

EPFL



HEATING BITS



**Reimagining Data
Centers as Energy
Assets: the EPFL
HeatingBits project**

Prof. Mario Paolone

Motivation

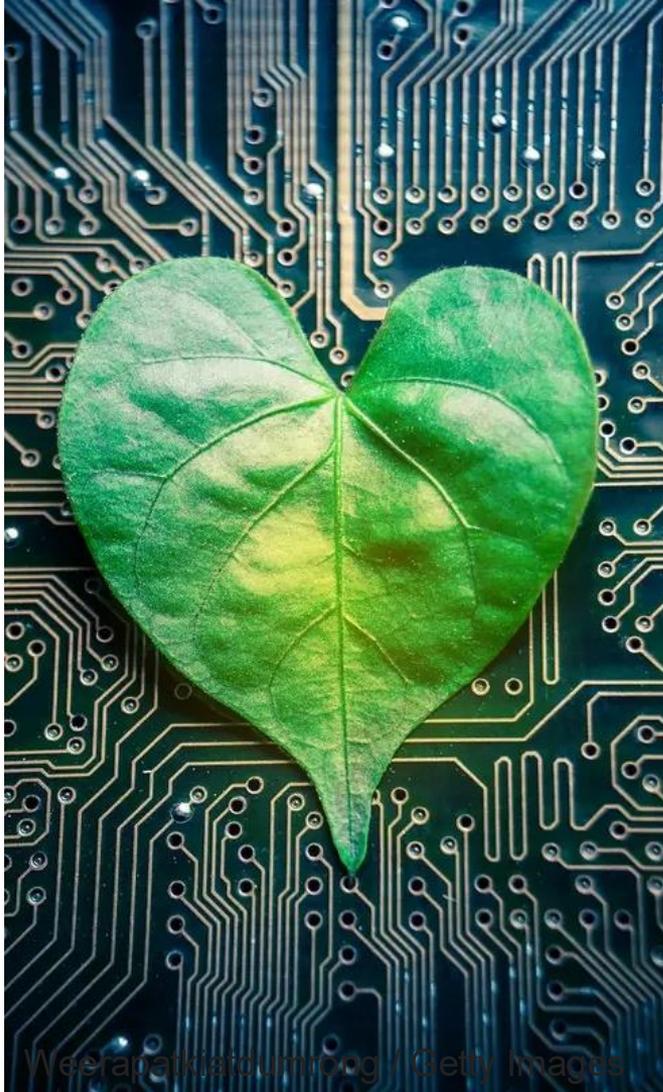
- 2022-24: Data Centers (DCs) used in average **400-500 TWh of electricity worldwide** $\approx 2\%$ of the global electricity demand.
- IEA expects the global annual electricity demand from DCs to range between **650 and 1050 TWh in 2026**, potentially accounting for up to **4.5%** of the global electricity demand.
- The DCs expansion is associated with key energy and climate-related challenges:
 - (a) inefficient energy usage;
 - (b) impact on the power grid;
 - (c) electricity-end-use carbon footprint.

E. Çam, Z. Hungerford, N. Schoch, F. Pinto Miranda, C. D. Yáñez de León, Electricity 2024 - Analysis and forecast to 2026 (2024).

IEA, Electricity and heat CO2 emissions in the Net Zero Scenario, 2000-2030, (2023)

■ <https://www.iea.org/data-and-statistics/charts/electricity-and-heat-co2-emissions-in-the-net-zero-scenario-2000-2030>

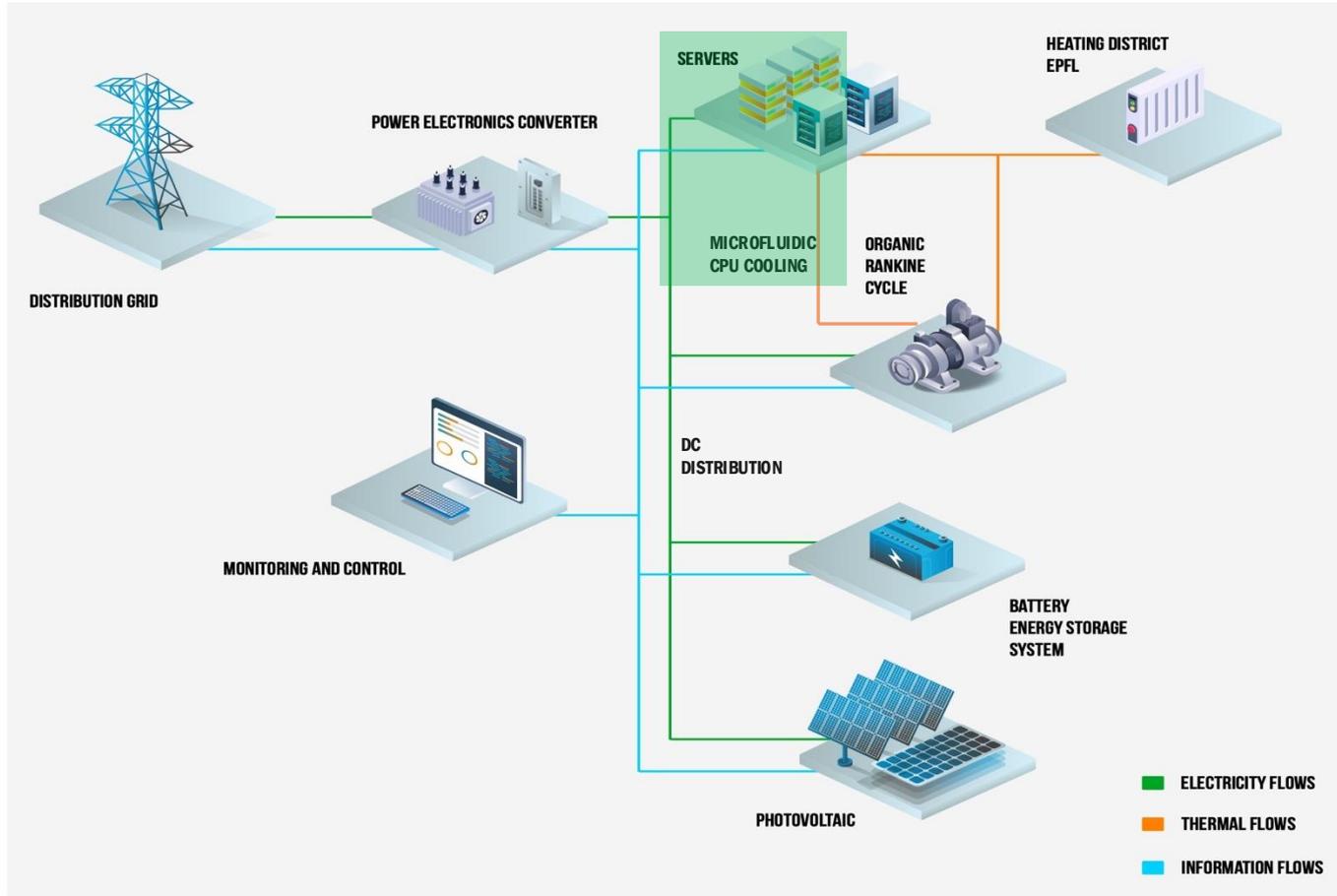




Goals of the project

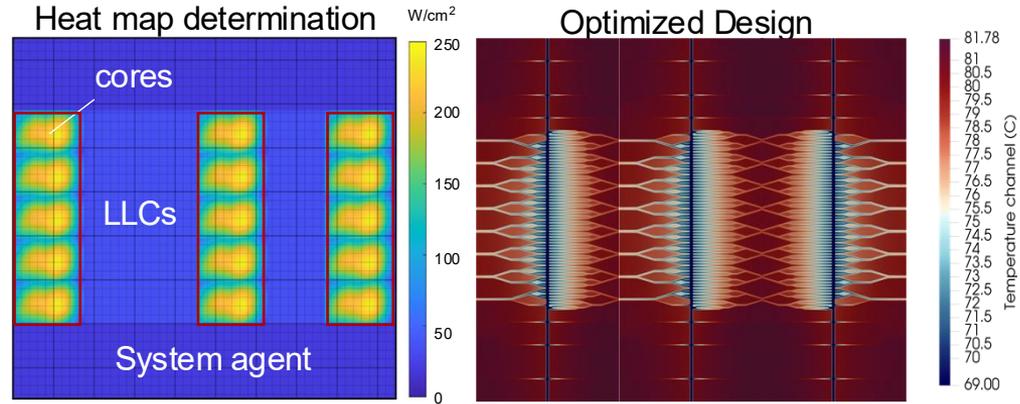
- Develop a set of technologies and controls for **heat recovery and utilization with the scheduling of the DC to achieve least emissions footprint.**
- Validate the solutions in a **first-of-its-kind demonstrator benefiting the entire EPFL campus leveraging EPFL research and tech transfer.**
- **Involve DCs stakeholders: DCs owners and operators, power utilities and technology providers.**

Overview of the proposed system

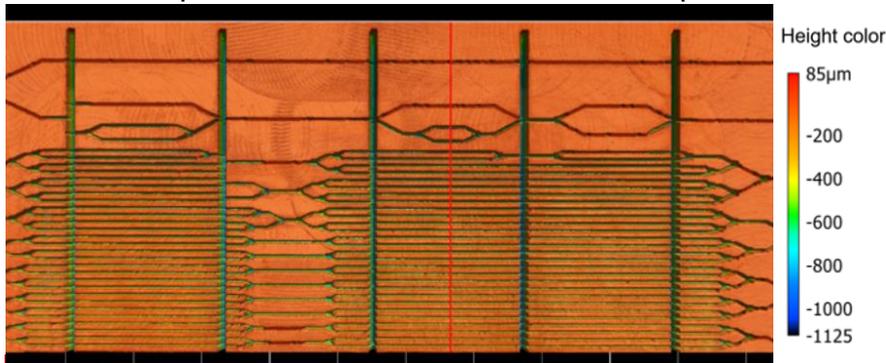


Design of microfluidic channels, including

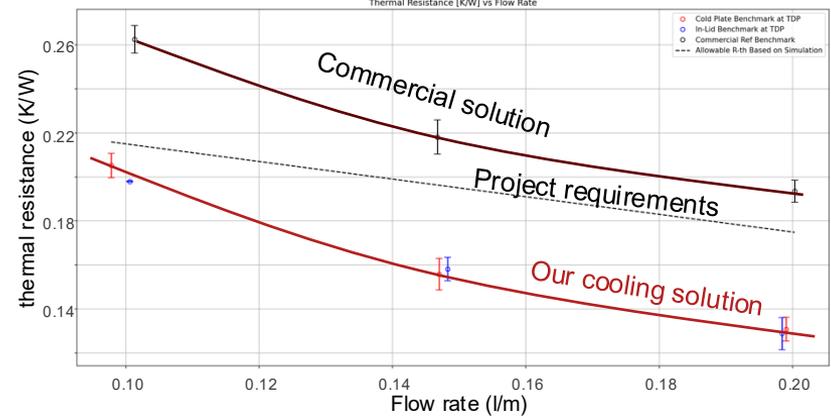
- Heat map measurements
- Microfluidic optimized design
- Cold-plate designs



Picture of optimized microchannels in the cold plate



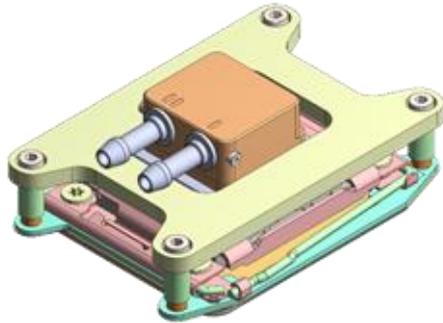
Improved thermal performance compared to commercial solutions



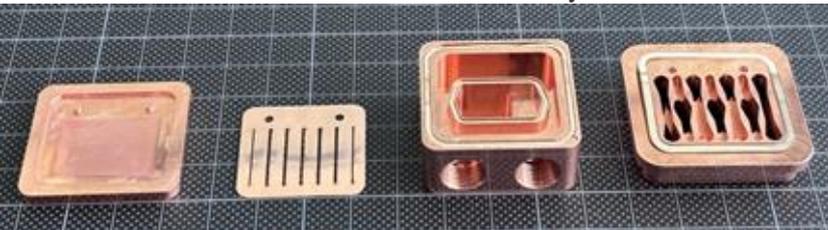
Optimal cooling and heat recovery

Cooling of CPUs, including demonstration of microfluidic-cooled devices in server blade prototype

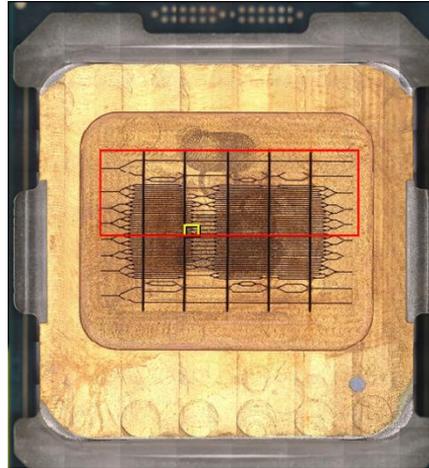
CPU Cold-Plate Assembly



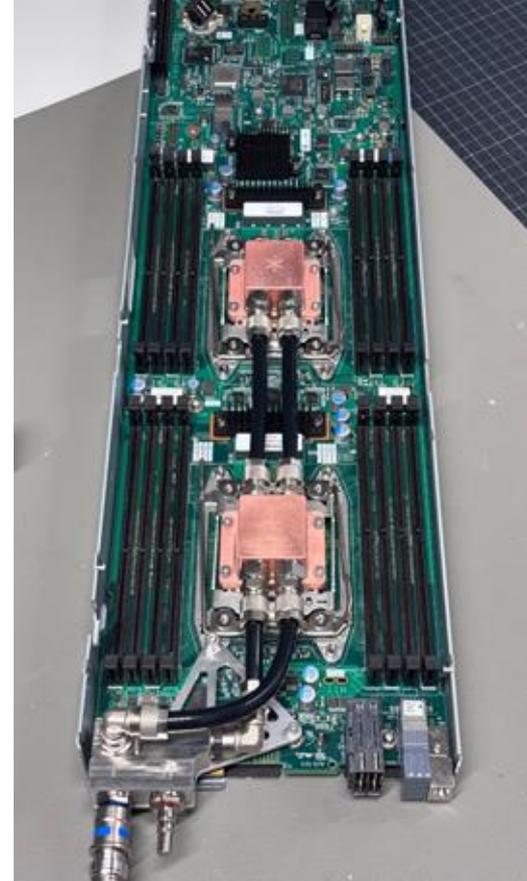
Cu Cold Plate Assembly



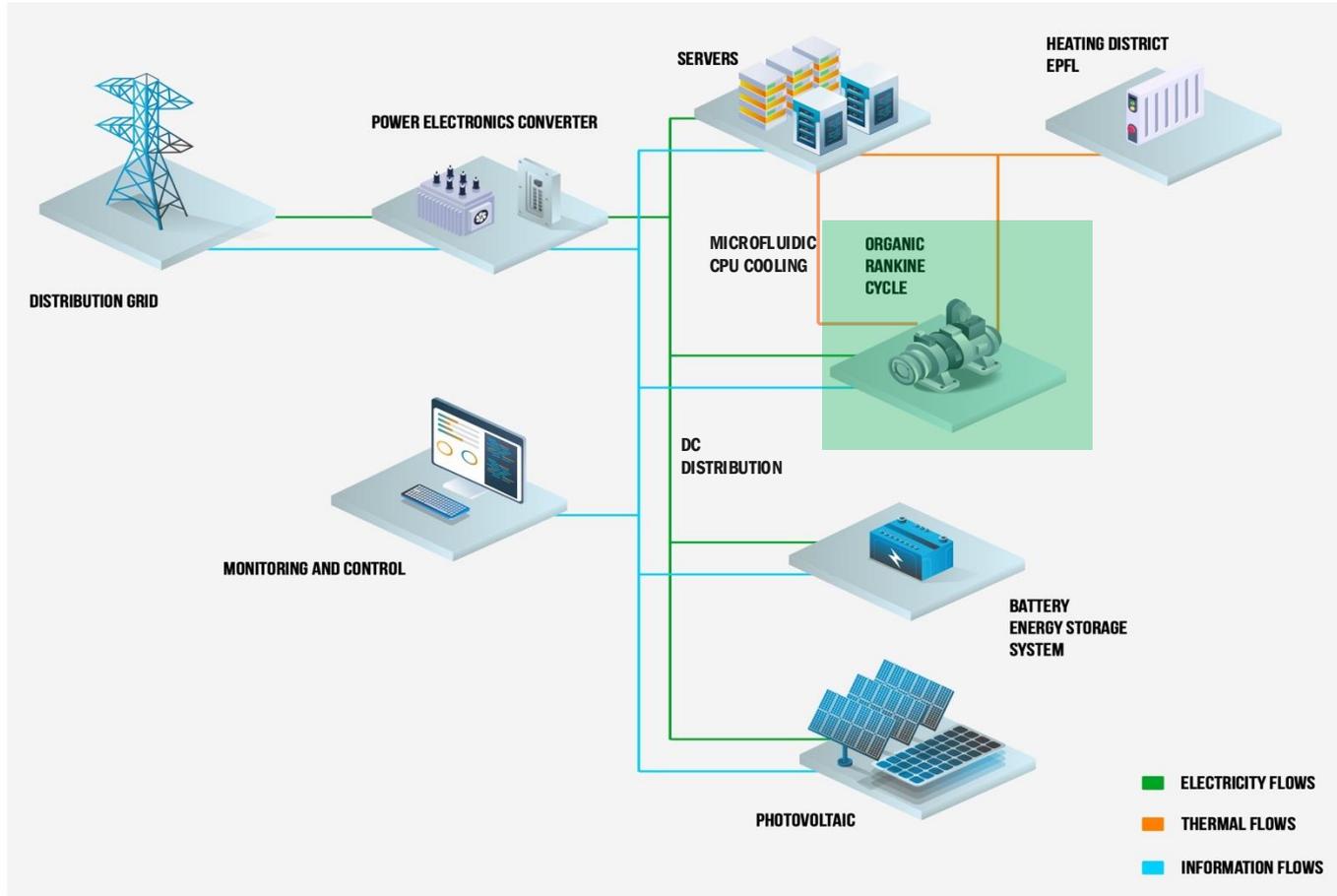
In-lid Etched CPU



Server Integration



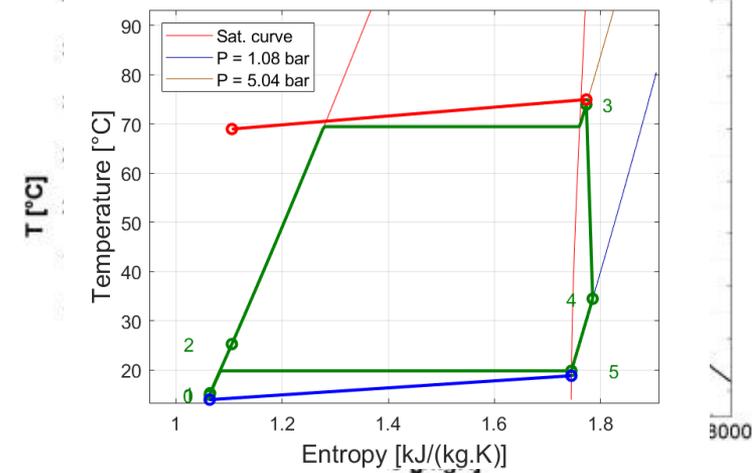
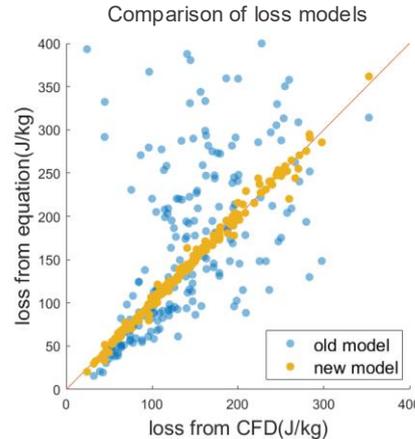
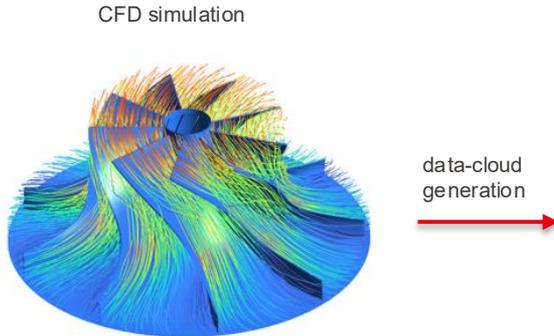
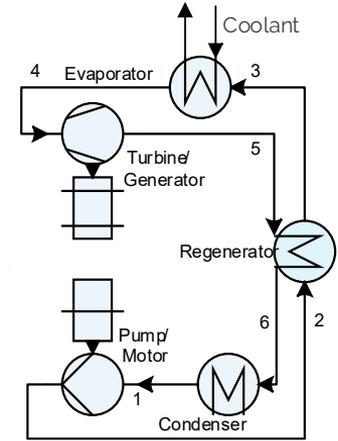
Overview of the proposed system



EPFL Waste heat to electricity

Heat valorisation system with Organic Rankine Cycle

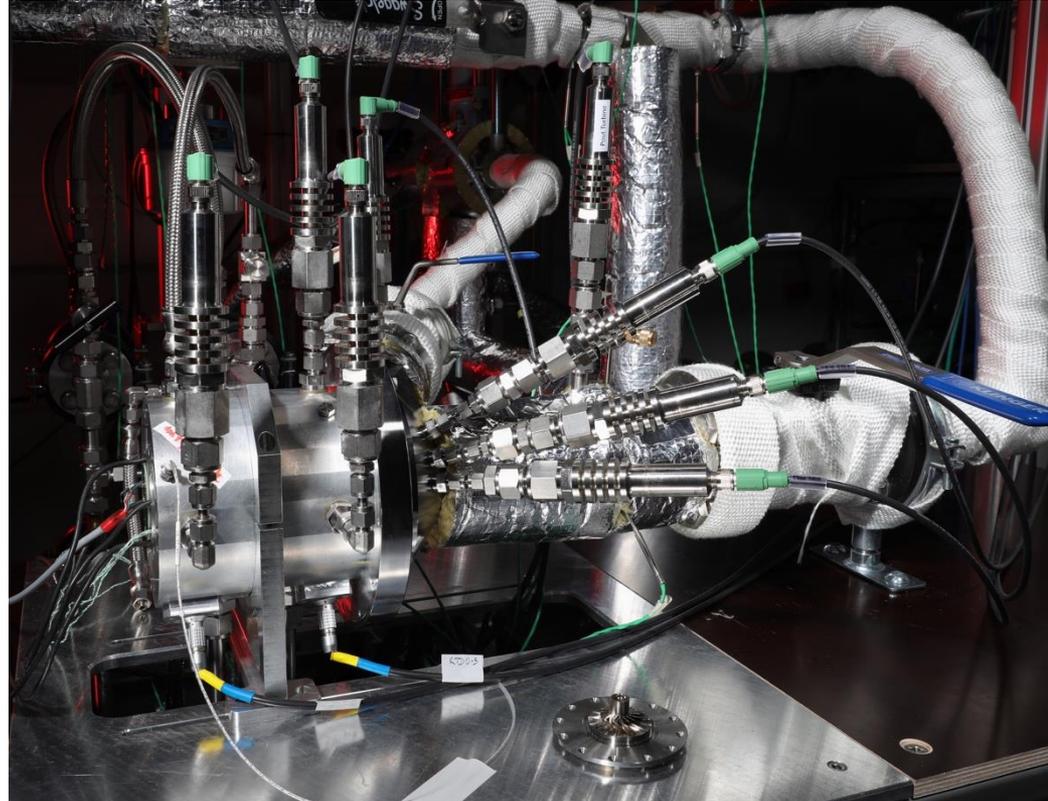
- Organic Rankine Cycle design and working fluid identified
- New data-driven models for variable nozzle turbine design for wide operation range
- Robust optimization of variable nozzle turbine design against operational and manufacturing uncertainties



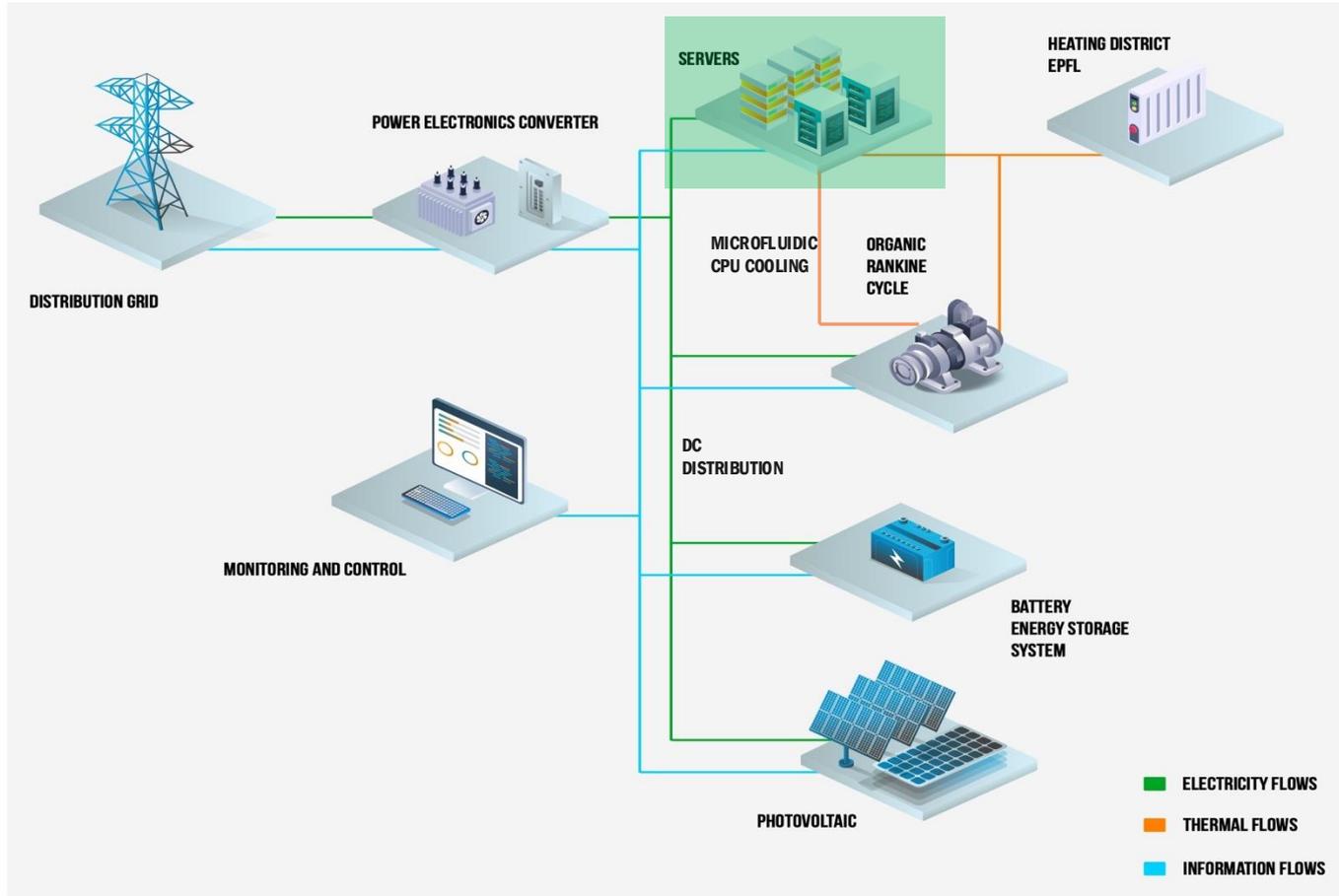
EPFL Waste heat to electricity

Results

- ✓ 4th generation refrigerant as working fluid for high performance with health and safety prioritized
- ✓ 100% heat recovery from CPU of which
 - 86.6% goes into the heating network and
 - 10% converted back into electricity



Overview of the proposed system



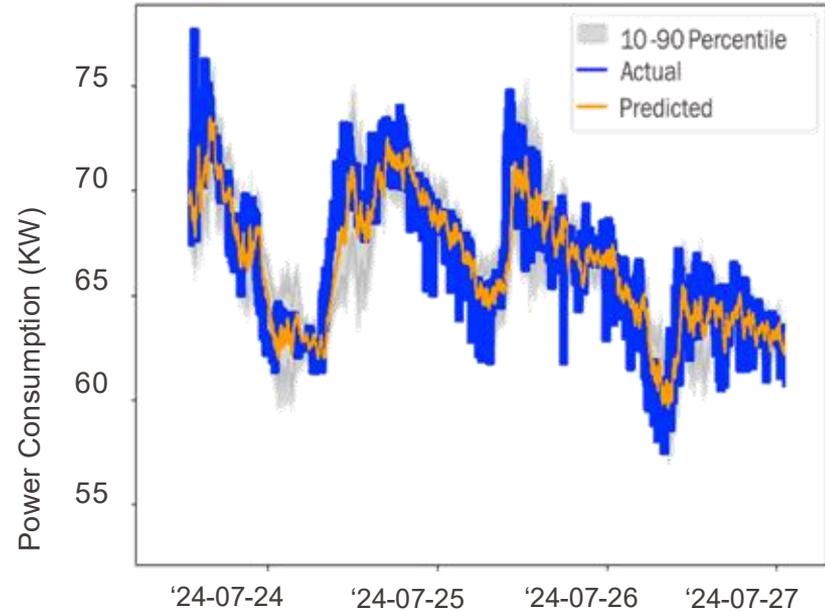
EPFL DC power consumption and distribution prediction

Workload and DC Power Consumption Prediction

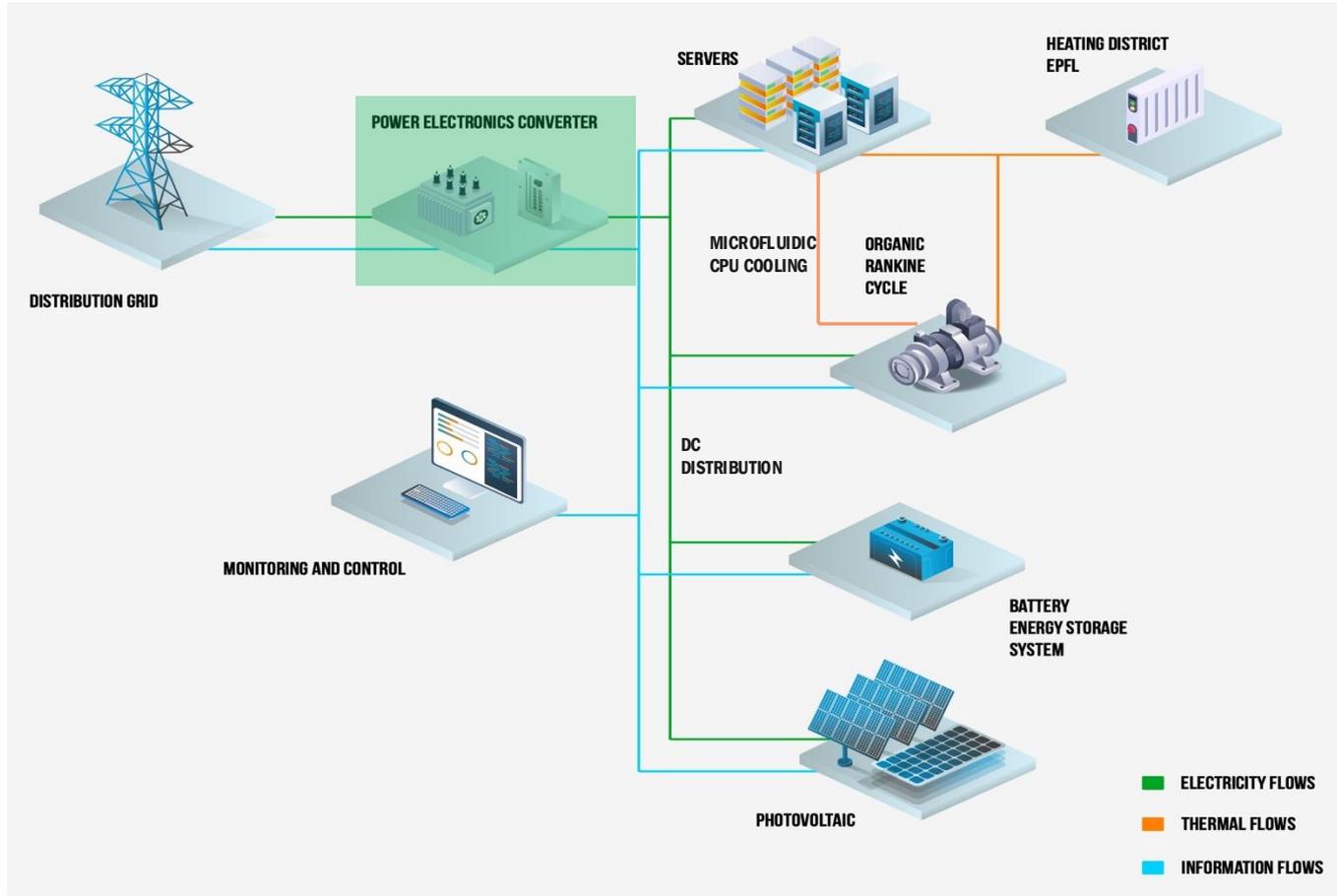
- CPU/GPU workload & power consumption data collected
- Development of a probabilistic forecasting model:
 - Based on Temporal Fusion Transformers
 - Captures long-range dependencies

Results

- ✓ Accurate short- and long-term power forecasts
- ✓ The probabilistic approach gives uncertainty bounds (risk-aware scheduling)
- ✓ Direct impact: energy savings & improved system reliability



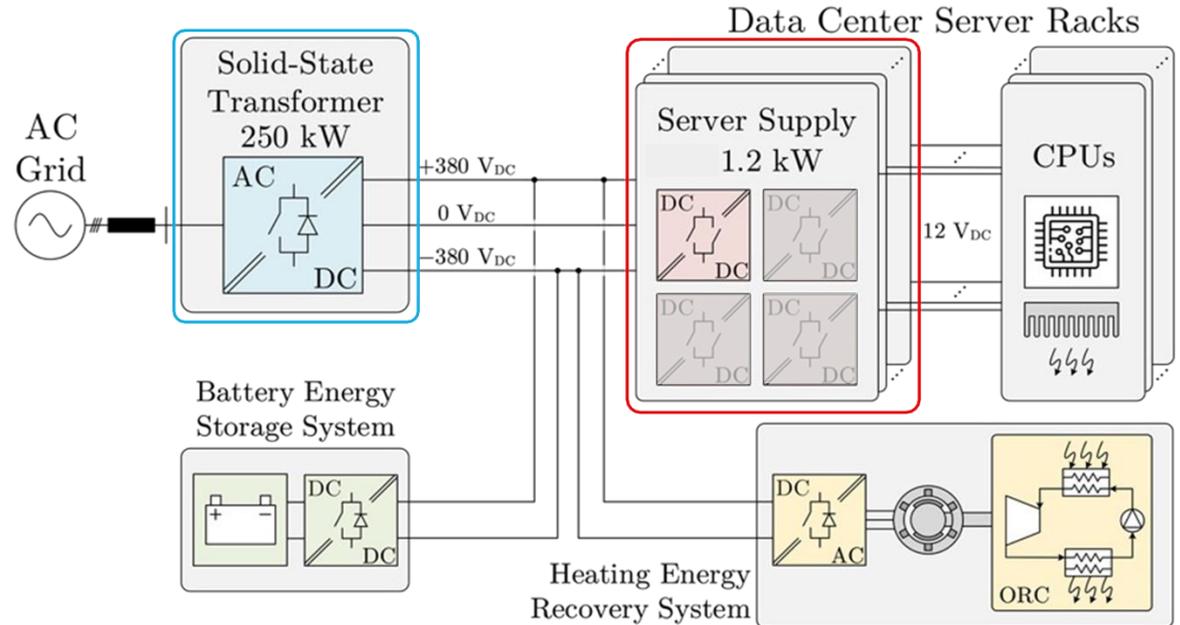
Overview of the proposed system



EPFL Power distribution and conversion architectures

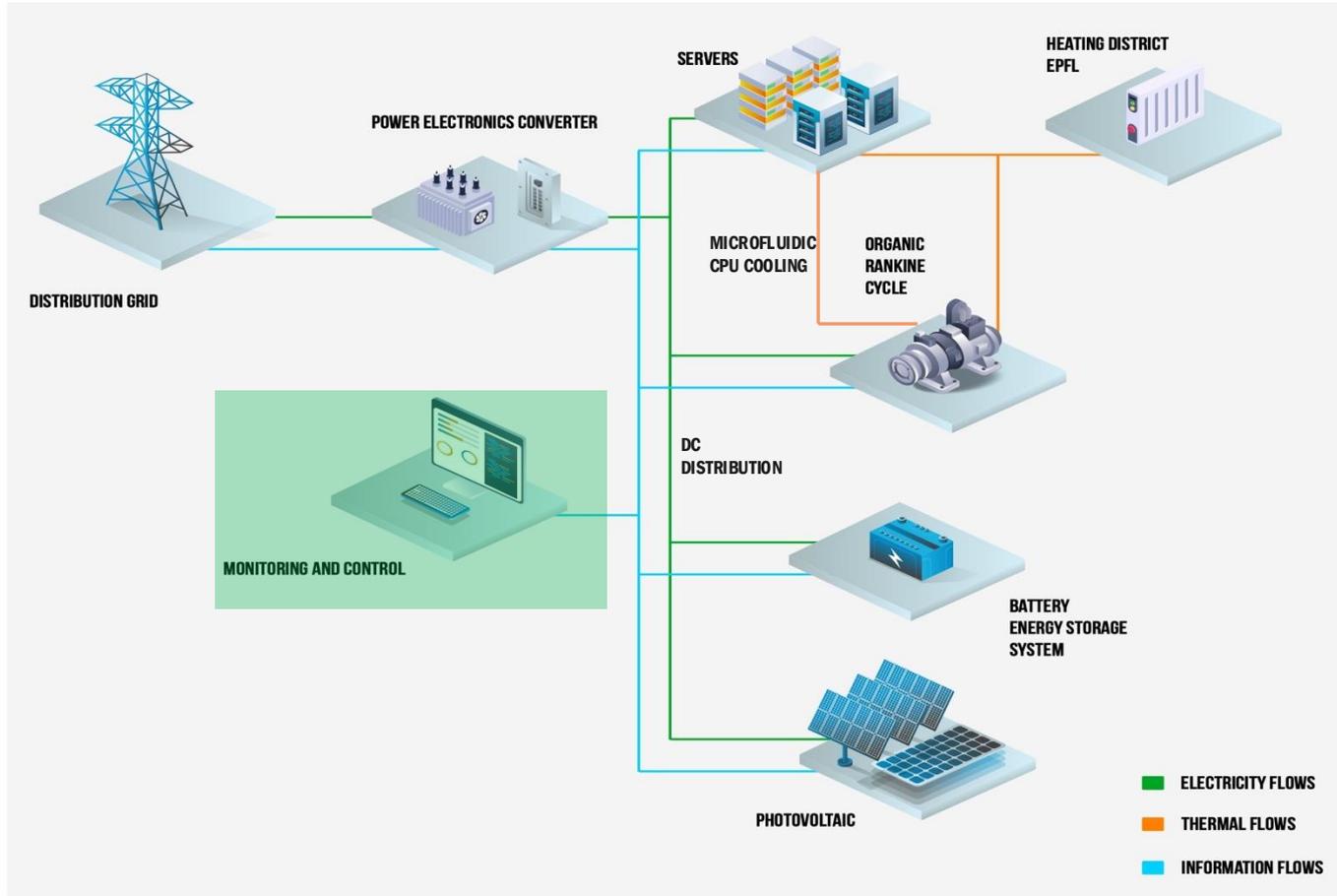
Improve efficiency, power density and reliability

- Moving to high-voltage 800V DC distribution
- Simplifying power delivery
- Deploying scalable interface with medium-voltage (MV) grid



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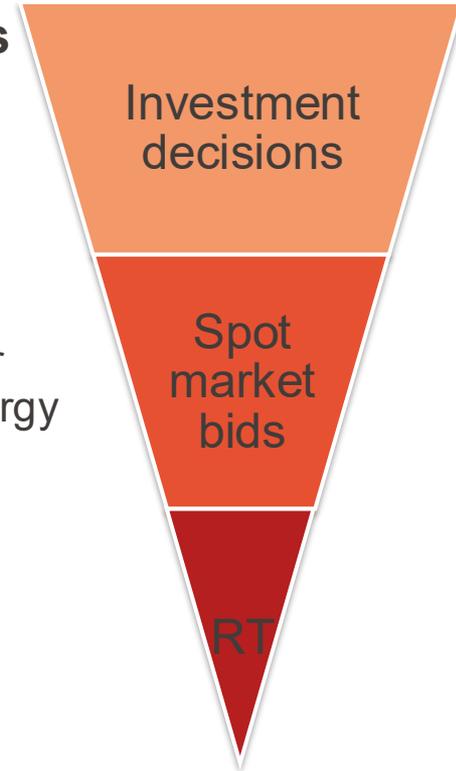
Overview of the proposed system



EPFL Multi-energy system operation (DESL)

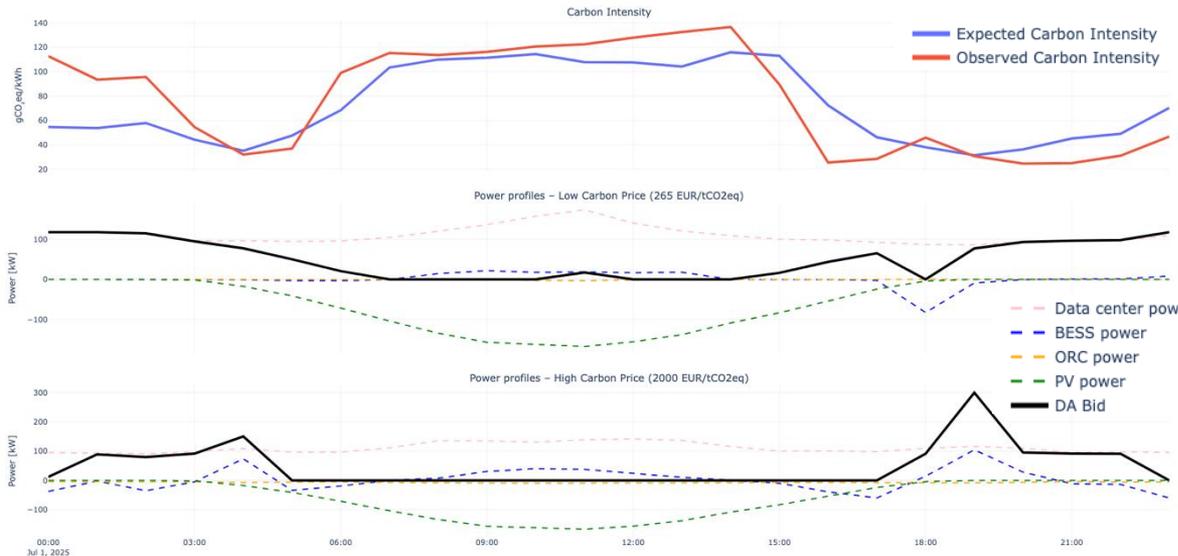
Carbon- and market-aware power system integration of DCs

- **Long-term planning for sustainable and grid-friendly DCs**
 - Ensure dispatchability
 - Sizing of battery and local electricity generation (PV)
 - Minimize **carbon footprint** and **OPEX**
- **Day-ahead bidding strategy for data centers**
 - Bid on electricity markets and compute virtual capacity curves for computational resources, including flexible workload; battery energy storage system; PV; ORC
 - Account for grid operator day-ahead power capping constraints
 - Minimize **OPEX** and **carbon footprint**, with **risk-awareness**
- **Real-time control framework**
 - Agents to assess real-time control performance



- Enea Figini, Mario Paolone, "Achieving dispatchability in data centers: Carbon and cost-aware sizing of energy storage and local photovoltaic generation," Sustainable Energy, Grids and Networks, Volume 43, 2025, 101920, ISSN 2352-4677, <https://doi.org/10.1016/j.segan.2025.101920>.

Day-Ahead Dispatches: Expected Operation with Different Strategies 2025-07-01



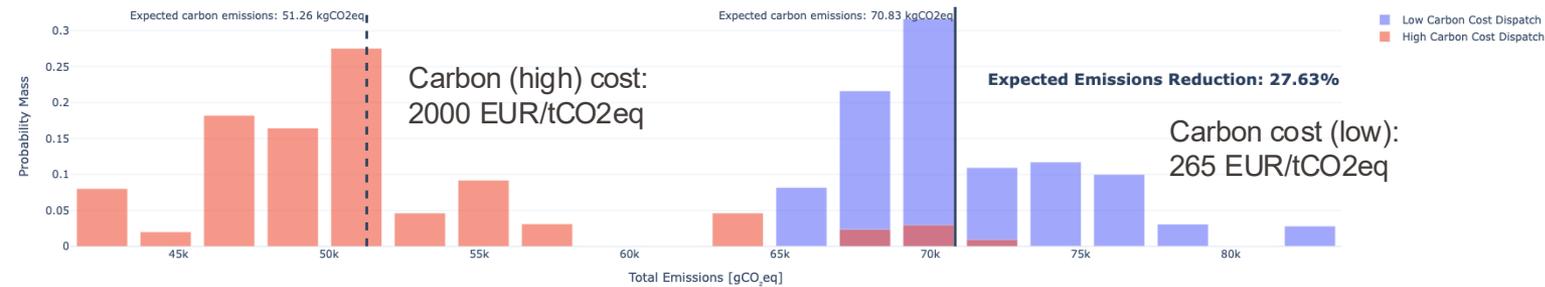
Example of operation of the EPFL RCP datacenter: DC 200kW
 PV 200kW, BESS 250kW/kWh
 ORC 10kW.

Day-ahead bidding strategy

Bid on spot market, leveraging flexible assets

- Spot electricity costs
- Imbalance costs
- Operational carbon emissions through carbon cost
- Risk aversion

Probability Distribution Functions of Carbon Emissions 2025-07-01



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Thank you.