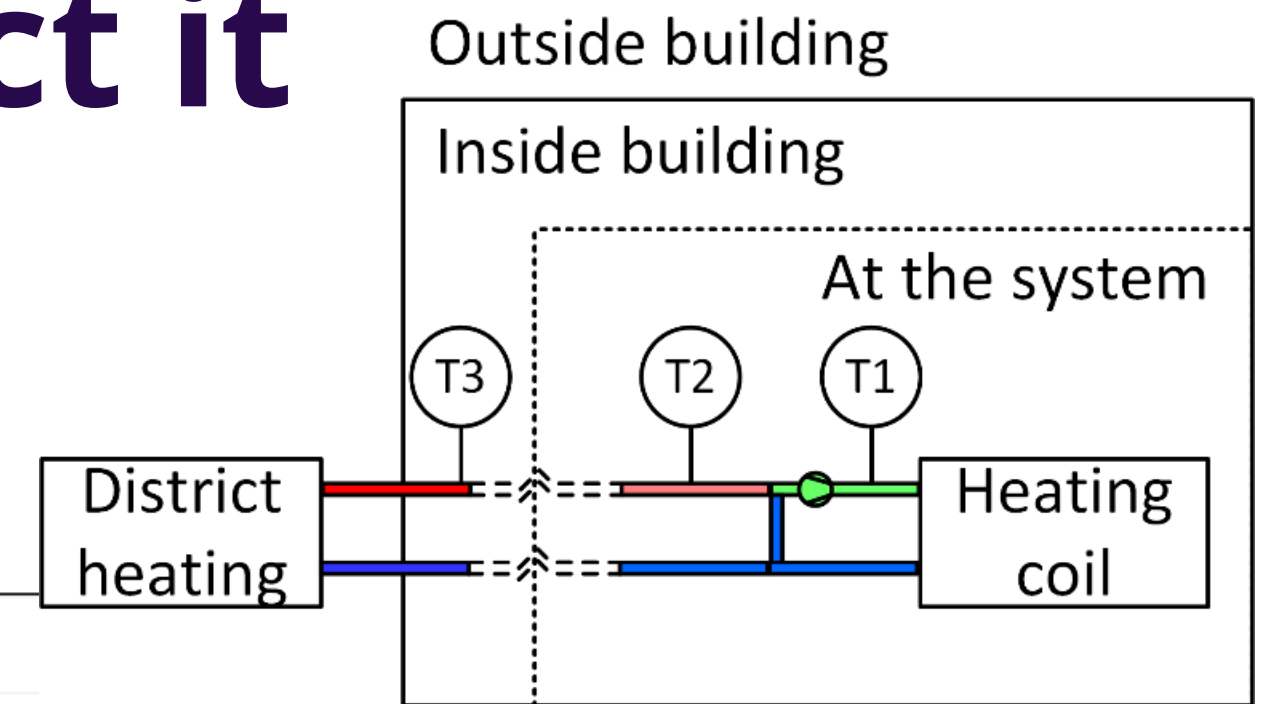
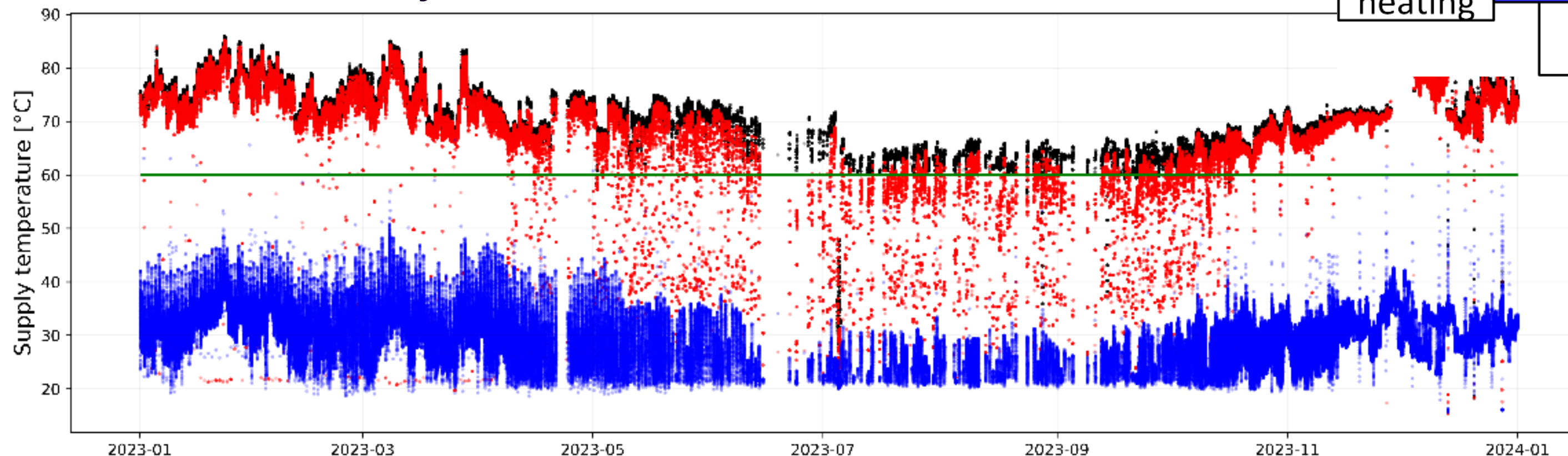
- At the main system
- At HVAC system category, e.g. ventilation, heating, ...
- At the individual systems





Waste heat potential of a building depends on how we connect it

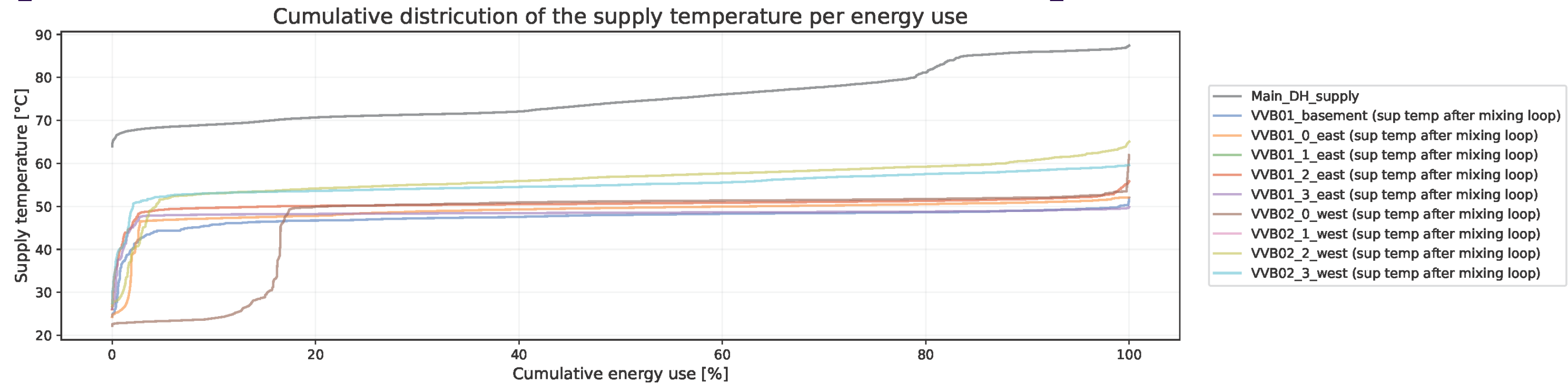
- At the main system (T3, black)
- At HVAC system category, e.g. ventilation, heating, ... (T2, red)
- At the individual systems (T1, blue)



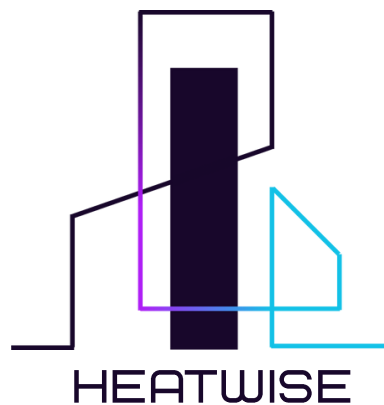
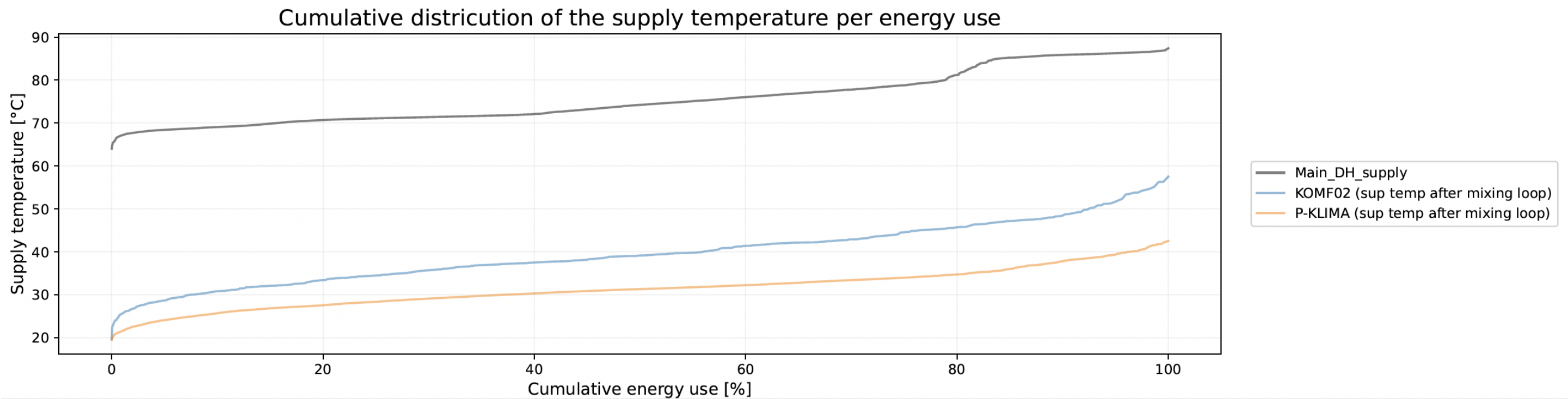


Temperature need for AAU pilot

Domestic
Hot Water



Ventilation





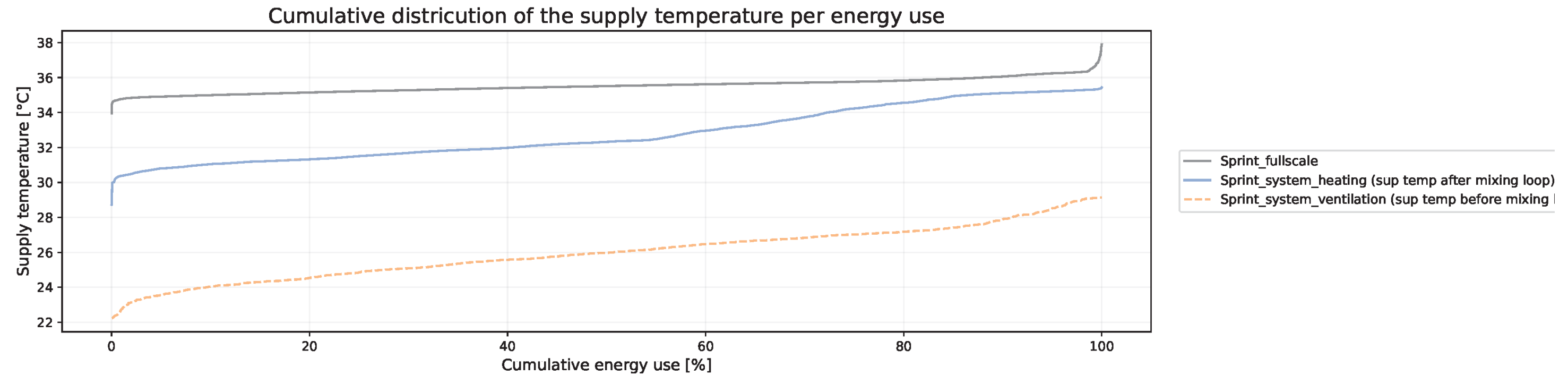
Empa pilot



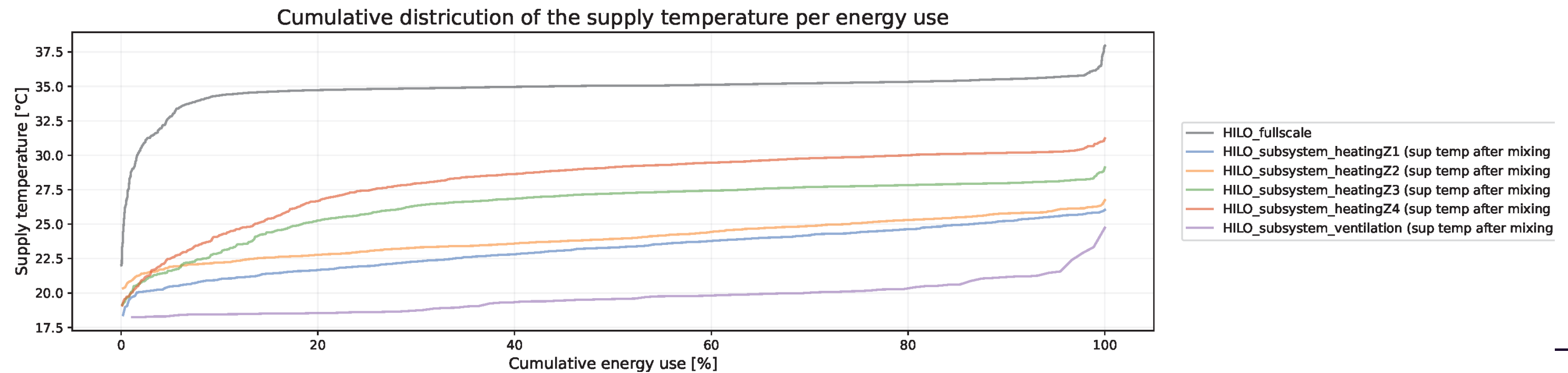


Temperature need for Empa pilot

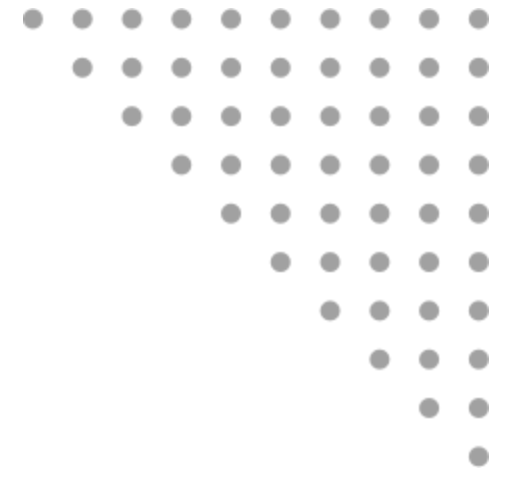
Sprint



HILO



Temperature needed for HVAC system



Ventilation:

- Normally never above 50°C (dust heated to more than approx. 53°C will emit a “burning” smell)
- Typically 25-35°C and rarely above 40°C

Heating (floor heating):

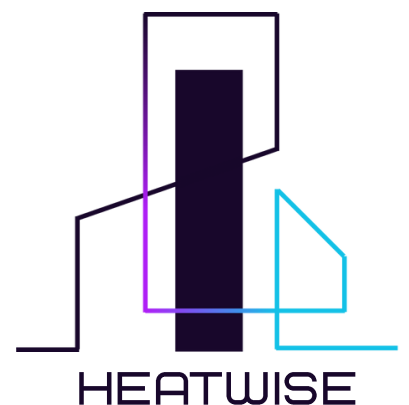
- Typically 25-35°C for wood floors and new installations
- Up to 60°C for concrete floor and similar

Heating (Radiators):

- Typically 40-65°C

Domestic Hot water:

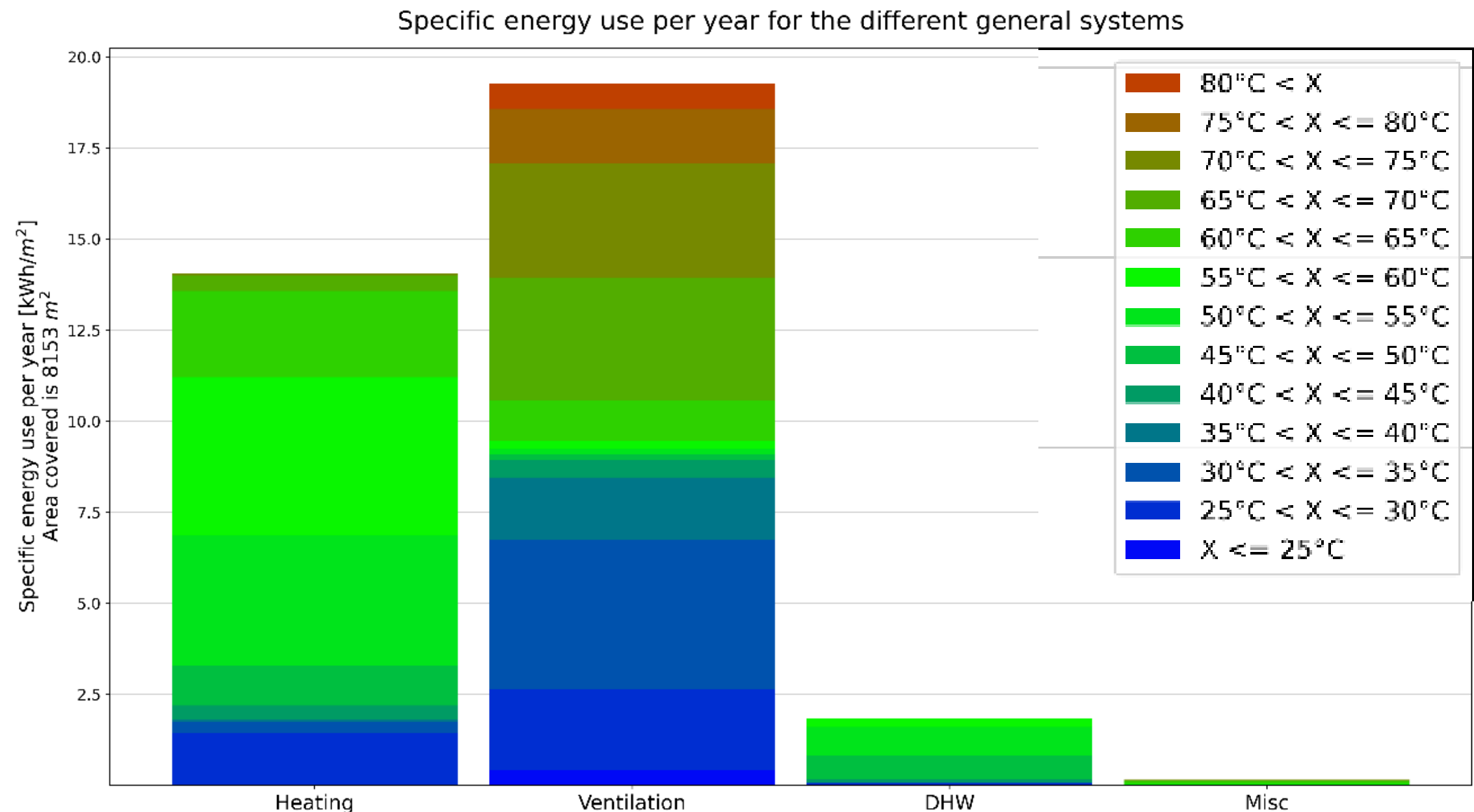
- Typically 45-65°C





Energy use per year (kWh/m² year)

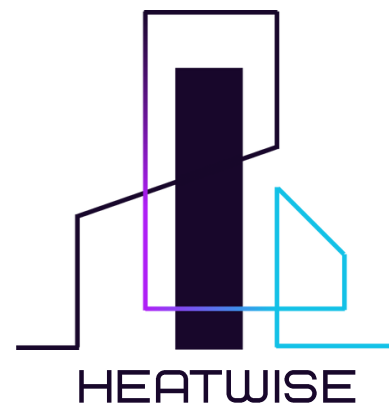
- More than 80% of the heat can be substituted by waste heat from datacentres
- The high temperatures for ventilation are due to a malfunctioning mixing valve and measuring before the mixing loop





What to do when the DC produces more heat than the building needs?

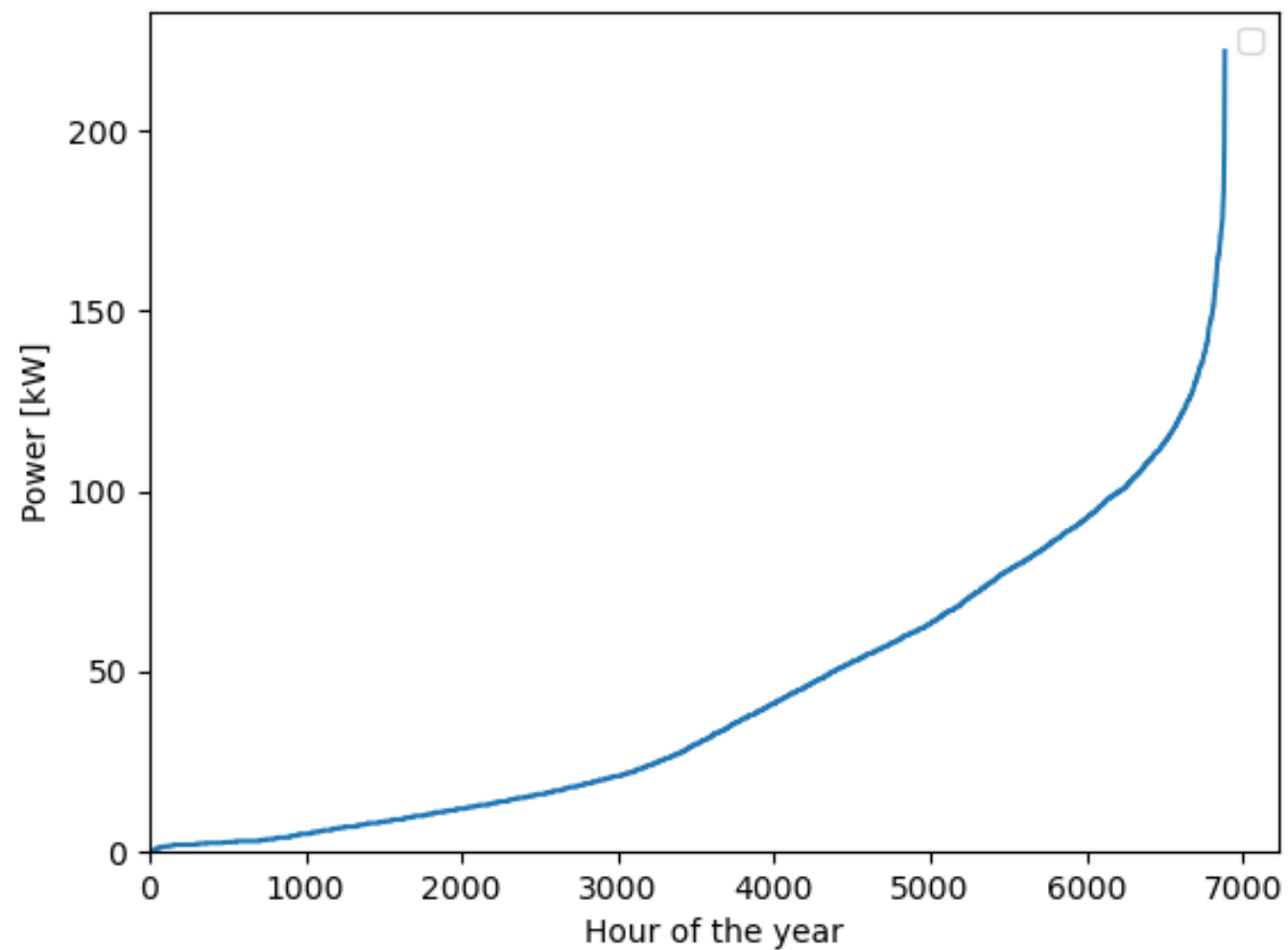
- Sell to the District Heating network or use the building as a heat sink
- Several scenarios will be tested to utilize more heating energy in the building than needed
 - Charging of storage tanks
 - Running systems in a way that increases the heating energy need
 - Dumping heat through HVAC systems instead of a dedicated cooling unit
 - Operate the building at higher temperatures
- Potential side effects of the scenarios
 - Increased/decreased electricity use
 - Increased/decreased cooling need
 - Increased/decreased quality of the indoor environment



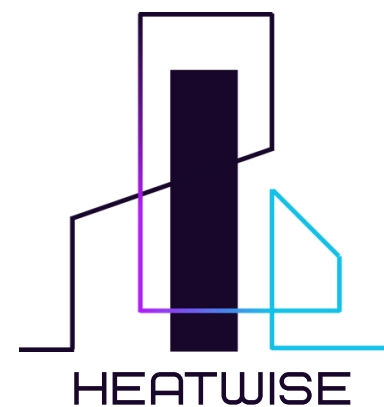
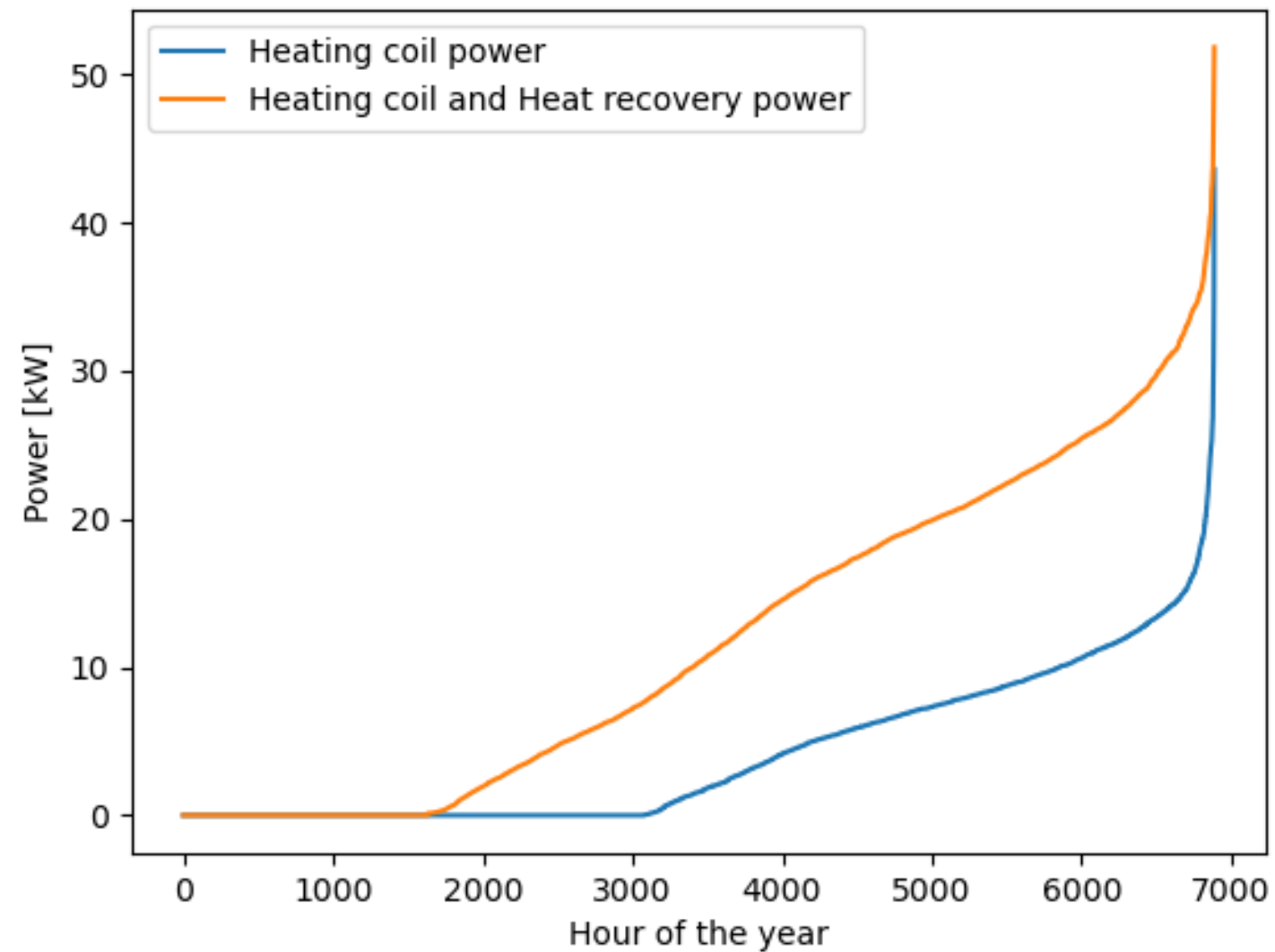


Energy use per year (9.000 m²)

- Building total



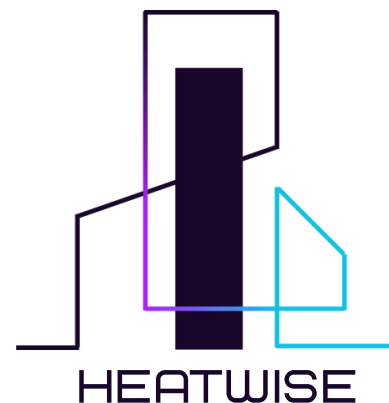
- One ventilation system





Conclusions

- Huge potential to use waste heat from datacenters – especially if connected to the individual HVAC systems
- If you want to evaluate the potential of a building, you need to measure at the individual systems, e.g. after the mixing loops
- The building can act as a heat sink even when there is no need for heating in order to reduce the cooling system for the datacentre



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**THANK
YOU**





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Self-Assessment Tool for Evaluating Efficiency of Data Centres

HEATWISE

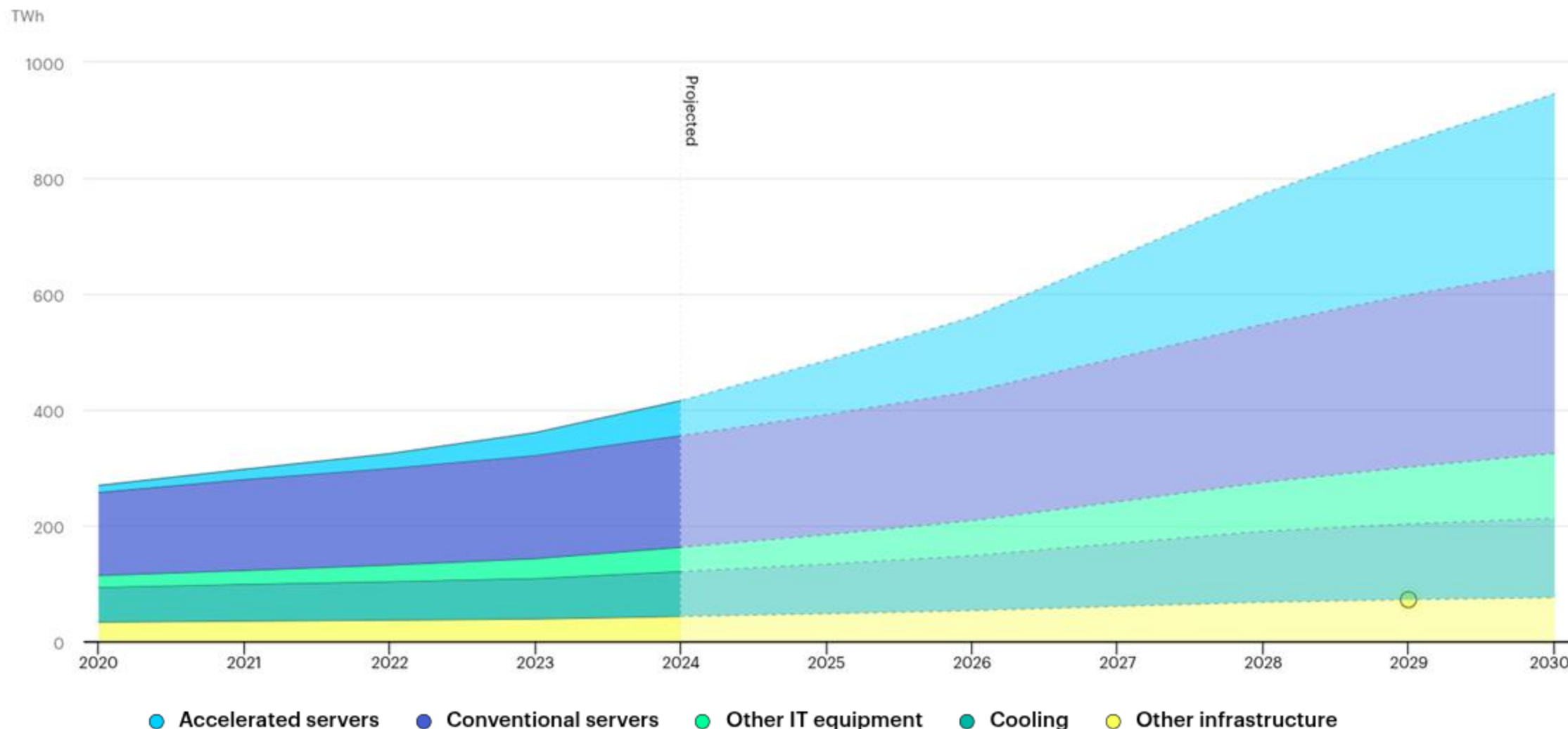
Mustafa Kuzay, PhD
Lead CFD Engineer
Design and Simulation Tech.

Luleå, 19th March 2026
www.heatwise.eu



Why Does Data Centre Efficiency Matter?

- Data centres account for a rapidly growing share of global electricity use (estimated at 3-4%)
- Rising pressure on energy efficiency and sustainability is driving data centres to adopt more structured and measurable assessment practices.
- Since 2024, the EU's Energy Efficiency Directive (EED) mandates reporting and continuous performance improvement.



<https://www.iea.org/data-and-statistics/charts/global-data-centre-electricity-consumption-by-equipment-base-case-2020-2030>



Energy Efficiency Directive

Using energy more efficiently will contribute to reducing the EU's overall energy consumption. The Energy Efficiency Directive is therefore a key driver of Europe's energy transition.



- Data centres = 3-4% of global electricity
- Sustainability pressure from regulators & customers
- Rising OPEX due to energy costs
- Efficiency = cost advantage + green reputation



Energy Efficiency Directive Requirements

🔍 Why It Matters

EED → Mandatory KPI Reporting (PUE, COP, WUE, REF, PES)

- ✓ Data centres >500 kW must report regularly
- ✓ Reporting today = manual, fragmented, time-consuming
- ✓ Only 36% participation (2025 EUDCA)
- ✓ Data access & compliance remain major challenges



Assessment of the energy performance and sustainability of data centres in EU

First Technical Report - July 2025

🚀 Our Solution

Automated EED Reporting Platform

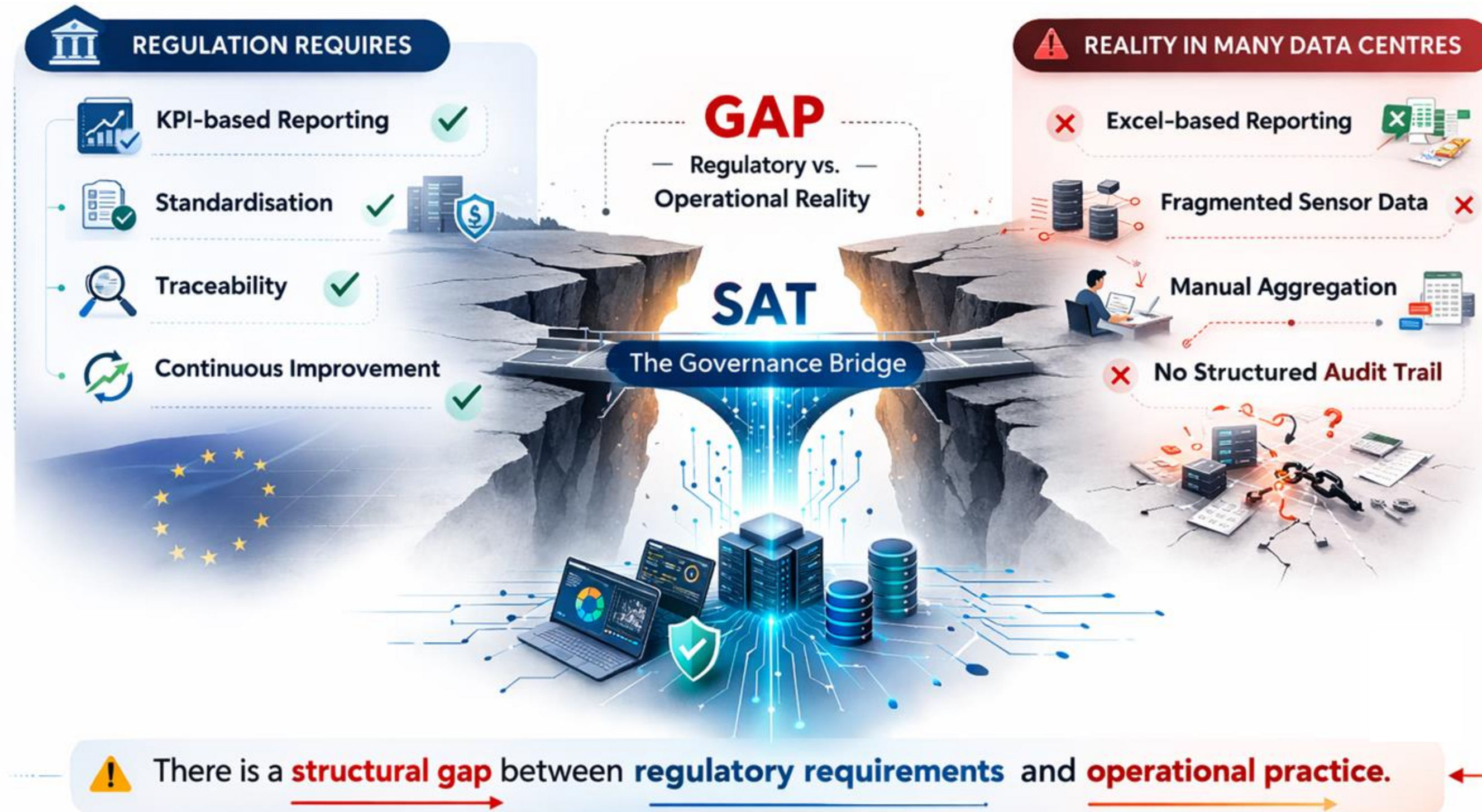
- ✓ Fully KPI-compliant (PUE, COP, WUE, REF, PES)
- ✓ Auditor-ready documentation
- ✓ No manual data handling
- ✓ Fast, reliable, and user-friendly
- ✓ Fully aligned with EU sustainability targets



The Heatwise Project is closely monitoring documentation and updates from EU and EUDCA.



The Compliance–Operation Gap in Data Centres



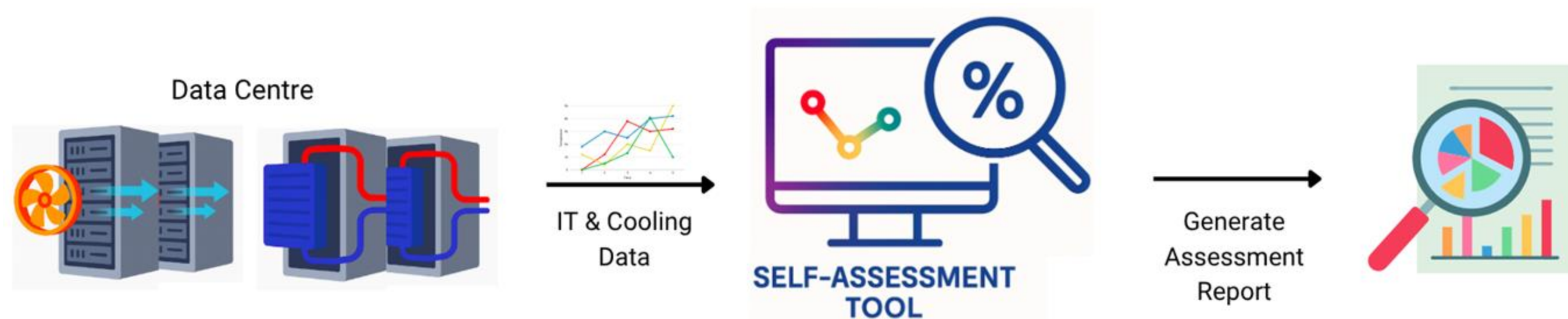
A structural gap exists between regulatory expectations and day-to-day operational reality.

The Self-Assessment Tool (SAT) was developed to close this gap.

Overview of the Self-Assessment Tool



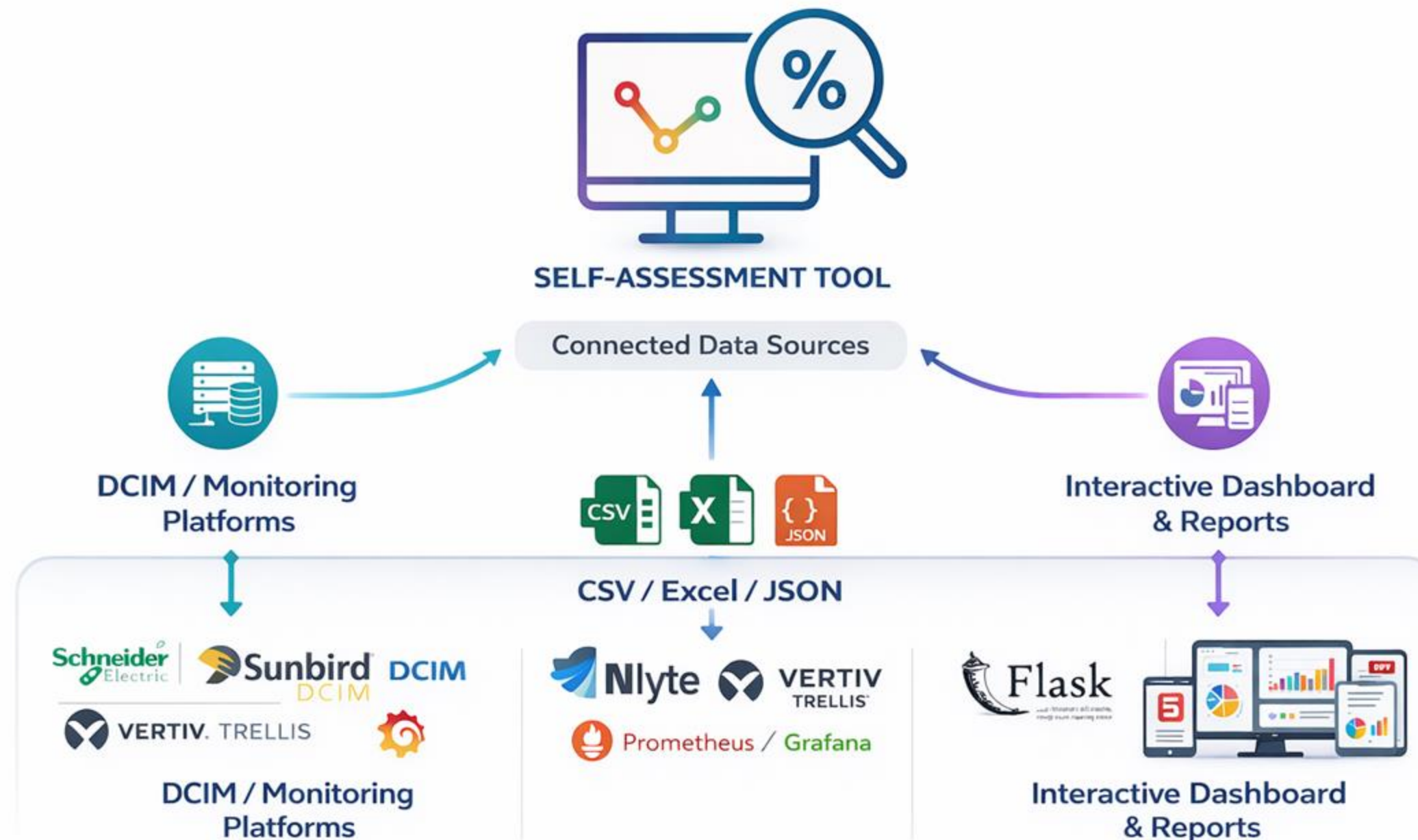
- The SAT is a flexible KPI-driven assessment platform developed within the **HEATWISE Project**.
- The SAT operates as a web-based service that can integrate directly with DCIM platforms (e.g., Schneider EcoStruxure, Sunbird DCIM, Nlyte, Vertiv Trellis) or analyse datasets manually uploaded by the user.
- The tool automatically generates comprehensive, EED-aligned performance reports for data centres.



- Evaluate efficiency of the data centre according to the KPIs in real time
- Generate a comprehensive report within the selected reporting period.

Overview of the Self-Assessment Tool

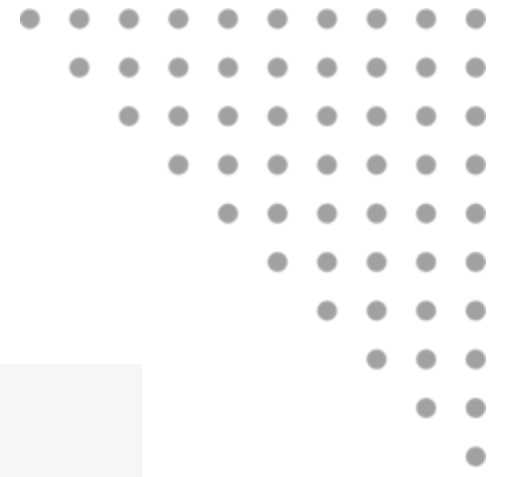
- Automated data capture from sensors & monitoring systems
- Real-time KPI calculation
- Interactive dashboard with heatmaps & bar charts
- Automated PDF report for management & regulators



We offer a web-based version of the tool designed to accommodate the diverse preferences and infrastructure requirements of data centres.



Data centre footprint in Europe



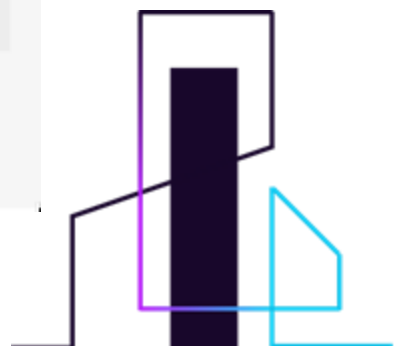
Question: Which of the following indicators are actively measured, based on actual data?



Source: European colocation and hyperscale survey, Pb7 Research, 2025 (N=69). © EUDCA 2026. All rights reserved.

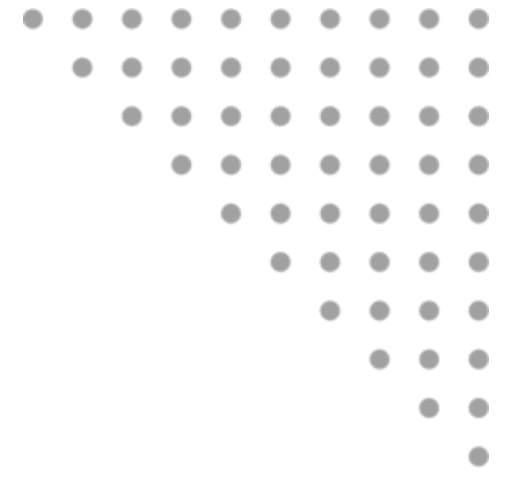
EED Aligned Data Centre Footprint EU-27 countries, 2024

indicator	EED Annex	Metric	Colocation	Hyperscale (Co-hosting)	Enterprise	Total
IT Power Demand Installed (nominal)	XVD 1	MW	5,230	2,697	2,602	10,529
total Energy Consumption	XVD 4.1	TWh	27.6	10.2	20.2	57.9
total Energy Consumption IT Equipment	XVD 4.2	TWh	20.3	8.9	11.0	40.2
total Water input	XVD 5	m3 (mln)	12.1			
total Potable Water Input	XVD 5	m3 (mln)	5.7			
waste Heat Re-used	XVD 6.1	TWh	0,16			
total Renewable Energy Consumption	XVD 8	TWh	24.7			
PUE (Power Usage Effectiveness)			1.36			
WUE (Water Usage Effectiveness)		l/kWh	0.44			
REFE (Renewable Energy Factor for Electricity)			0.90			
ERF (Energy re-use factor)			0.01			



HEATWISE

KPIs in Self-Assessment Tool



EED-ALIGNED REGULATORY KPIS

Power Usage Effectiveness

It expresses the ratio between the total energy consumed by the data center and the portion used directly by IT equipment, indicating how efficiently the facility operates.

PUE

Energy Reuse Factor

It represents the fraction of a data center's waste heat that is recovered and reused for useful heating purposes.

ERF

Renewable Energy Factor

It indicates the share of a data center's total heat output that is successfully recovered and delivered for external useful heating.

REF

Primary Energy Savings

It reflects the amount of primary energy saved when a data center's recovered heat is used to replace heat that would otherwise be produced by conventional energy sources.

PES

Coefficient of Performance

It expresses how much heating or cooling a system delivers per unit of electrical energy it consumes, indicating its efficiency.

COP

Water Usage Effectiveness

It expresses the ratio between the total water consumed by the data center and the energy used by IT equipment, indicating how efficiently water is used to support IT operations.

WUE

- Validates data
- Harmonises metrics
- Standardised methodology
- Produces regulator-ready output

EXTENDED DIAGNOSTIC KPIS (HEATWISE)

Rack Cooling Index

It measures how closely the rack inlet temperatures stay within ASHRAE thermal limits, indicating the effectiveness of the cooling delivery to the rack. (High and Low)

RCI

Return Temperature Index

It compares the actual temperature rise of the air returning from the racks to the ideal rise, revealing how effectively the cooling air is being used.

RTI

Return Heat Index

It indicates the proportion of return air that has effectively absorbed server heat, showing how well the cooling system captures and returns thermal energy.

RHI

Recirculation Index

It quantifies how much of the hot exhaust air unintentionally returns to server inlets, raising inlet temperatures above the supplied cooling air.

RI

Leakage Index

It quantifies how much unwanted cold air leaks through a rack into the hot region, lowering outlet temperatures and revealing airflow inefficiencies.

LI

Heat Transfer Efficiency

It expresses how effectively a cooling or heat exchange system transfers heat compared to its theoretical maximum potential.

HTE

CDU Heat Exchanger Effectiveness

It expresses how efficiently the CDU heat exchanger transfers thermal energy between the primary and secondary coolant loops.

CDU HEX

Heat Rejection Efficiency

It expresses the ratio between the heat successfully rejected by the cooling system and the heat absorbed from IT equipment.

HRE

Energy Demand for Cooling

It expresses the electrical energy demand of cooling systems required to maintain acceptable thermal conditions in the data center.

EDC

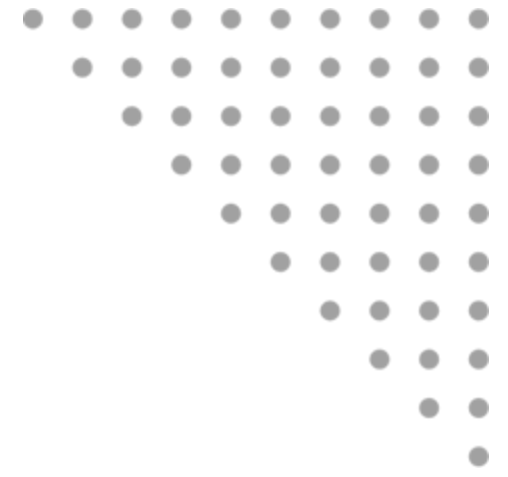


The broader the data label coverage, the more comprehensive and detailed the KPI assessment becomes.

More data → More insights → Better decisions



Features of the Self-Assessment Tool

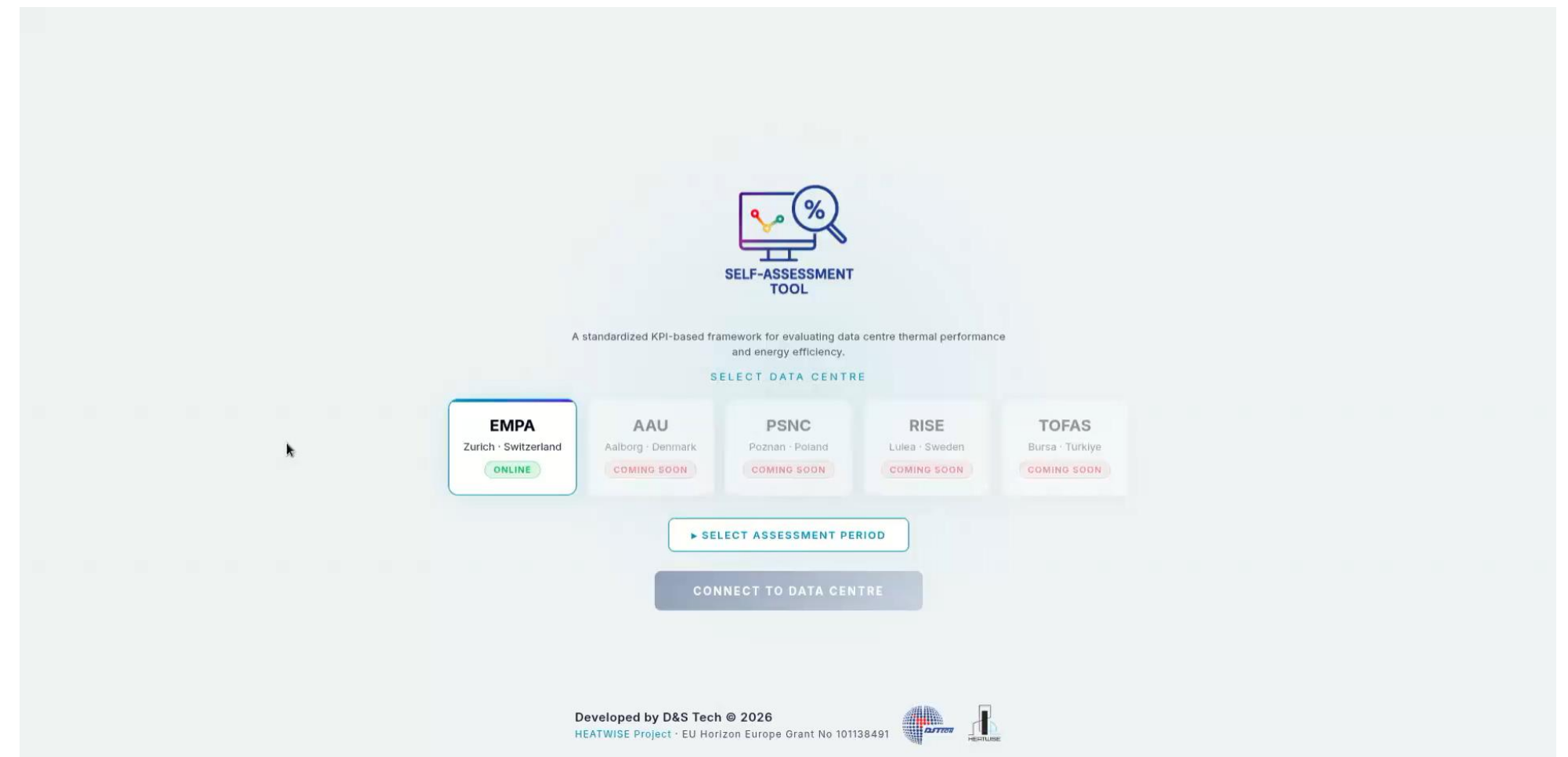


- **Data**
 - From DMS
 - Select Period
 - Historical Data
 - From External Source
 - Import Data
- **Data Centre**
 - Heatwise Pilots (AAU, EMPA, PSNC, RISE, TOFAS)
 - 5 External Pilots → tertiary buildings
- **Report**
 - Data Centre Informations
 - Layout
 - Thermal Energy and Waste Heat KPIs
 - Assessment
 - Thermal and Power Maps
 - ASHRAE Checks for air and hybrid cooled DCs



Latest version of the SAT

- Real-Time Data Integration
 - DCIM, monitoring platforms, API, etc.
- Comprehensive KPI Analytics
 - Thermal and energy efficiency KPIs
- Advanced Data Processing Engine
 - Parallel data acquisition, synchronization, data aggregation and validation
- Interactive Operational Dashboard
 - Visual analytics interface, monitoring, dynamic visualisation
- Multi Data Centre Support
- Automated Reporting
- Modular and Extensible Architecture
 - Easy integration of new metrics and data sources



Self-Assessment Report Layout



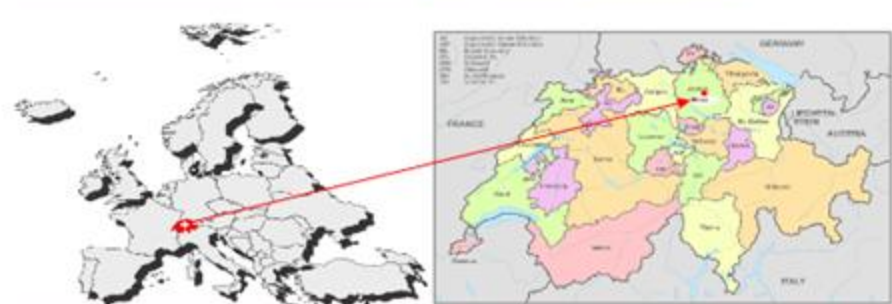
Self-Assessment Report

Data Centre Thermal Performance & Energy Efficiency

Generated: 2026-03-12 07:23 UTC

Data Centre Overview

Data Centre: EMPA	Location: Zurich - Switzerland
Cooling Strategy: Direct to Chip Two-Phase Liquid Cooling	Reporting Period: 2026-02-26 11:00 – 2026-02-26 16:00 (UTC)
Logging Interval: 15 min	Number of Active Servers: 37
Avg Inlet / Outlet Temperatures: 28.0°C / 49.9°C	Air Supply / Return Temperatures: 26.8°C / 33.0°C
Water Inlet / Outlet Temperatures: 26.5°C / 33.5°C	Total Server Power: 6.97 kW



About This Report

This report was generated using the Self-Assessment Tool (SAT), developed as part of the HEATWISE Project. The SAT provides a standardized KPI-based assessment framework for evaluating data centre thermal performance and energy efficiency.

Self-Assessment Tool (SAT) - HEATWISE Project - EU Horizon Europe Grant No 101138491 | Report ID: SAT-EMPA-2026-071 | SAT Web Edition v2.4.0

SAT Assessment Report

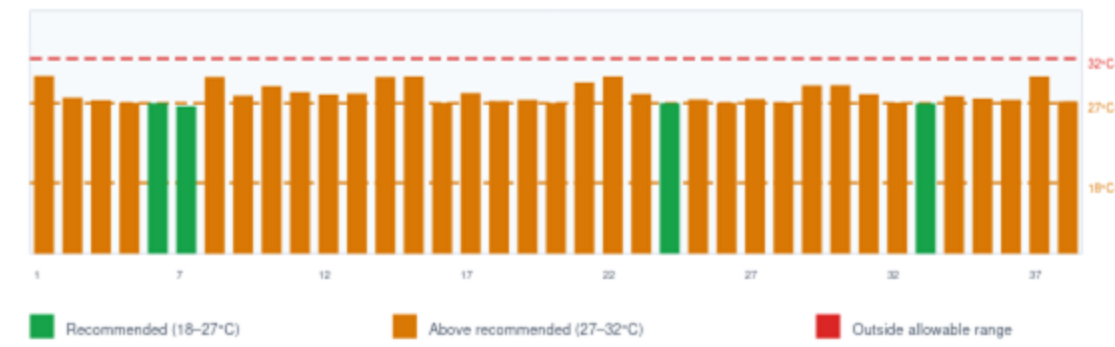
KPI SUMMARY — THERMAL PERFORMANCE					
KPI	Description	Value	Ideal	Assessment	Period Avg
RTI	Return Temperature Index	128.1%	100%	Recirculation	128.1%
RHI	Rack Heat Index	0.194	1.0	Unacceptable	0.194
RCI HI	RCI High	99.53%	100%	Good	99.53%
RCI LO	RCI Low	107.76%	100%	Poor	107.76%
RI	Recirculation Index	115.02%	100%	Hot Air Recirculation	115.02%
LI	Leakage Index	53.78%	100%	Cold Air Leakage	53.78%

KPI SUMMARY — ENERGY & WASTE HEAT				
KPI	Description	Value	Ideal	Assessment
PUE	Power Usage Effectiveness	1.536	1.0	—
COP	Coefficient of Performance	1.867	*	—
ERF	Energy Reuse Factor	-49.1252	1.0	—
PES	Primary Energy Savings	0.10 kW	0	—
P REUSE	Power Reuse	-8.79 kW	max	—

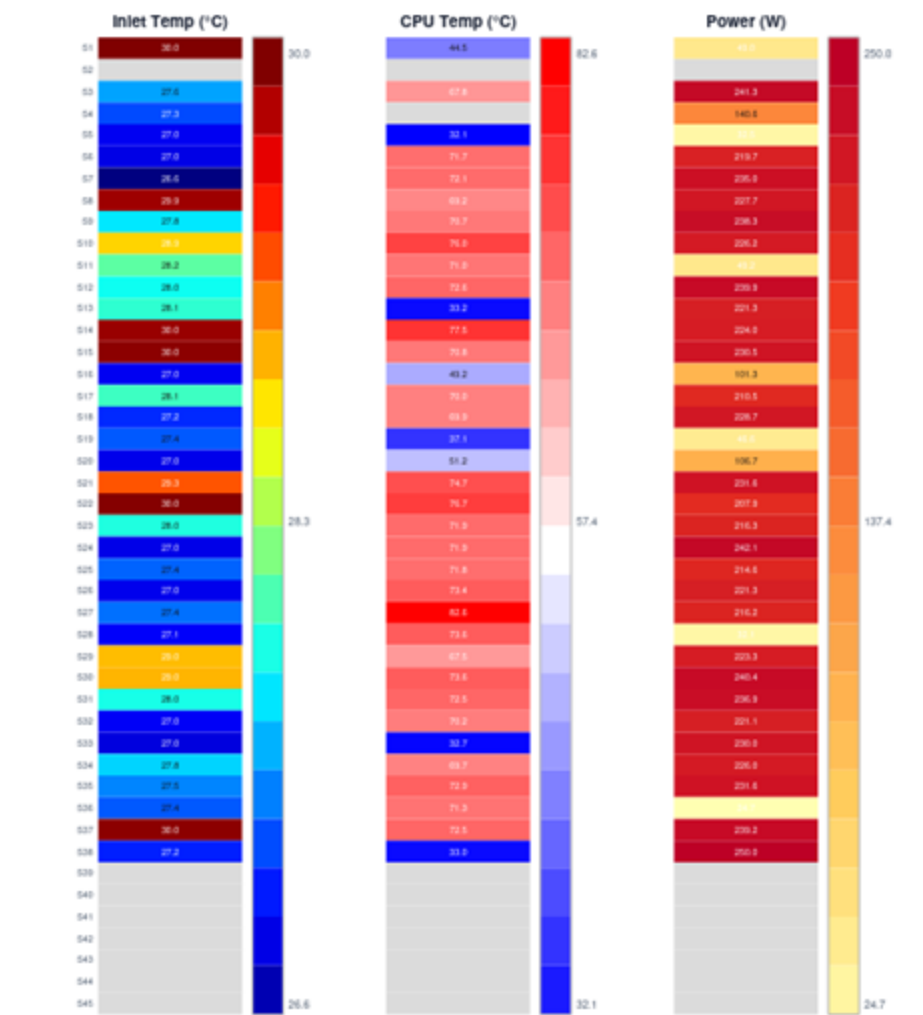
TEMPORAL KPI PERFORMANCE TRENDS



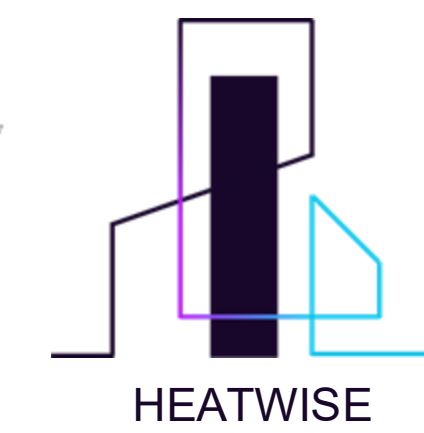
SERVER TEMPERATURE OVERVIEW



SERVER HEATMAP OVERVIEW



The SAT evaluates thermal efficiency of the data centre according to the calculated KPIs
This is a both technical report and management-level decision document.

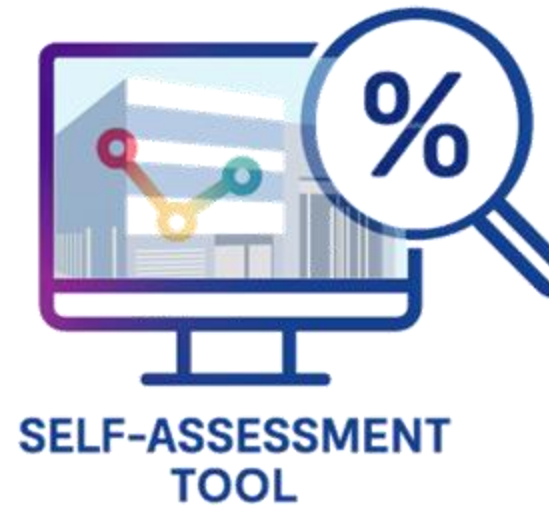


Market Value of the Self-Assessment Tool

- ✓ EED reporting simplified → automated & consistent
 - ✓ Operational insights → detect hotspots & inefficiencies
 - ✓ Benchmarking → compare across sites
 - ✓ Customer transparency → promote green and efficient operat
- With the SAT, your data centre doesn't just run, it runs transparently.*
- ✓ Saves time → no more manual reporting
 - ✓ Supports cost reduction → by identifying inefficiencies
 - ✓ Supports compliance → by providing EED-aligned documentation
 - ✓ Strengthens brand → through transparent sustainability reporting



Commercialisation activities are being developed jointly with H1 Systems. A Communication & Exploitation Agreement (CEA) is currently under preparation. SAT implementation has already started at H1 Systems as an external pilot.



IMPORTANCE OF ASSESSING DATA CENTRE EFFICIENCY



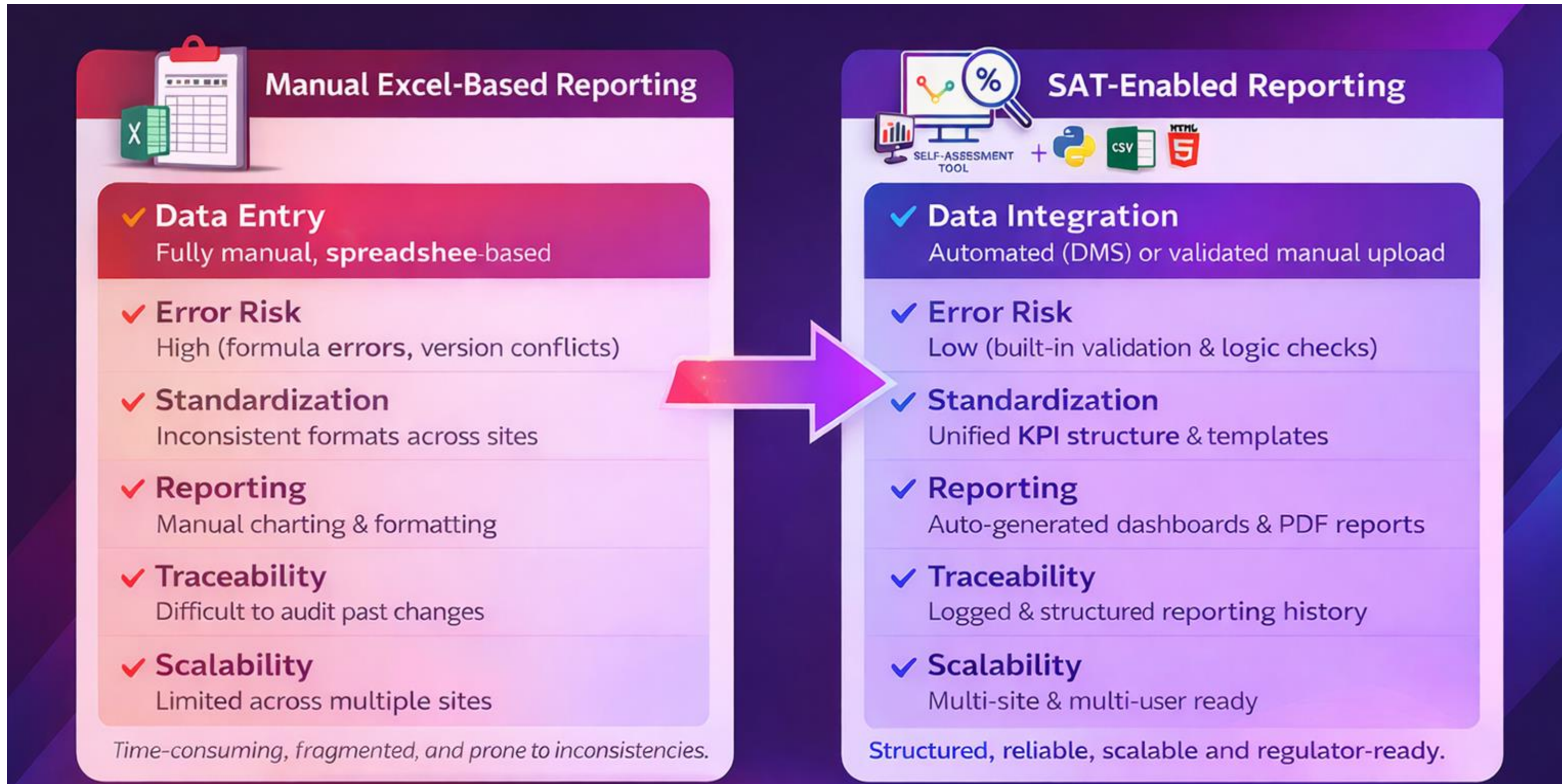
Risk of Non-Compliance



Non-compliance escalates from reporting gaps to regulatory exposure.



Comparison of the SAT Reporting with the Manual Excel-Based Reporting



Moving from spreadsheets to a structured SAT platform enhances accuracy, compliance, transparency and operational efficiency.

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HEATWISE

www.heatwise.eu

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Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI
EU Framework Programmes

Thermal Prediction and Optimization Models for Maximum Waste Heat Reuse in Data Centres

HEATWISE

Başak Bayraktar
CFD Engineer
Design and Simulation Tech.

Luleå, 19th March 2026
www.heatwise.eu



Energy Challenge in Data Centres

- Data centres currently consume about 1.5% of global electricity consumption (≈ 415 TWh), with demand growing rapidly due to AI and accelerated computing.
- Global electricity use from data centres is projected to more than double to ≈ 945 TWh by 2030.
- In the EU, data centre consumption was estimated at 70 TWh in 2024, expected to rise to 115 TWh by 2030.



European Data Centre Association

Energy Efficiency Directive

Using energy more efficiently will contribute to reducing the EU's overall energy consumption. The Energy Efficiency Directive is therefore a key driver of Europe's energy transition.



- This growth challenges EU energy efficiency targets, including the 11.7% reduction in final energy consumption by 2030 and the global pledge to double efficiency improvements.
- Rapid expansion also creates grid connection and capacity constraints, stressing energy systems.

https://energy.ec.europa.eu/news/focus-data-centres-energy-hungry-challenge-2025-11-17_en

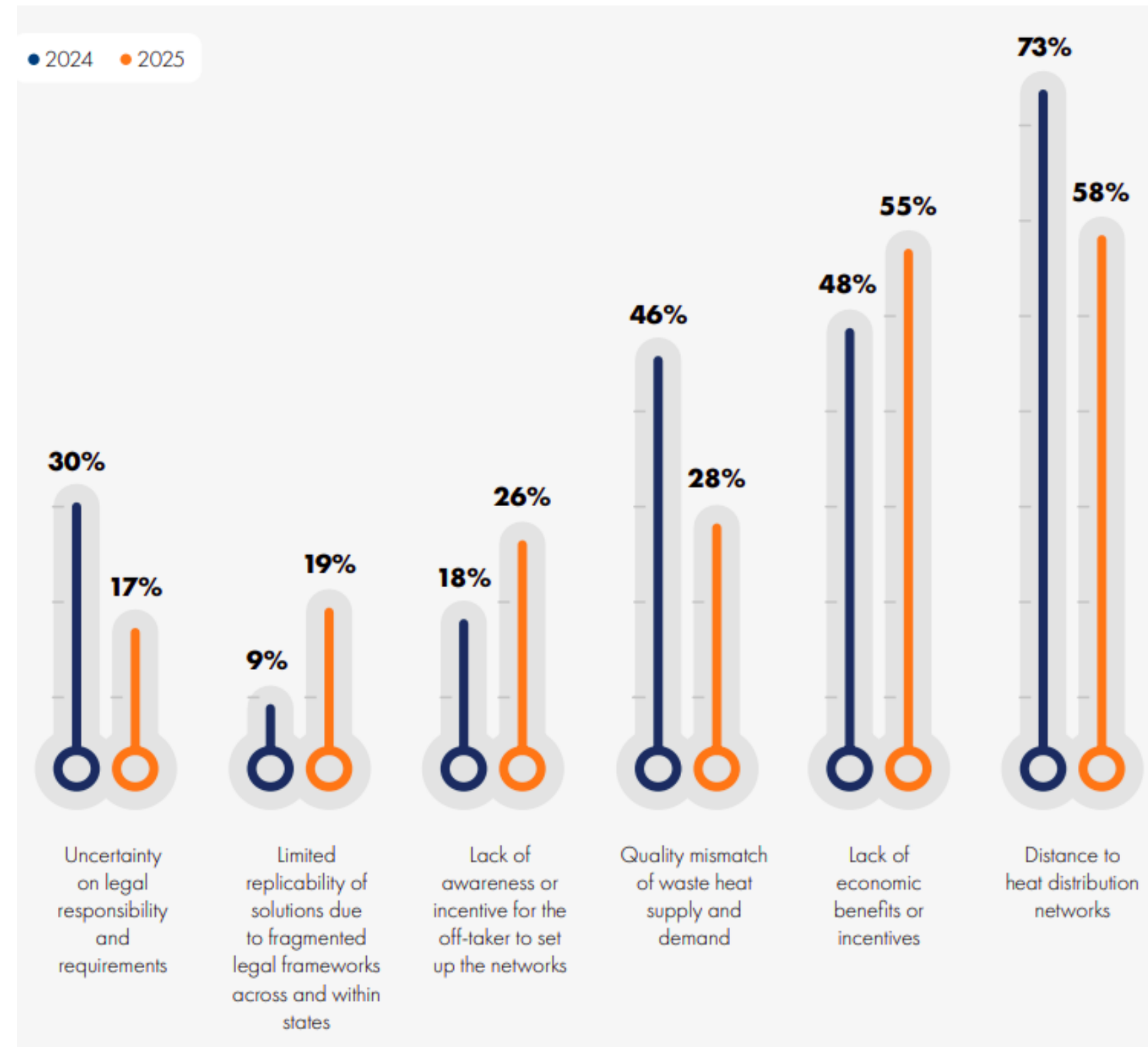


Heat Reuse in Data Centres

- Waste heat typically ranges between 25–30°C (air-cooled) and 40–48°C (liquid-cooled), often requiring temperature upgrading for practical reuse.
- The expansion of liquid cooling improves heat quality, reducing reliance on heat pumps and increasing reuse potential.
- Key barriers remain distance to networks, infrastructure costs, economic feasibility, and temperature mismatch.
- When properly integrated, waste heat reuse can reduce fossil fuel use, cut emissions, and improve overall heating network efficiency.
- Emerging policies (e.g., Germany’s Energy Efficiency Act) are introducing heat reuse obligations, encouraging new data centres to be designed with heat export capability.

Source: European Data Centre Association (EUDCA). (2026). State of European Data Centres 2026. Spa Communications.

What are the main barriers to the export of heat?



Source: European colocation and hyperscale survey, Pb7 Research, 2025 (N=69). © EUDCA 2026. All rights reserved



Why Traditional Cooling Limits Heat Recovery Potential?



- Dispersed and low-quality heat output (room-level air capture)
- Requires air-to-water transfer layer (extra coils, pumps, losses)
- Higher energy overhead for heat capture and upgrading
- Dependent on nearby district heating infrastructure
- Complex and costly retrofitting in legacy facilities
- Limited monitoring for heat reuse optimisation
- Difficult integration with local energy systems



Why data-driven optimization is needed?



- Data centres already operate close to high efficiency, yet significant energy savings remain possible
- Cooling systems involve complex and nonlinear interactions between load, temperature, and flow
- Operators typically rely on static setpoints and conservative settings
- Small operational adjustments can reduce cooling energy and waste heat reuse while maintaining safety
- Large volumes of operational data exist but are not fully utilized for optimization

Data-driven optimization transforms monitoring data into actionable improvements for greener and more efficient data centres.

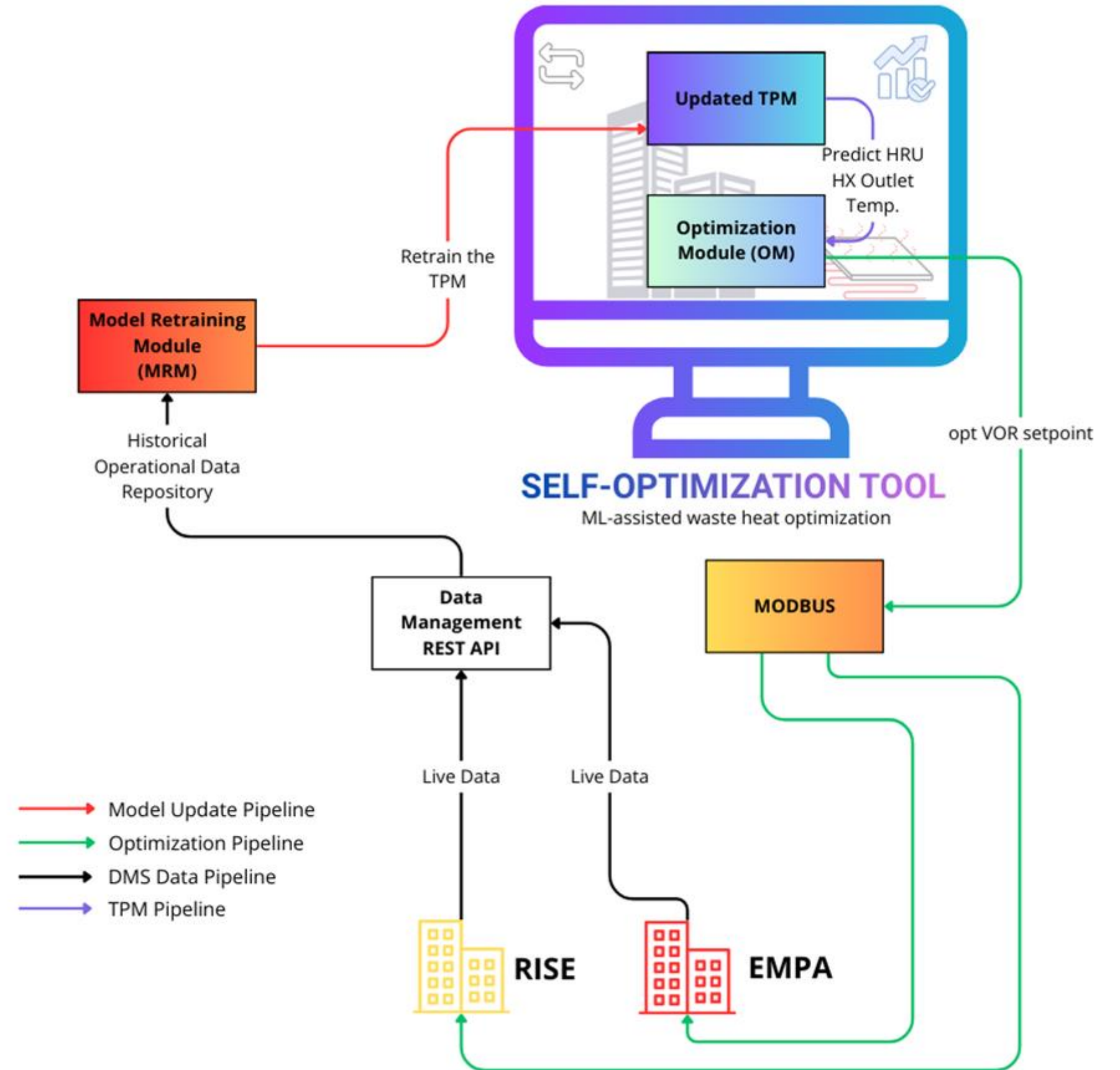


Self-Optimization Tool (SOT)

- The Self-Optimization Tool (SOT) is being developed as a ML-assisted data-driven framework with two core modules: Thermal Prediction Module (TPM) and the Optimization Module (OM).
- The architecture aims to be fully integrated with live data pipelines (Grafana / REST API) and supported both RISE and EMPA pilot sites.

SOT Objectives

- ✓ To determine the valve operating point that maximizes recoverable waste heat under given IT load and cooling system conditions.
- ✓ To maximize waste heat recovery performance (HRU supply temperature and flow optimization).
To adapt cooling system parameters (VOR, supply temperature, flow rate, boiling temperature) based on learned thermal behavior.
- ✓ To compare optimization-based control vs. conventional control strategies at EMPA and RISE pilots.



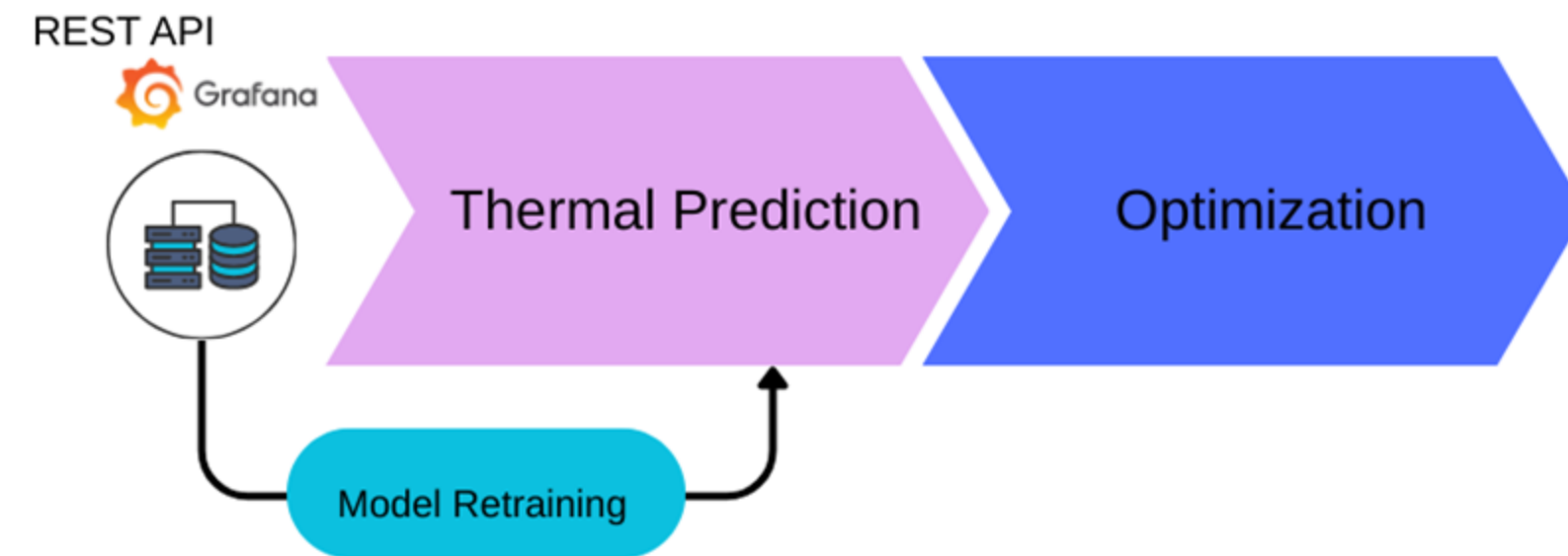
Self-Optimization Tool (SOT) Modules

- Thermal Prediction Module (TPM):

- Uses machine learning to learn the thermal behaviour of the HRU at the cooling system from operational data.
- Predicts the HRU-HX outlet water temperature
- Captures dynamic system behaviour using transient features (lag and trend variables).

- Module Retraining Module (MRM):

- Periodically retrieves newly collected operational data from the data buffer and historical data repository.
- Retrains the thermal prediction model using the expanded dataset to incorporate newly observed operating regimes.
- Deploys the validated TPM model to maintain long-term prediction accuracy.



- Optimization Module (OM):

- Determines the optimal valve operating point (VOR setpoint) using predictions from the thermal surrogate model.
- Evaluates feasible operating conditions under IT load and cooling system constraints.
- Identifies operating points that improve waste heat recovery while maintaining safe system operation.

The SOT aims to maximize reusable waste heat by identifying optimal operating points based on the operational characteristics of the EMPA and RISE pilots using a thermal prediction surrogate.



Thermal Prediction Module (TPM)

- **Objectives**

- Predict key thermal and performance parameters of the cooling system
- Learn nonlinear relationships between IT load, flow rates, temperatures and system response
- Enable near real-time prediction for control adaptation

- **Features:**

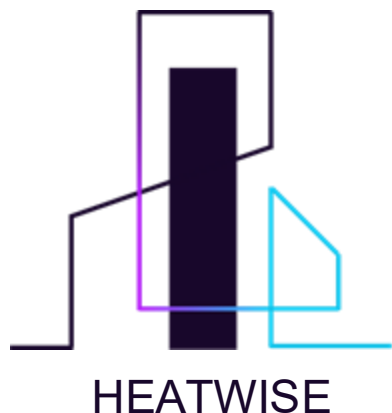
- Temporal lag features (thermal inertia learning)
- Transient operational change indicators
- Chronological dataset preparation
- Regularized XGBoost learning (L2 activated)
- Can be fully integrated with live data pipelines (Grafana / REST API)



Why XGBoost?

- Parallel tree boosting (GBDT / GBM) for high predictive accuracy
- Highly efficient and computationally fast
- Flexible and portable across different computing environments (faster with GPUs)
- Scalable to very large datasets (billions of samples)
- Proven stability in structured tabular data problems

The TPM developed by DSTECH provides the predictive intelligence that enables the Self-Optimization Tool to transform operational data into actionable waste heat maximization strategies.



RISE Cooling System and TPM Architecture

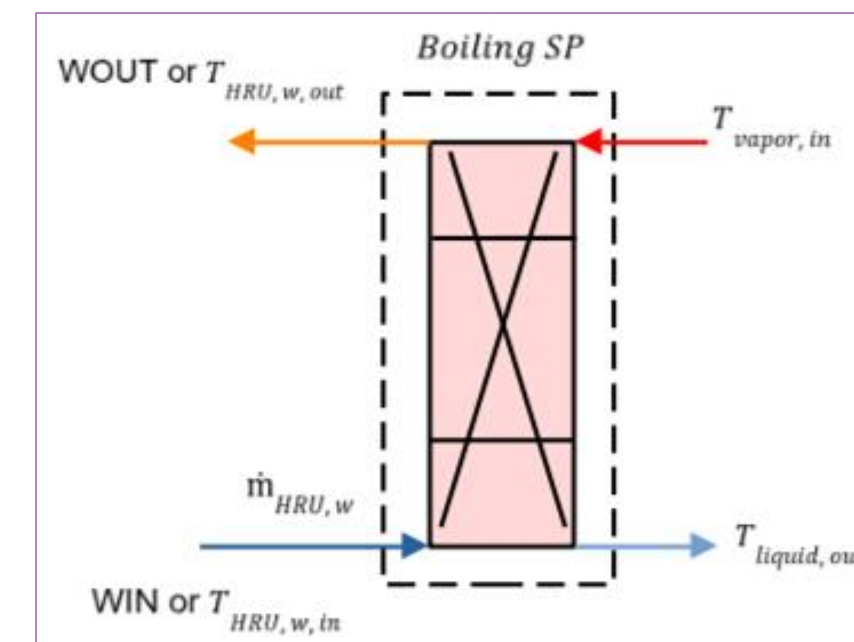
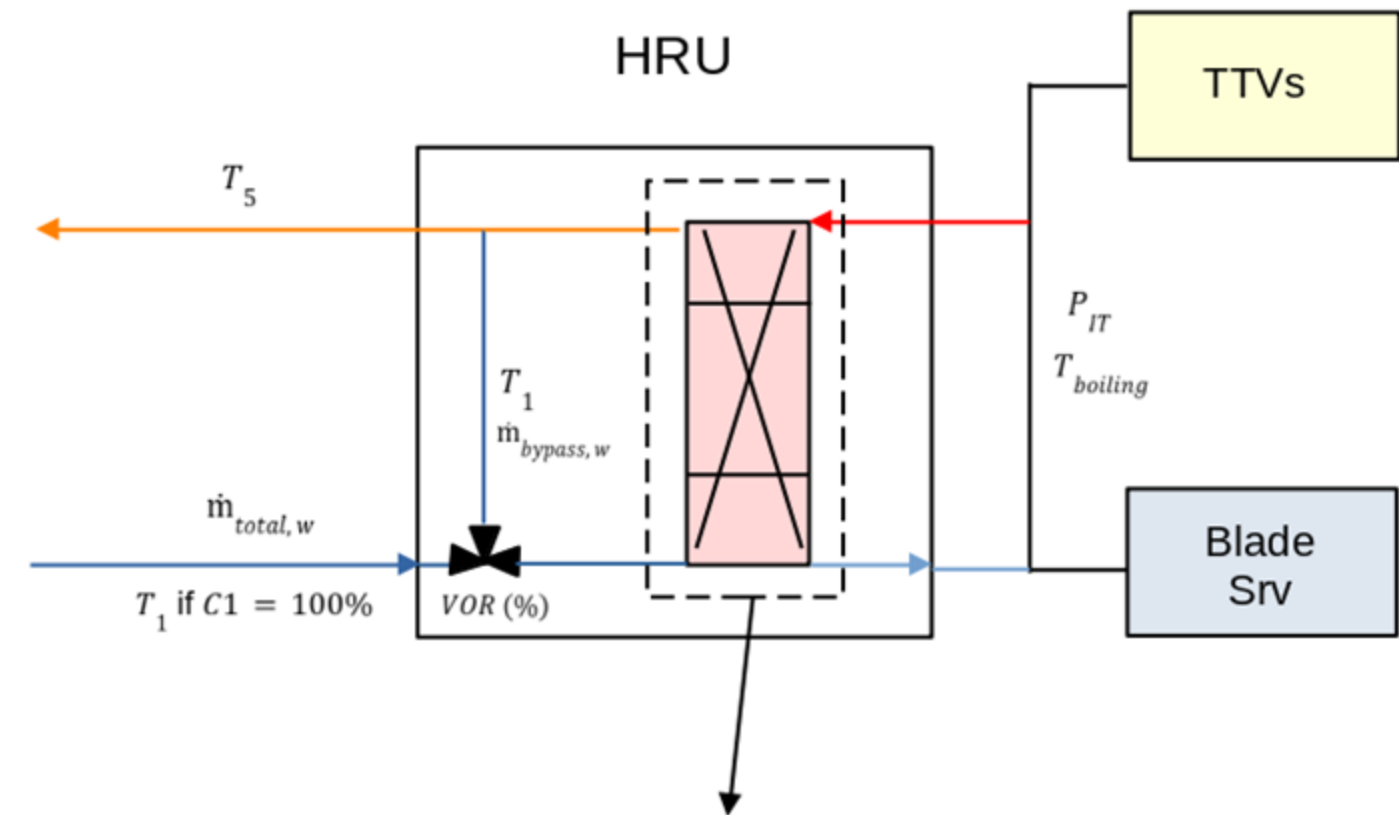
$$\hat{T}_{out,w} = f(P_{IT}, T_{c,vap}, T_1, T_{in,w}, \text{diffs}, \text{lags})$$

Base Features
Temporal Features

Base Features: Measurement data that defines the system state and make surrogate to learn non-linear relation between these inputs and target parameter to be predicted.

Temporal feature construction: Lag features to allow the model capture the thermal inertia and difference features represent operational change between time steps.

The thermal prediction surrogate learns the dynamic behaviour of the cooling system from operational data and enables fast evaluation of different operating conditions for optimization.



*Representative schematic only

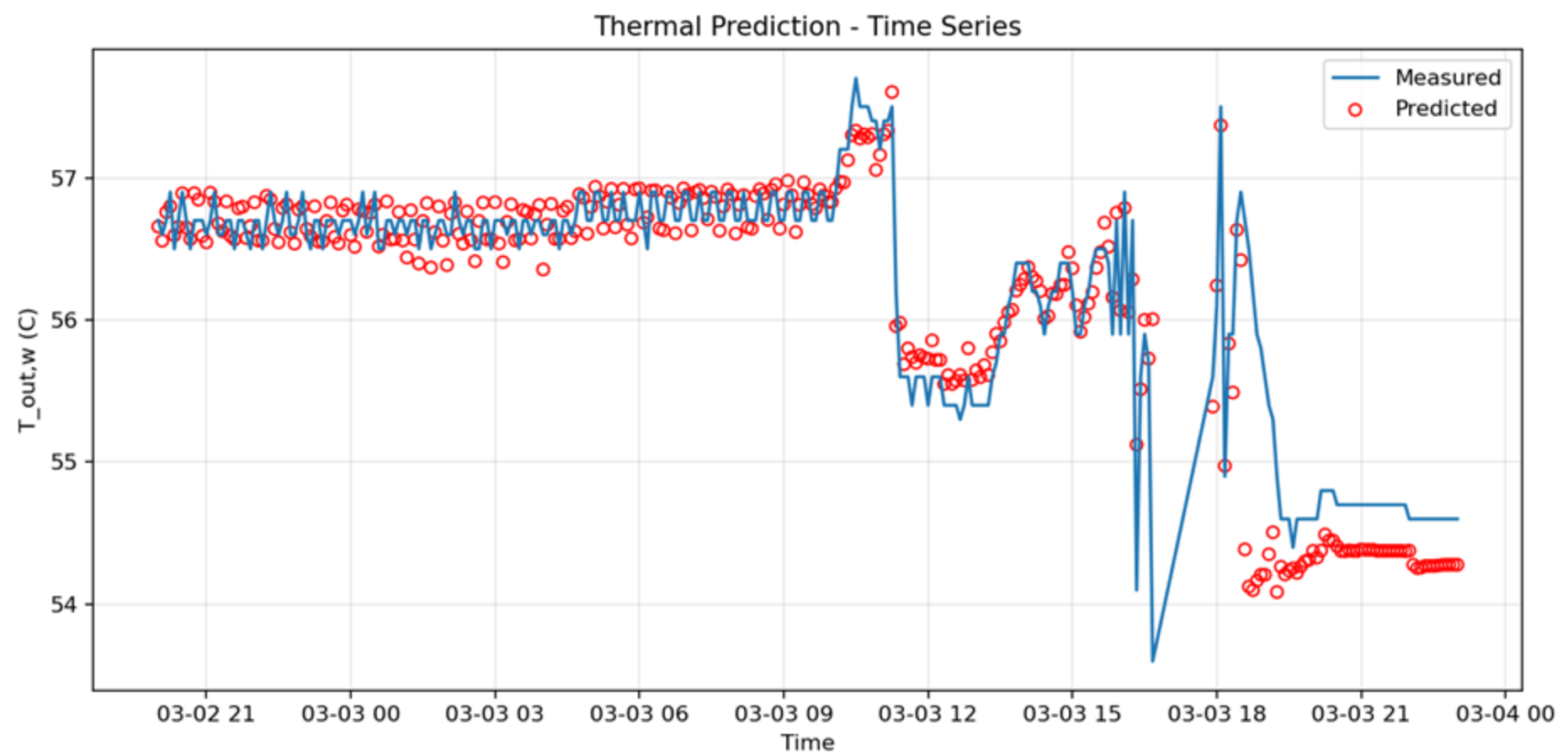
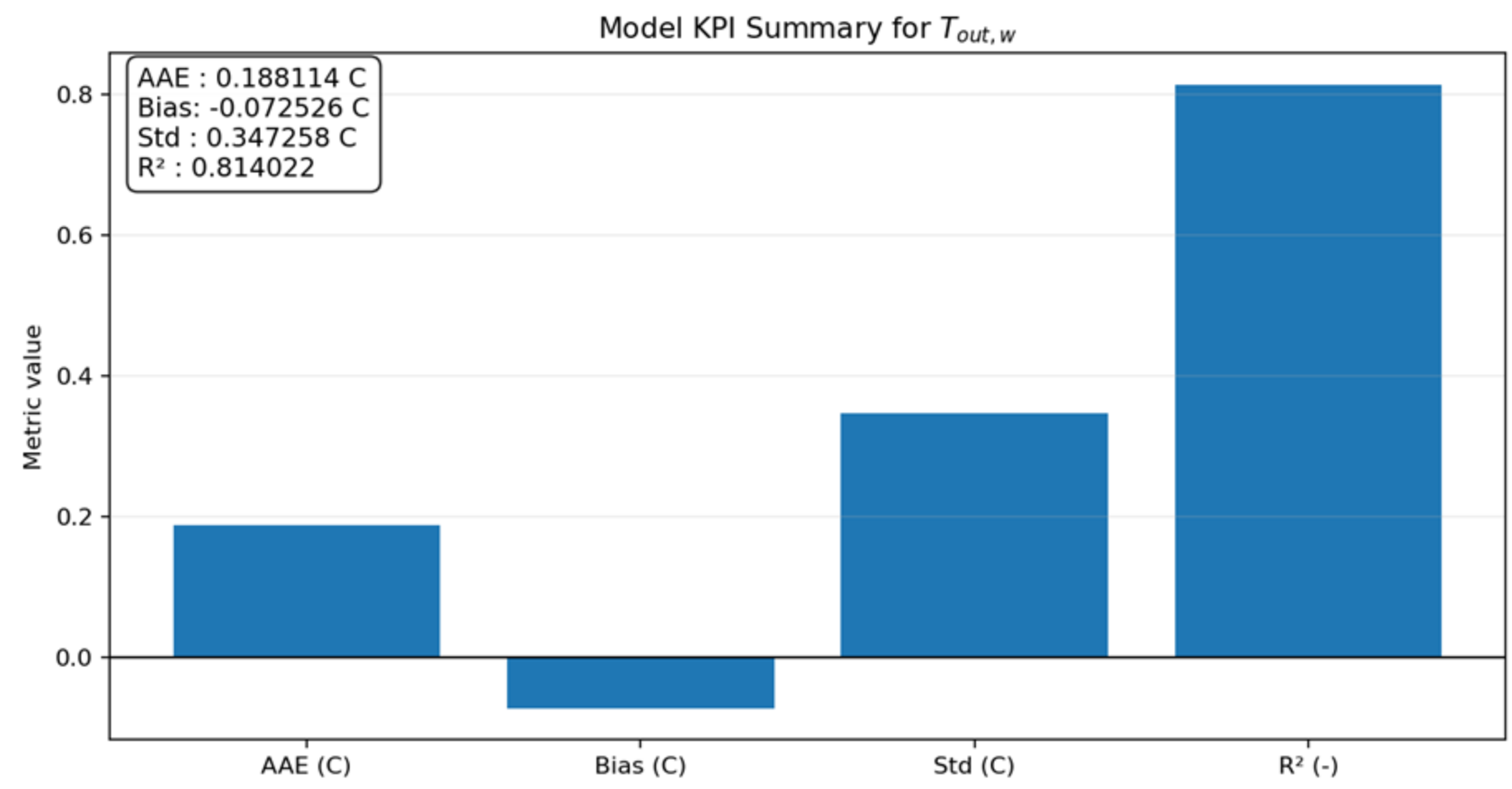




Self-Optimization Tool (SOT)

Development of the TPM at RISE Pilot

- Cooling system architecture mapped and parameterized (HRU, 3-way valve, DrC1, pumps, energy meters) to define the constraints and to be able to understand the system.
- A machine learning based TPM using XGBoost was implemented with transient features.
- Significant prediction performance under temporal ordering.
- Multivariate time-series regression/forecasting with exogenous variables
- Model execution time (dataset build + train + test) \approx 0.65 sec



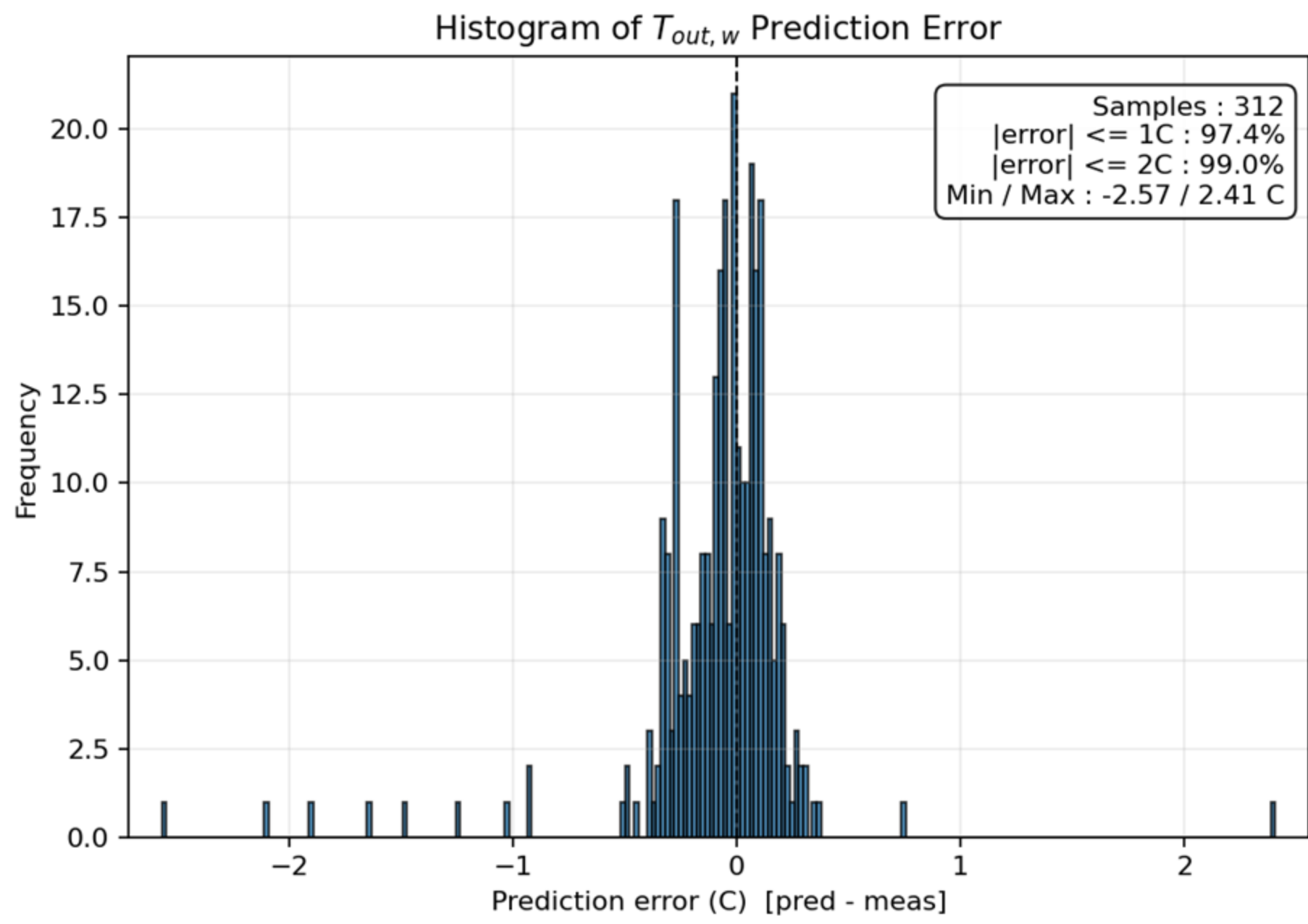
Temporal split: train = 1244, test = 312
Train range: 2026-02-26 12:15:00 -> 2026-03-02 19:50:00
Test range: 2026-03-02 19:55:00 -> 2026-03-03 23:00:00





Self-Optimization Tool (SOT)

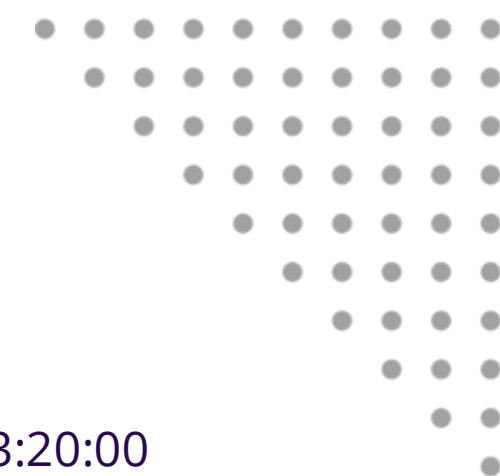
Development of the TPM at RISE Pilot



TPM dataset build time	~ 0.013 seconds
TPM training time	~ 0.627 seconds
TPM test- prediction time	~ 0.008 seconds
TPM total time	~ 0.648 seconds
Train time per tree	$2.089 \times 10^{(-4)}$ sec/tree

The prediction accuracy is within the range reported for data-driven thermal models in the literature while maintaining sub-second prediction time.



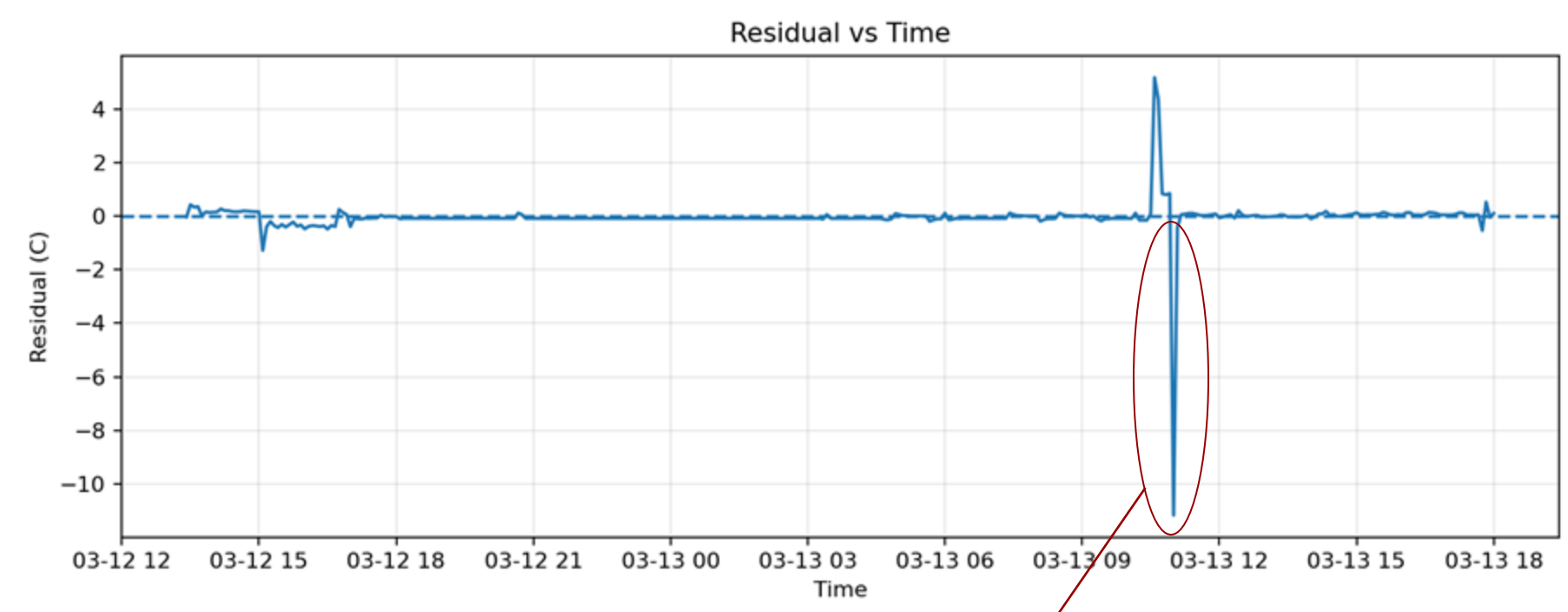
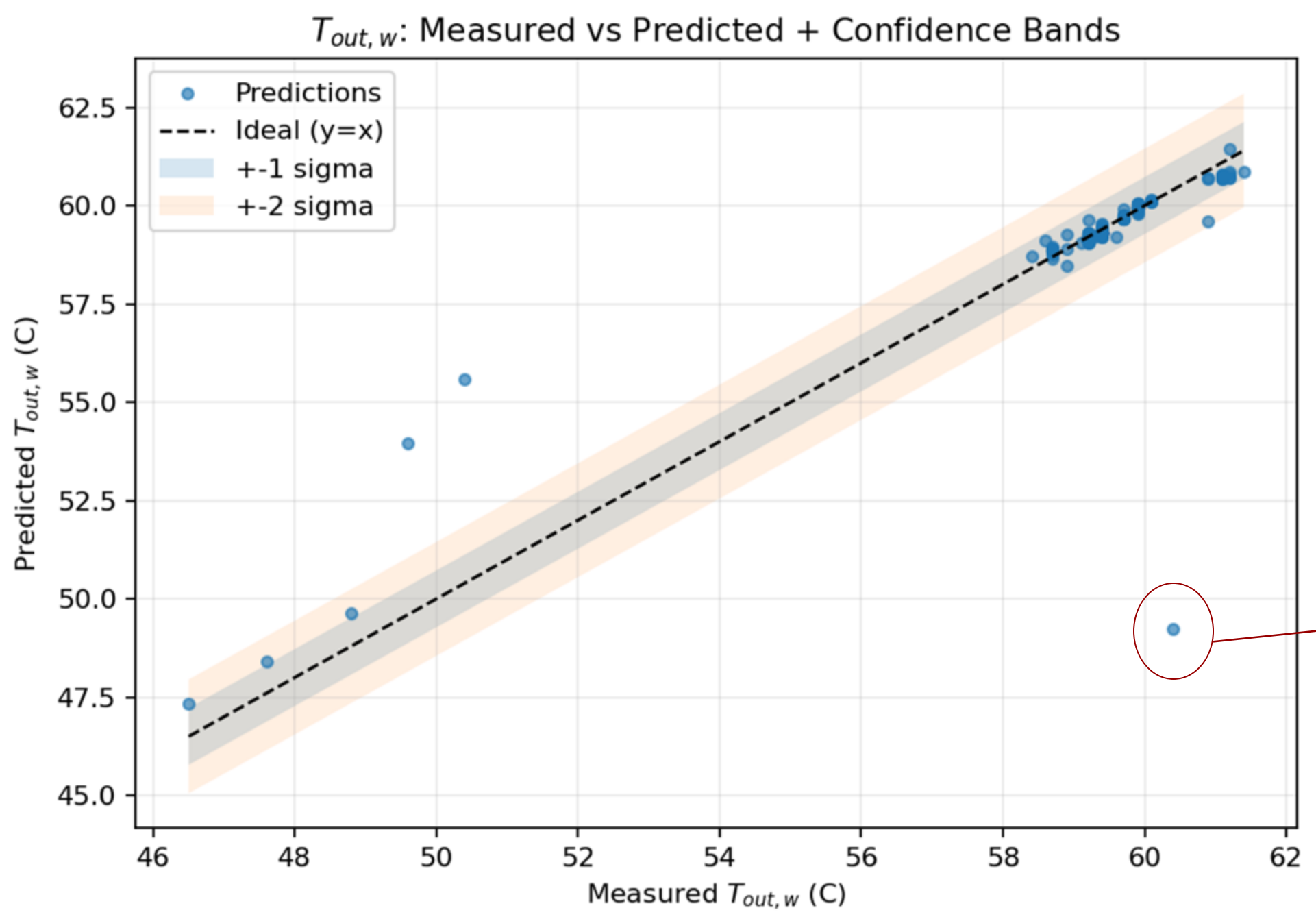


Self-Optimization Tool (SOT)

Development of the TPM at RISE Pilot

- AAE ≈ 0.174 // Bias ≈ -0.047 // Std ≈ 0.723 // $R^2 \approx 0.74$
- Model execution time (dataset build + train + test) ≈ 0.66 sec

Temporal split: train=1373, test=344
Train range: 2026-03-07 19:00:00 -> 2026-03-12 13:20:00
Test range: 2026-03-12 13:25:00 -> 2026-03-13 18:00:00

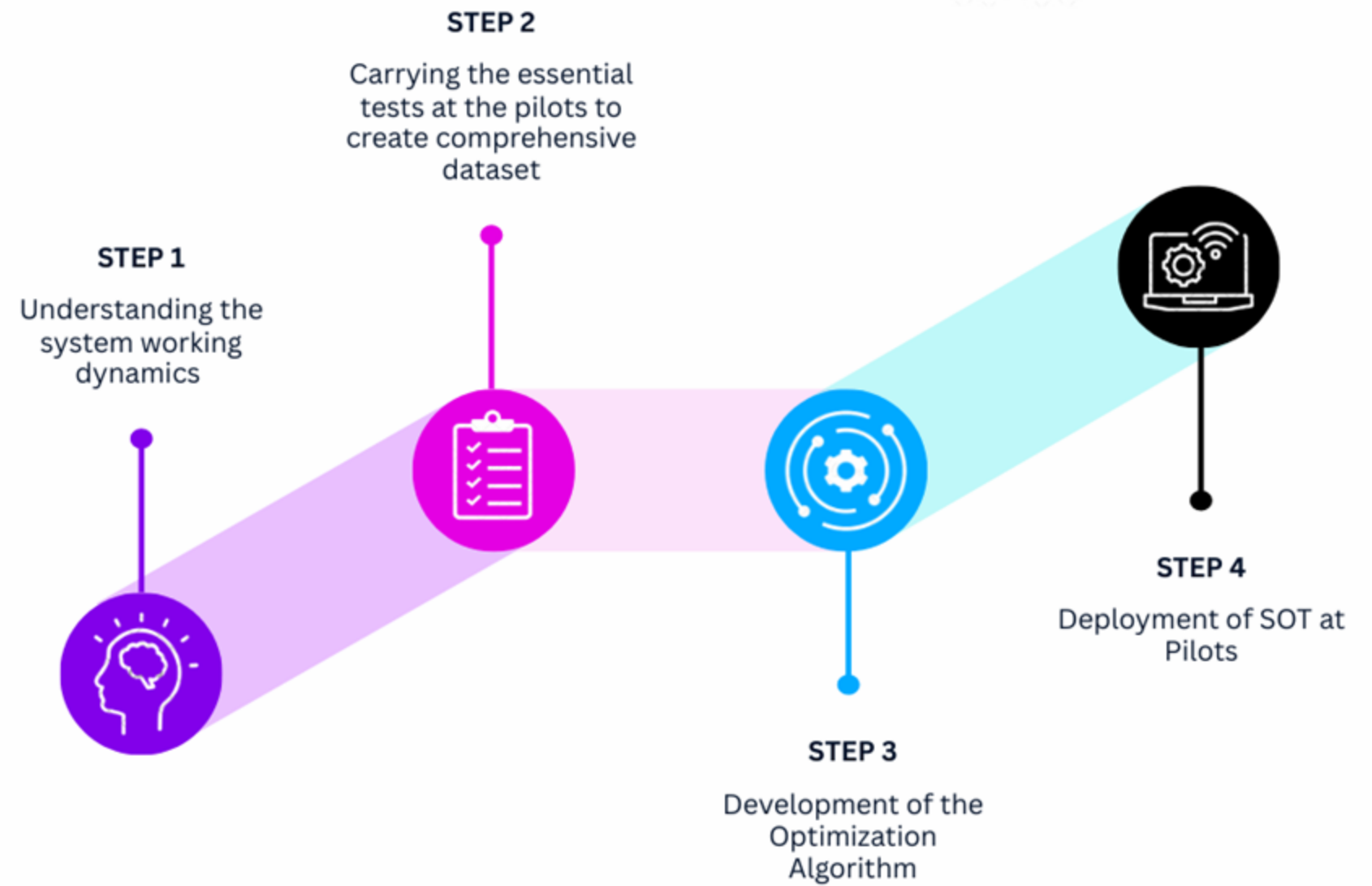


Will be improved via lag tuning acting as a hyperparameter and controlled data ingestion with abrupt load/valve transition data for model retraining



Ongoing Studies for the SOT

- We maintain close collaboration with the EMPA and RISE pilot sites and continuously monitor cooling system behaviour and ongoing transient operations
- We analyse operational data from the pilots to evaluate and improve the performance of the thermal prediction model.
- We update and retrain the thermal prediction model using the latest operational datasets.
- We aim to achieve precise optimization by expanding the dataset with more extensive real operational data.
- We will be sharing dedicated SOT testing template with specific setpoints and operational configurations with the pilot partners to support systematic testing and validation.



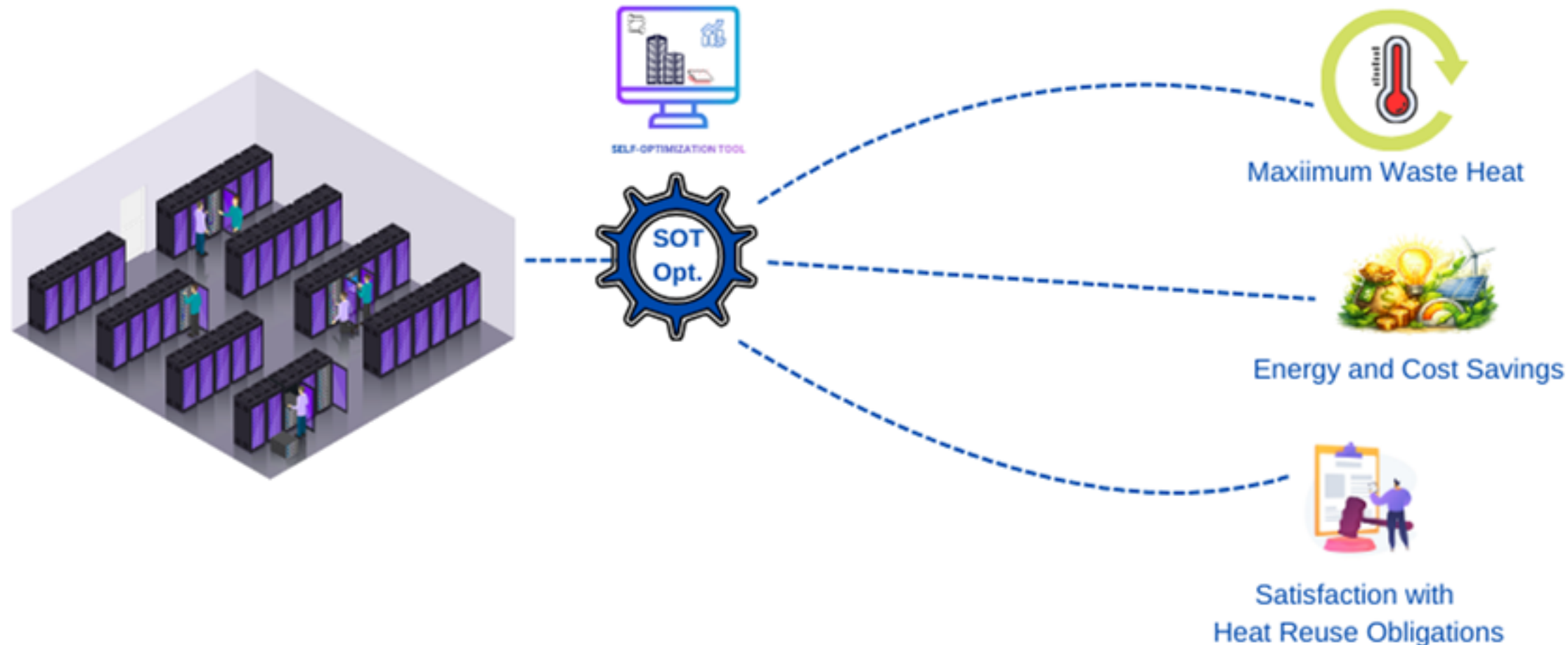
Continuous pilot data integration and systematic testing ensure the thermal prediction model becomes progressively more accurate and optimization-ready.



Future Studies for the SOT



- We will develop pilot-specific waste heat optimization models using the collected operational test datasets.
- The SOT can be integrated into the pilot's holistic control framework as a modular component, enabling automatic valve setpoint provision via Modbus.
- We aim to evaluate the reusable waste heat achieved by the SOT through quantitative analysis of relevant KPIs.
- We aim to identify potential energy savings and operational improvements enabled by data-driven optimization strategies.
- The results will support the validation of the SOT methodology across different pilot infrastructures with Direct-to-Chip liquid cooled pilot sites.



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Digital Twins For Holistic Data Centre Management

Grid Symbiosis: Integrating Data Centres into the Energy Ecosystem

Henrik Barestrand

Researcher in Sustainable Data Centre Technology,
RISE Research Institutes of Sweden



Funded by
the European Union



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
**State Secretariat for Education,
Research and Innovation SERI**
EU Framework Programmes

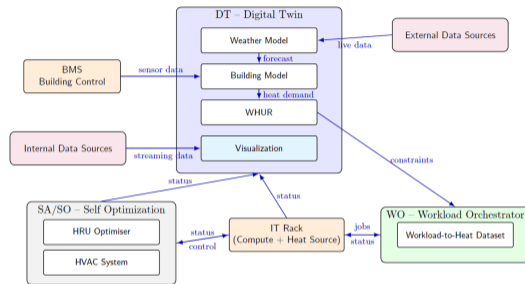
The Challenge

- Data centres generate significant excess heat — largely **underutilized**
 - Workload scheduling is siloed; schedulers (e.g. Kubernetes) are **not optimized** for heat recovery
 - Few existing solutions coordinate energy exchange between data centres and district heating networks
- ⇒ Need for **holistic, data-driven** data centre management — particularly at the **edge**, where heat reuse potential is highest



ZutaCore on-chip two-phase liquid cooling at the RISE ICE data centre

- **Digital Twin** concept (ISO/IEC 30173:2023): physical–digital convergence
- **WHUR** – Waste Heat Utilization Restrictors: coordinating decision framework that aligns data centre operations with building energy demand and broader energy-system signals
- **Edge-based** real-time processing, modular microservices



Conceptual system architecture

Targeting maximized heat capture across pilot sites.

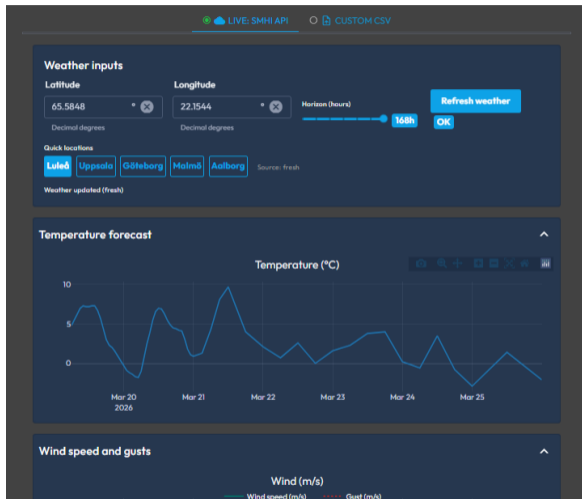
Weather Service — SMHI forecast API

- Temperature, cloud cover, wind
- 24 h – 7 d forecast horizon
- 15-minute cache, unit conversion

Building Model — Bayesian soft-hinge model

Captures the nonlinear relationship between outdoor temperature and heating demand.

- Probabilistic heat demand modelling
- Balance-point detection, hurdle for zero-heat days
- Calibrated against measured heating data from the RISE pilot site

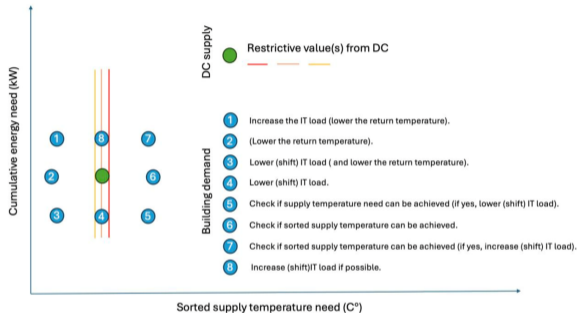


Weather forecast & demand predictions

WHUR Engine — Decision framework

- Evaluates available heat supply against building demand constraints
- Detects heat surplus and recovery opportunities
- Outputs: workload plans (server / Chip Load Emulator levels) + cooling setpoints (pump, fan, valve)

Aligns IT workload placement with building thermal demand.



WHUR decision logic

Workload Orchestrator

Applies compute workloads to servers;
adjusts Chip Load Emulator (CLE)
power envelopes

Self-Optimization — Setpoint routing

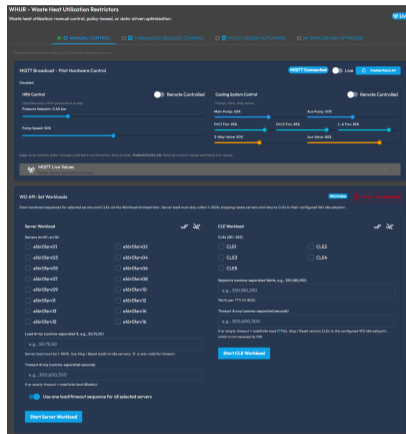
Validates via Cooling Simulation,
routes to MQTT

Telemetry Bridge — REST ↔ MQTT

Telemetry ingest, setpoint publish

Self-Assessment — KPI engine

Power Usage Effectiveness (PUE),
Energy Reuse Factor (ERF),
Renewable Energy Factor (REF),
Primary Energy Savings (PES)



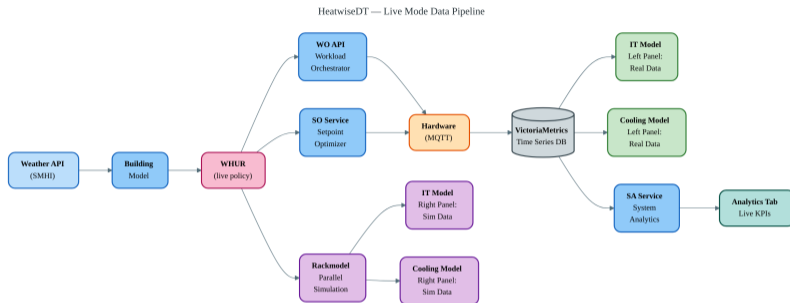
Workload orchestration interface

DAE thermal-hydraulic simulation

- Acausal component-based modelling
- Stiff DAE solver for real-time fidelity
- Multi-loop cooling: primary, secondary, and recirculation circuits
- 16 server loads, 10 CLE power levels, pump/fan/valve setpoints
- Warm-start for continuous simulation



Rackmodel simulation output



Forward chain:

SMHI → Weather → Building → WHUR
→ WO/SO → MQTT → pilot hardware

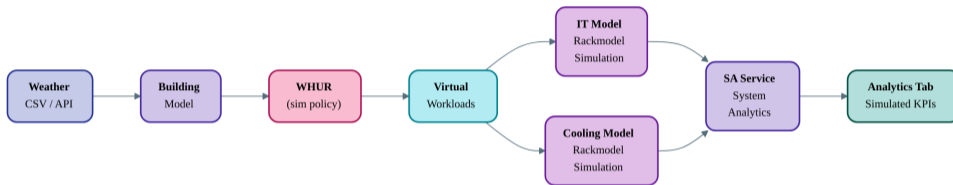
Feedback loop:

Sensors → MQTT → VictoriaMetrics → Dashboard

Affects real hardware — live KPIs

Deployed and operational at the RISE ICE pilot site.

HeatwiseDT — Simulation Mode Data Pipeline



Same model chain, sandboxed execution

Cooling Simulation: DAE thermal-hydraulic model (ModelingToolkit.jl)

No hardware side effects

Use cases:

- What-if analysis
- Weather sensitivity studies
- Workload scheduling optimization
- Operator training

The screenshot displays the Heatwise Digital Twin Platform dashboard. At the top, there is a navigation bar with tabs for DASHBOARD, WEATHER/BUILDING, WHUR/WORKLOAD, IT, COOLING SYSTEM, ANALYTICS, SETTINGS, and ABOUT. Below this is a secondary navigation bar with a 'Live' toggle and a 'Simulation' toggle, both currently set to 'Live'. The main content area is titled 'Service Status' and features a grid of service health indicators. A 'Refresh Services' button is located in the top right of this section. The services and their statuses are as follows:

Service Name	Service Health
Weather Model	OK
Building Model	OK
Cooling System	OK
WHUR Model	Offline
Workload Orchestrator	OK
SO Service	Offline
SA Service	Offline
VictoriaMetrics	OK
MQTT Broker	OK
External Data	View
Jeeves	OK
Wooster	OK

Below the service status grid, there are two expandable sections: 'Digital Twin Data Pipelines' and 'System Architecture'.

Live / Simulation toggle as parallel, isolated workflows

Tabs: Dashboard, Weather/Building, WHUR/Workload, IT, Cooling System, Analytics

The screenshot displays the Heatwise Digital Twin Platform interface. At the top, the title "Heatwise Digital Twin Platform" is centered. Below it is a navigation bar with tabs: DASHBOARD, WEATHER/BUILDING, WHUR/WORKLOAD (selected), IT, COOLING SYSTEM, ANALYTICS, SETTINGS, and ABOUT. A secondary bar shows various system status indicators: Live, Simulation, PIPELINE: LIVE, Weather: 5:00 AM, Building: 5:00 AM, and WHUR: Manual. The main content area is titled "WHUR - Waste Heat Utilization Restrictors" and includes a description: "Waste heat utilization: manual control, policy-based, or data-driven optimization." Below this, four control modes are listed with radio buttons: MANUAL CONTROL (selected), TABULAR/SCHEDULED CONTROL, POLICY BASED AUTOMATIC, and DATA DRIVEN OPTIMIZED. A "Live" button is visible in the top right of the content area. At the bottom, there is a note: "Manual setpoints and loading CSV files with sequences to run."

Four operation modes — from manual override to fully data-driven optimization — giving operators progressive autonomy over heat recovery control.

Setpoint sequences with CSV upload for repeatable experiments.

Key takeaways:

1. **Holistic Digital Twin** – weather, building, IT, and cooling models integrated as microservices
 2. **WHUR-driven coordination** – decision framework aligns workload placement with building thermal demand
 3. **Dual-mode operation** – Live pipeline controls real hardware; Simulation pipeline enables risk-free analysis
 4. **Validation on live hardware** at the RISE ICE pilot in Luleå
-

Let me show you...

- ▷ The live connected pipeline
- ▷ The simulation pipeline
- ▷ Building-side data flow
- ▷ The simulation model of the physical cooling system

and the heatwise digital twin, is it running?

Q1 Jeeves
Tänkte i 17 sekunder ▾
🟢 Visa resultat från `heatwise-dt_get_control_room_overview` ▾
Tänkte i 40 sekunder ▾

The Heatwise digital twin is operational, sir. Here's the state of things:

System Status

- **Mode:** Live (not simulation)
- **Services:** 7 of 10 healthy. Weather, building, MQTT, cooling, workload orchestrator, and VictoriaMetrics are all reporting OK.
- **Simulation:** Not currently running.

Configuration

- Building model: Rise
- WHUR tab: Manual, mode set to "building_first"
- Weather source: Live API
- MQTT live mode: Disabled (setpoints are staged but not publishing to hardware)

Workloads & KPIs

- No active server or CLE workloads at present.
- KPIs have not yet been populated (all zeros)—they'll need to be computed when data accumulates.

The twin is standing by, sir. Services are healthy, and it's ready to run a simulation or compute metrics should you wish. Would you like me to start a simulation, fetch fresh weather data, or compute the KPIs?

Prototype: AI copilot for Digital Twin situational awareness

hi

01 ICE-Jeeves
Tänkte i 2 sekunder ▾
Hello. I'm Jeeves, your data center assistant. How may I help you today?

how is the heatwise digital twin today?

01 ICE-Jeeves
Tänkte i 2 sekunder ▾
🟢 Visa resultat från **heatwise-dt_get_control_room_overview** ▾
Tänkte i 1 sekunder ▾
🟢 Visa resultat från **heatwise-dt_get_readiness** ▾
Tänkte i 3 sekunder ▾
The Heatwise digital twin status:

Operation Mode: Simulation
Service Health: 6/10 healthy

Live Pipeline:

- Weather: ✓ populated
- Building demand: ✓ populated
- WHUR: ✗ not loaded
- KPIs: ✗ not calculated