Innovative Approaches for Deep Decarbonisation of Data Centers and Building Space Heating Networks

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The presentation

Reusing data center (DC) waste heat for building space heating

Beyond the state-of-the-art

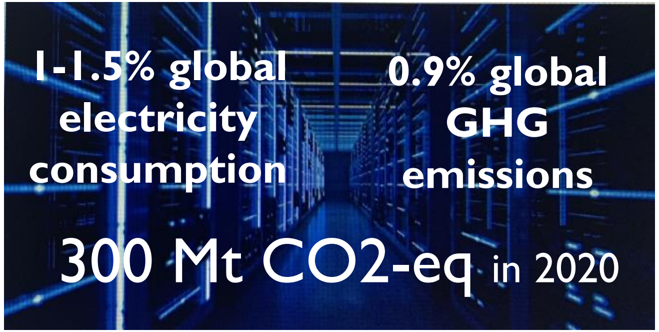
- Complete waste heat recovery
- No heat pumps
- Minimal investments, limited to short pipes and heat exchanges
- Payback time less than one year

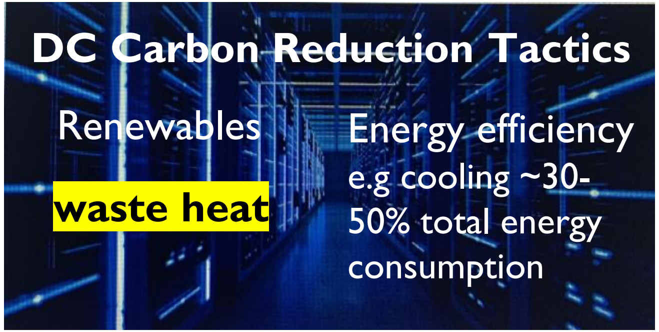
Affordable, sustainable, and innovative solutions for DC waste heat recovery

Background

Data centers (DCs) & carbon emission reduction

- Since 2010, global internet traffic has grown 25-fold, leading to substantial growth in data centers (DCs).
- DC carbon footprint is equivalent to the world's airline industry. DC energy consumption was projected to increase to 4.5% by 2025 and 8% by 2030.





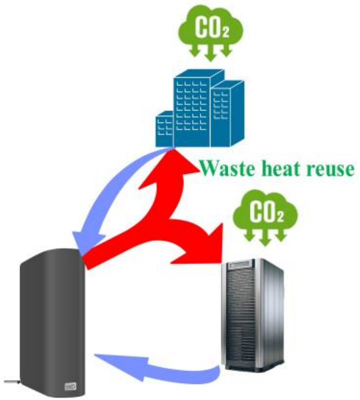
- ➢ Over 90% of the energy consumed by IT is transformed into heat, simultaneously IT requires cooling for operation
- ➢ Our research indicates that theoretically over 97% of waste heat can be utilized, the potential is huge
- ➢ A few applications target district heating networks (DHs) primarily in Finland and Sweden

Sources: IEA. Lu T et al. Investigation of air management and energy performance in a data center in Finland: Case study. *Energy and Buildings*, 2011; 43:3360–3372

Why reusing DC waste heat for building heating

- Buildings consume ~40% global energy and emit ~36% CO2 emissions.
- Fossil fuels provide ~70% energy used for building heating/cooling in the EU (Eurostat).

Reduce CO_2 emission for
buildings + DCs

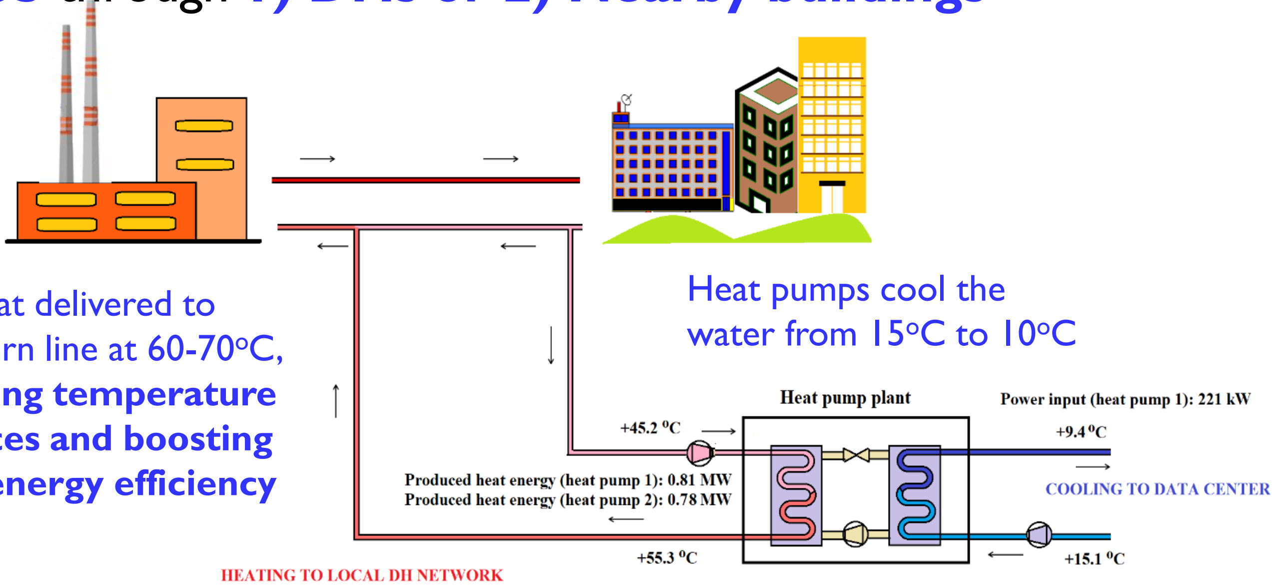


Finland aims at carbon neutrality by 2035, the world's first carbon neutral welfare society. It leads Nordic countries' DHs production per capita, major cities exceeding 90% adoption rates with cleaner generation than other EU countries. Many IT firms contribute waste heat to DHs. Small DCs are advised to employ their waste heat in nearby buildings.

- In 2010, Helsinki energy company and IT Academica established a 2 MW DC in an underground bomb shelter. This DC waste heat now heats ~1500 apartments.
- In 2019, Telia built the Nordic countries' largest colocation DC in Helsinki. Since 2022, company Helen has harnessed the DC waste heat to heat over 20,000 dwellings.
- Microsoft plans to build a DC in Espoo and Kirkkonummi, with Fortum investing to provide 40% of DHs for both cities. This initiative, the world's largest DC heat recovery project, aims to cut annual CO2 emissions by 400,000 tons.

The state of the art

Technically, the biggest obstacle is that the waste heat is low-quality heat. The state-of-the-art solutions are recycling DC waste heat for heating buildings using **heat pumps** through **1) DHs or 2) Nearby buildings**



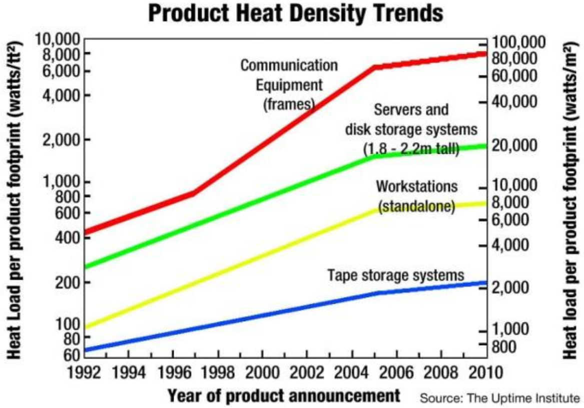
Waste heat delivered to DHs' return line at 60-70°C, **minimising temperature differences and boosting system energy efficiency**

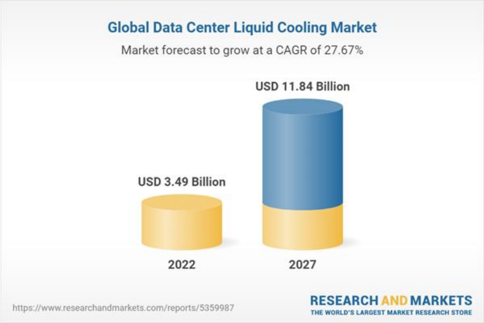
Heat pumps cool the water from 15°C to 10°C

Typical design of DC waste to DHs in Finland (applicable to nearby buildings)

Technical challenges in the state of the art

- DCs face power density challenges, projecting up to a 100% growth in average server rack density. Liquid cooling technologies, especially direct-to-chip cooling, are now widespread and expected to grow at a 6% rate over the next decade.





- Most DC waste heat recovery relies on energy-intensive heat pumps, raising concerns about their impact on CO_2 emissions and profitability due to significant electricity consumption.

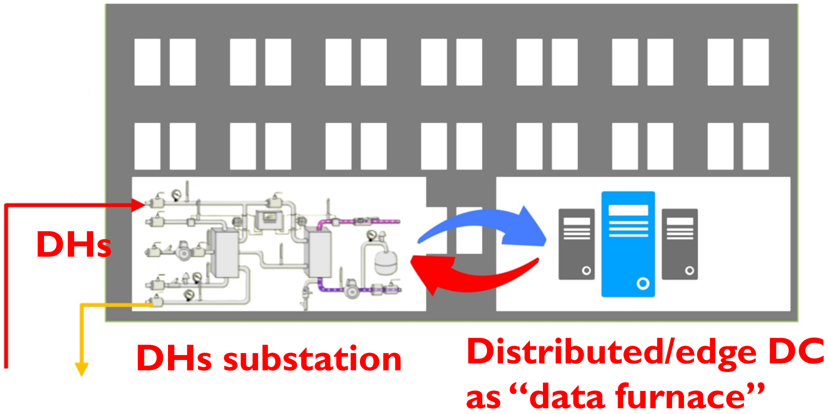
Research gaps and solutions in the state of the art

Limited research exists on **passive** DC waste heat recovery, excluding heat pumps, like **passive** liquid cooling heat recovery, which could eliminate the need for them. Unresolved critical issues:

1.Can waste heat from a liquid cooling system be fully recovered with just a heat exchanger?

2. Limited CDU (coolant distribution unit) research focuses on primary side waste heat recovery, neglecting secondary side recovery.

CDU: cooling distribution unit.



Distributed/edge DCs, with a few racks, can be strategically placed within or near building DHs substations to lower piping costs. This setup also decreases heat loss from enclosed pipes within buildings

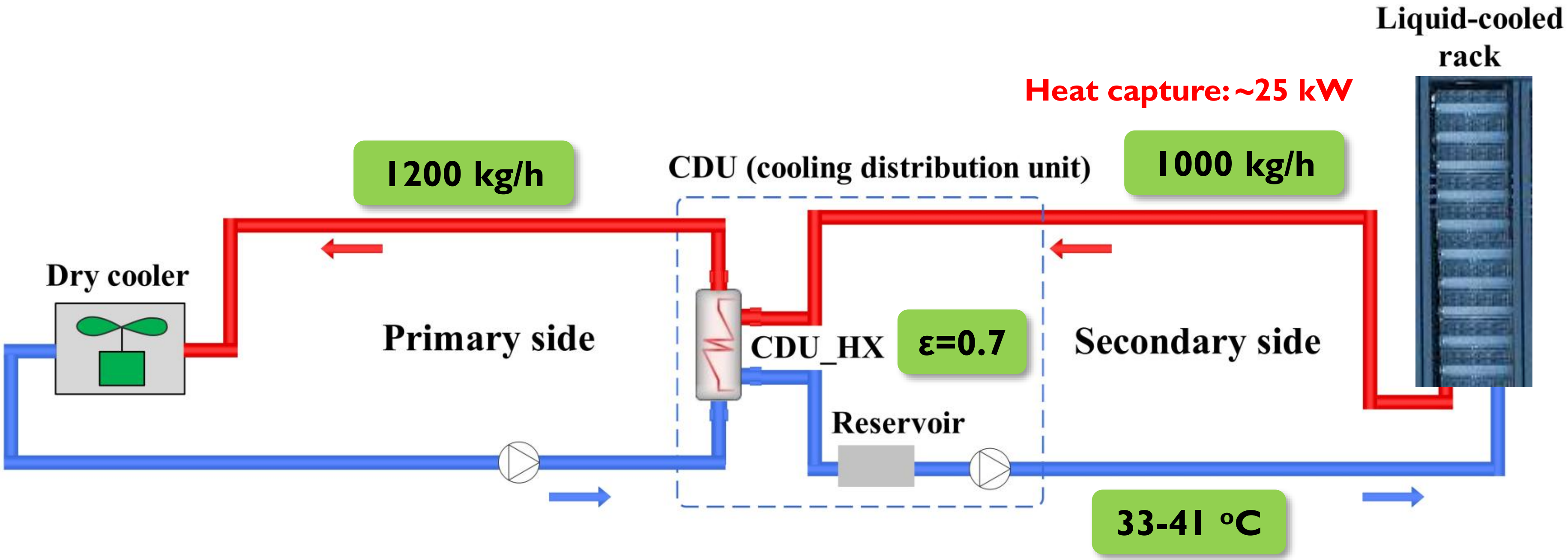
We address challenges by introducing the data furnace concept through direct-to-chip cooling

Technological Solutions & Results

Showcase data center (DC)

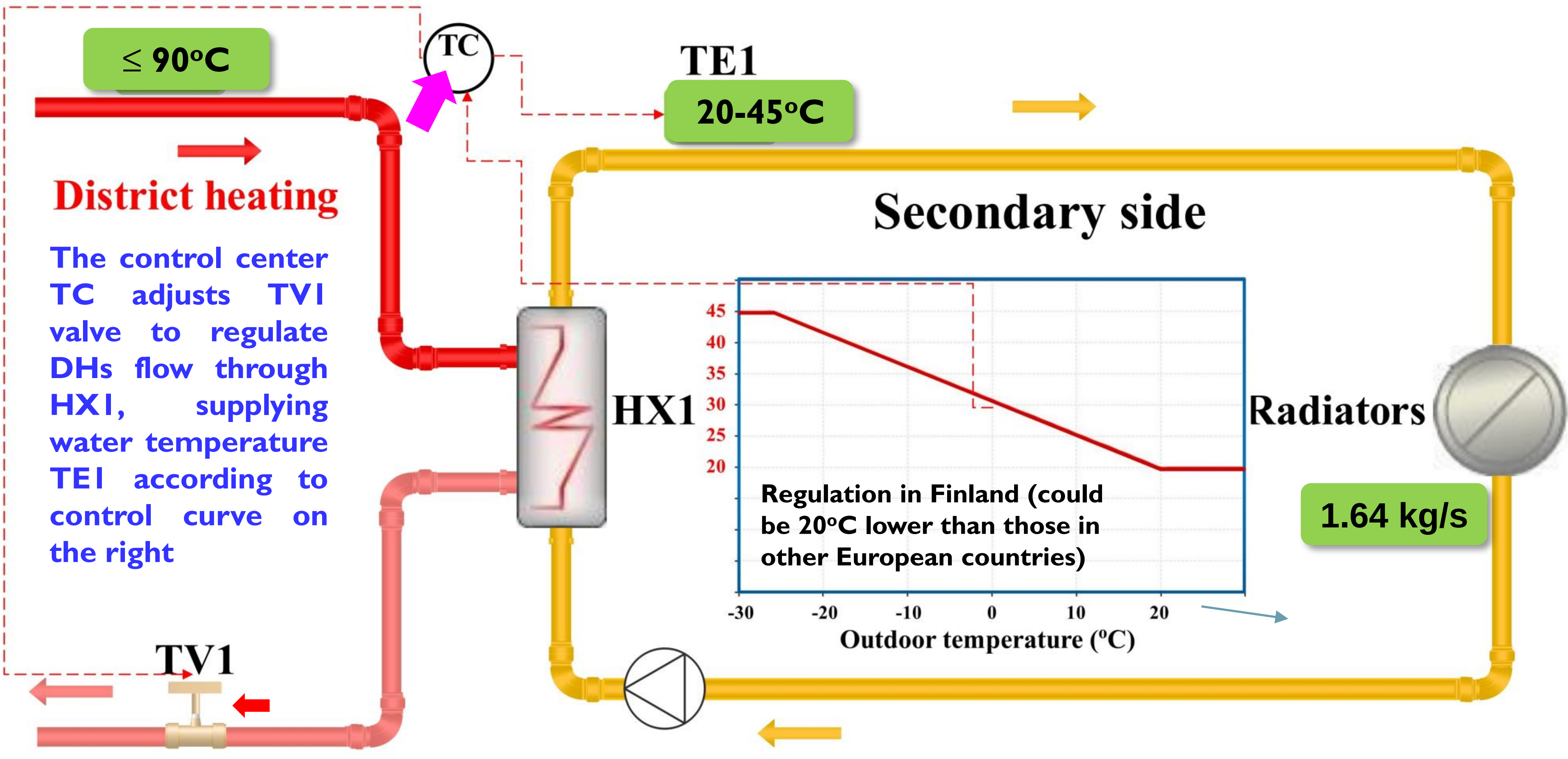
- This study is part of the "WSTAR" project (funded by the EU's NextGenerationEU instrument and the Academy of Finland), aiming at a distributed/edge WSTAR DC with zero CO_2 emissions.
  - WSTAR DC location: Vaasa, Finland (63°06′N 021°37′E).
  - IT capacity: 50 kW (30 kW direct-to-chip cooling for a single rack and 20 kW for free air cooling).
  - Office building: ~3000 m^2 floor, heated by DHs with annual space heating 285,662 kWh (96 kWh/m^2).
- We demonstrate our solutions for WSTAR DC, featuring a standalone **direct-to-chip cooling system** and a **building space heating network** as the base case.
- We propose **two liquid-to-liquid heat exchanger schemes** to recover waste heat from the primary or secondary side of the CDU (cooling distribution unit).

Standalone direct-to-chip cooling system (base case)



ε=0.7 the average among commonly used heat exchangers

Standalone building space heating network (base case)

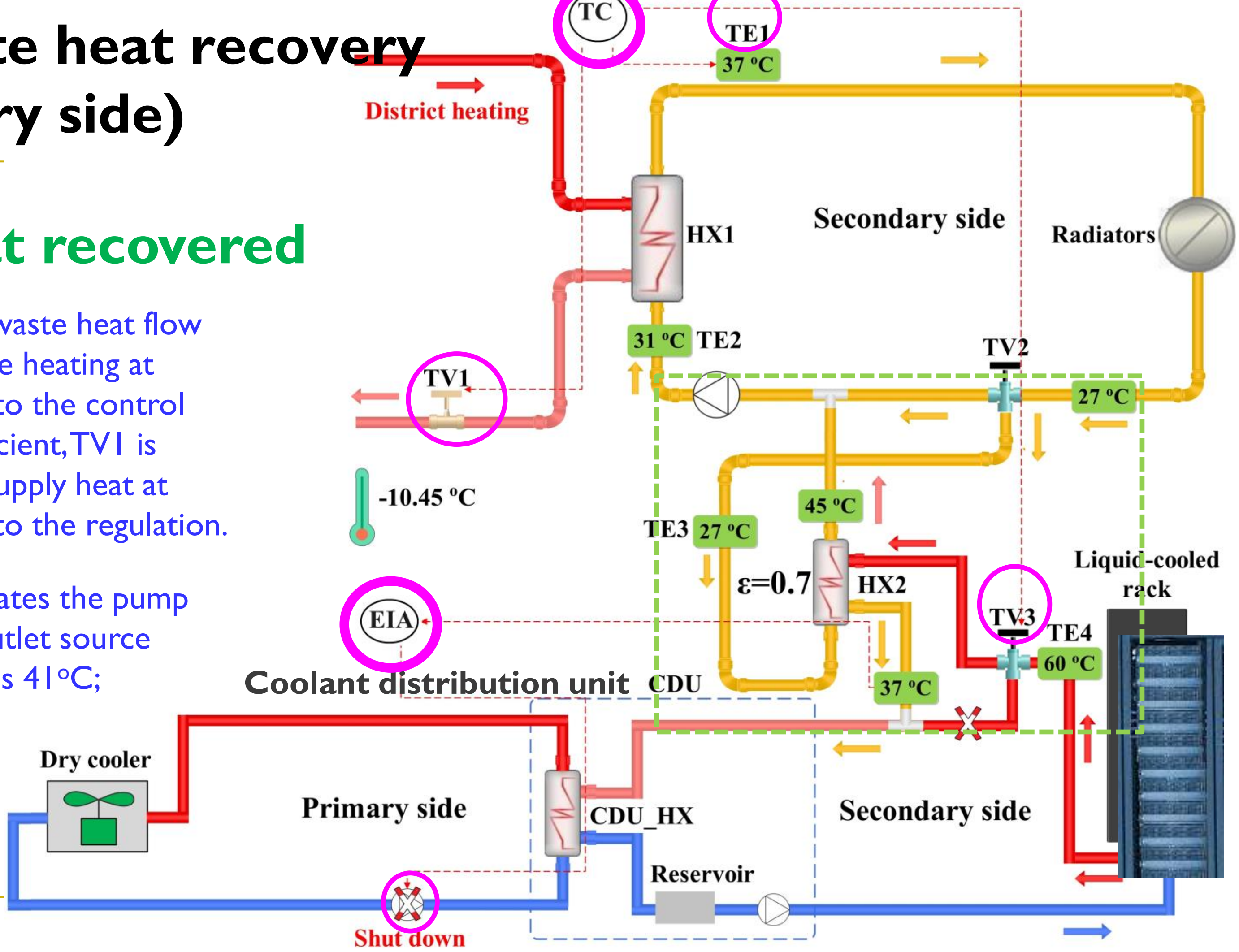


Scheme 1 (waste heat recovery on the secondary side)

100% waste heat recovered

TC: adjust TV3 to regulate waste heat flow through HX2 to supply space heating at temperature TE1 according to the control curve. If waste heat is insufficient, TV1 is activated to utilize DH to supply heat at temperature TE1 according to the regulation.

EIA: emergency that activates the pump on the primary side if the outlet source temperature of HX2 exceeds 41°C; otherwise, keep it off

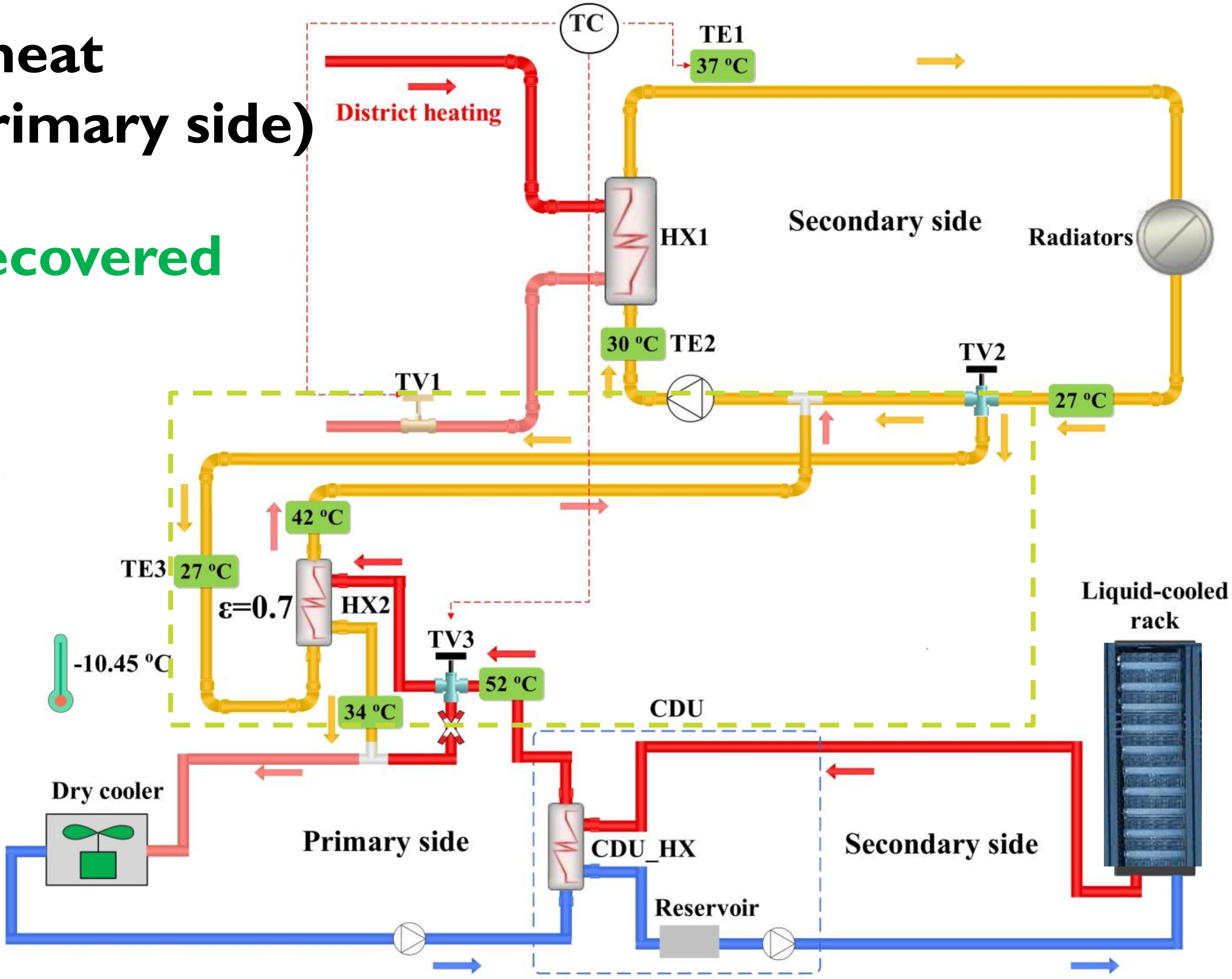


Scheme 2 (waste heat recovery on the primary side)

83% waste heat recovered

TC: same as Scheme 1

The pump and dry cooler on the primary side must operate continuously.



Scheme 1 vs. Scheme 2

Scheme 1

- Annual utilized waste heat ~ **155.2 MWh, ~71%** waste heat.
- **~2291 kWh** electricity from the dry cooler and pump on the primary side is saved annually due to the utilization of waste heat.

Scheme 2

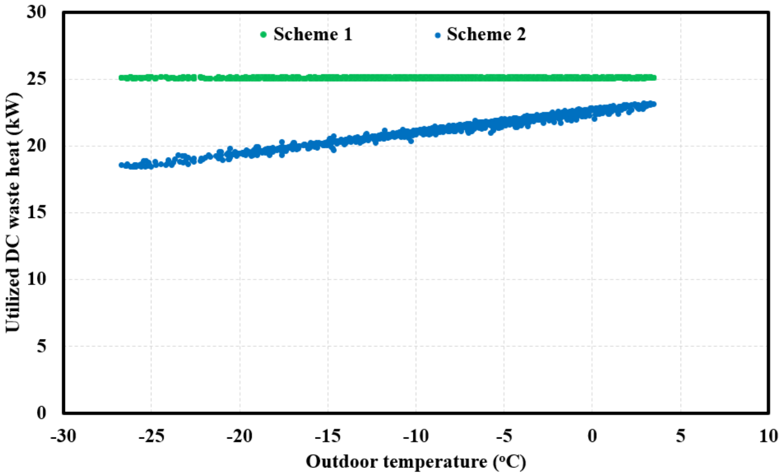
- Annual utilized waste heat **~138.2 MWh, ~63%** waste heat.
- **~905 kWh** electricity from the dry cooler and pump on the primary side is saved annually due to the utilization of waste heat.

Novel relationship graph for two schemes

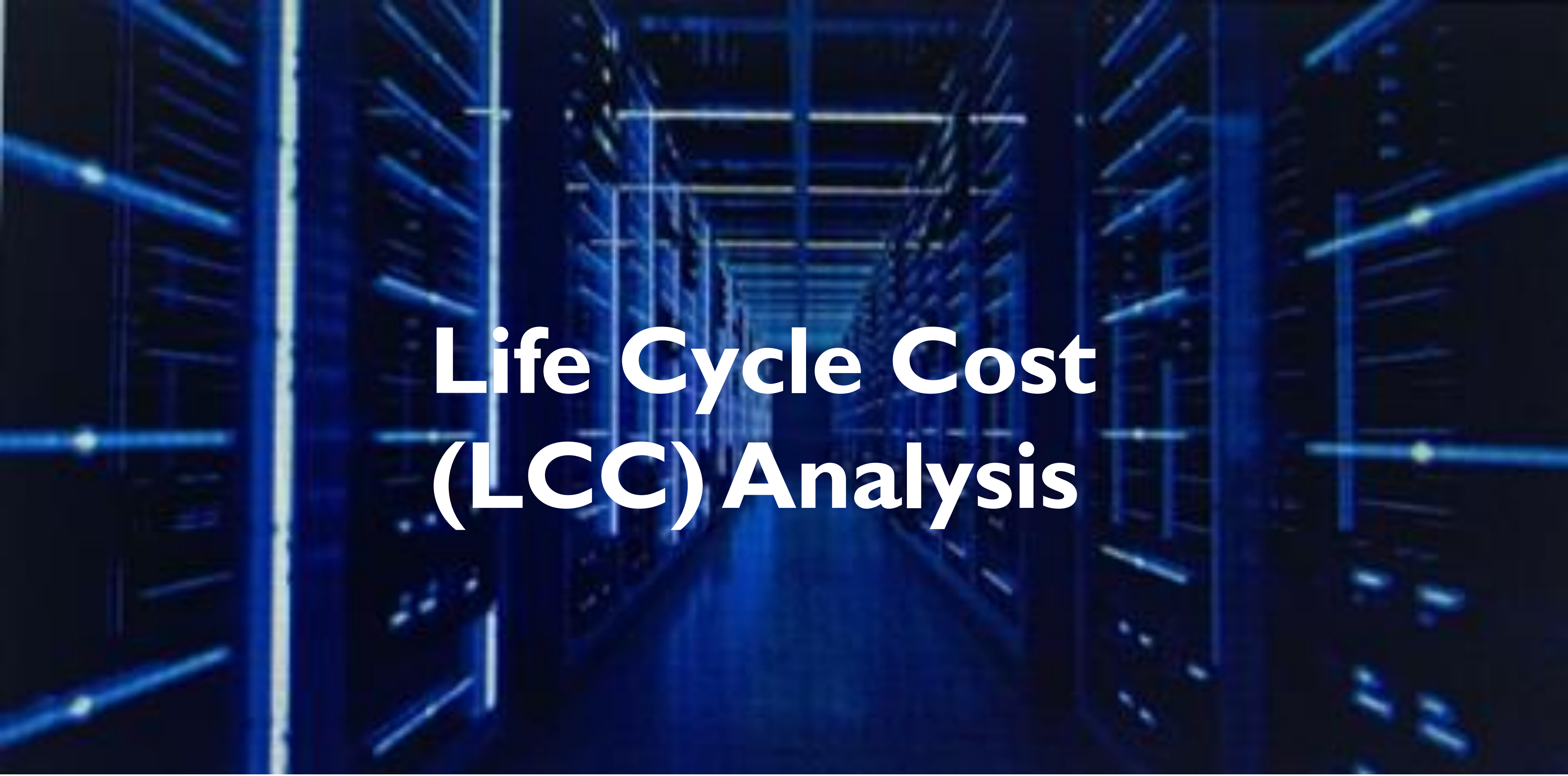
The graph can aid in designing heat recovery systems or HX2.

Some new discoveries are revealed by the graph:

- Scheme 1 maintains consistently full waste heat recovery, outperforming Scheme 2 which decreases as outdoor temperatures drop.
- **The slope indicates the effectiveness of HX2**. Improving Scheme 2 narrows the performance gap with Scheme 1 but does not eliminate it due to primary and secondary side differences.
- In an ideal scenario, the graph should show no correlation between waste heat recovery rate and outdoor temperature, indicating complete recovery.

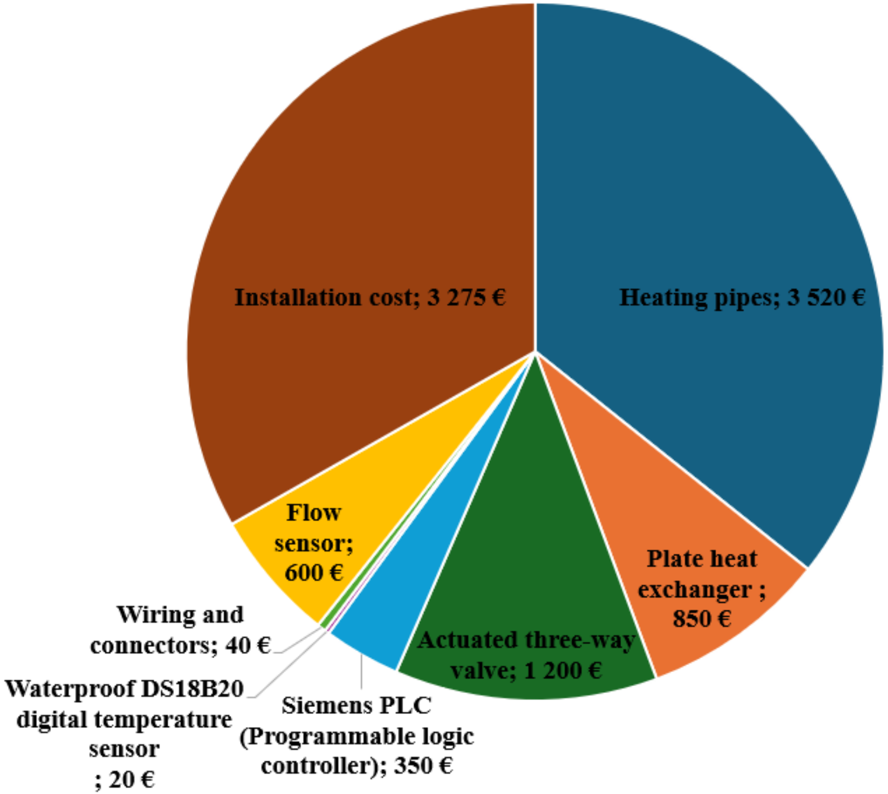


These discoveries significantly enhance the current state of the art.



Life Cycle Cost (LCC) Analysis

Capital cost



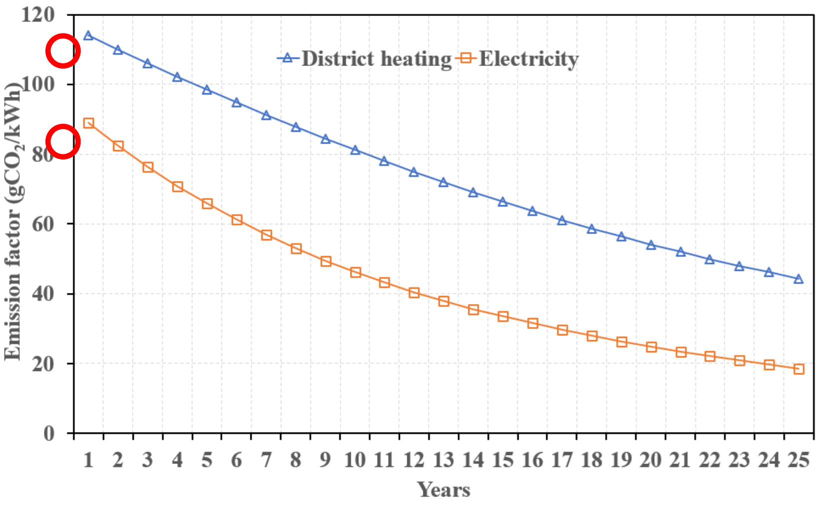
- LCC analysis is conducted from **building owner's perspective**.
- Prices are indicative of averages or above-average figures based on online sources.
- As no heat pump is required and all pipes are installed within the building, the investment cost is substantially reduced to ~ €10,000.

LCC and CO_2 emission reductions

Input parameters for NPV (net present value)

Cost factor	Value
Number of years	25
Discount rate	7%
Inflation rate	2%
Electricity price 1st year	120.69 €/MWh
Electricity inflation rate	2%
DHs price 1st year	89.33 €/MWh
DHs inflation rate	3%

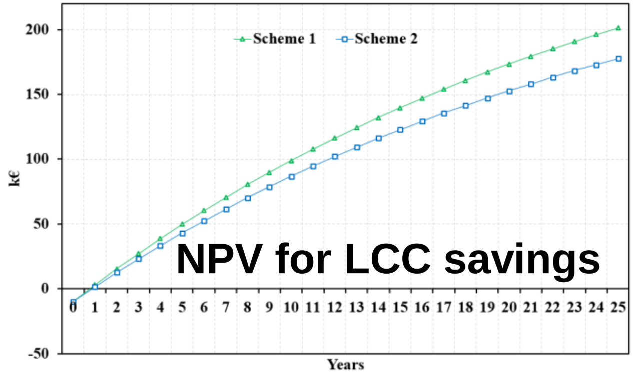
CO_2 emission factors (gCO_2/kWh)

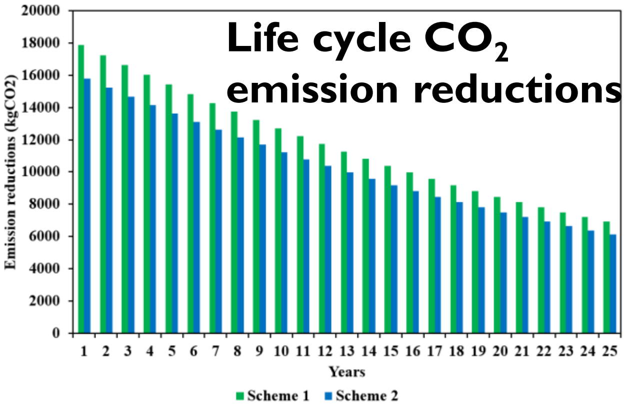


Emission data in Finland (lower compared to other European countries)

LCC results

Both schemes have payback time < a year and contribute significantly to CO2 reduction





Scheme 1 saves **~€203287** and **~291996 kgCO2** in DHs costs over 25 years

Scheme 2 saves **~€177443** and **~258192 kgCO2** in DHs costs over 25 years

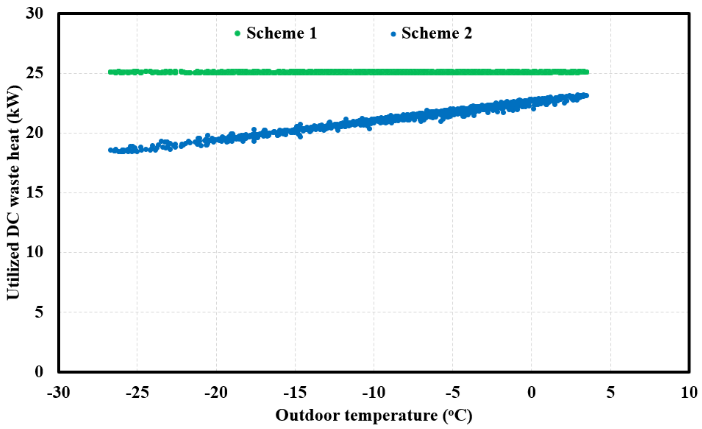
54% (Scheme 1) and 48% (Scheme 2) DHs cost savings and carbon reductions are achieved

A single rack 25kW waste heat
In cold weather in Finland

Discussion & Conclusions

Discussion

Initially, we anticipated full recovery of waste heat from DC when building heating demand exceeds waste heat. However, results revealed a different reality. Scheme 2 leads to reduced waste heat as outdoor temperatures drop. Conversely, Scheme 1 avoids this issue, maintaining a constant waste heat recovery rate irrespective of outdoor temperature. **This crucial finding represents a new insight.**



Conclusions

For direct-to-chip cooling system and low-temperature space heating, our developed waste heat recovery schemes, Scheme 1 and Scheme 2, can achieve full waste heat recovery of **71%** and **63%**, respectively.

Reference: Oltmanns et al (2020)'s simulation results:

- two waste heat reuse concepts for a university-based DC (360 kW)
- first involved transferring waste heat to the campus DHs, achieving **50%** of the waste heat annually
- second directly utilized waste heat to heat nearby buildings, achieving **20%** of the waste heat annually

Source: Oltmanns et al. (2020), Potential for waste heat utilization of hot-water-cooled data centers: A case study, Energy Sci. Eng. 8 1793–1810

Conclusions

Utilizing waste heat from liquid cooling systems without a heat pump is highly profitable for space heating, regardless of recovering waste heat from the secondary or primary side. The payback period is less than **one year**!

Comparison: Oró et al. (2019)'s analyses

- waste heat of 1000 kW air-cooled DC sold to a local DHs in Spain with two cooling methods.
- They found that heat recovery from the return hot aisle was more economically feasible, with a payback period of **10-14 years**, while heat recovery from the chiller condenser had longer payback periods exceeding **15 years**.

Source: Oró et al. (2019) Waste heat recovery from urban air cooled data centres to increase energy efficiency of district heating networks, Sustain. Cities Soc. 45, 522–542

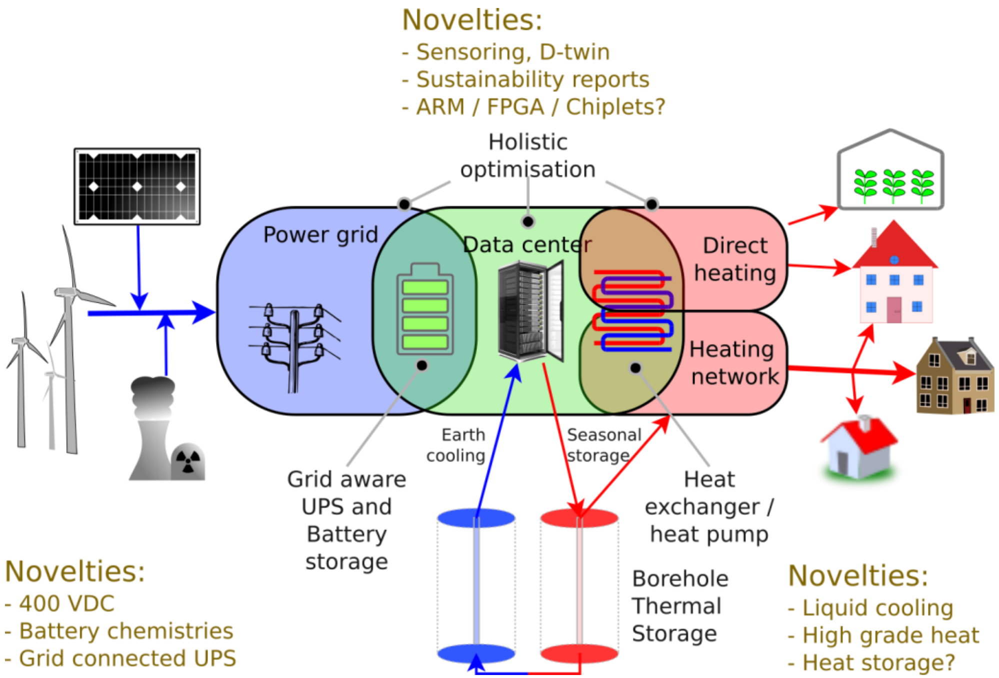
Key takeaways

- Achieve complete waste heat recovery in extreme cold weather.
- Eliminate the need for heat pumps.
- Implement cost-effective investments limited to heating pipes and heat exchangers.
- Applicable beyond DHs, particularly beneficial for 4G/5G DHs, and especially suitable for low temperature heating systems.
- Achieve a rapid carbon reduction with a quick payback time.
- Present an affordable, sustainable, and transformative approach to waste heat recovery in DCs.

Appendix

WSTAR: Vaasa zero emission data center research infrastructure

- Open research infrastructure for studying energy efficient data centers.
- Sector coupling of power and heat.
- Testing novel sector coupling methods, including cooling and heat recovery options.
- Optimisation of AI training in data centers, considering the energy constraints.
- Provision of metrics and automated energy performance monitoring to meet EU's EED reporting requirements and encourage energy-efficient applications.



WSTAR: Vaasa zero emission data center research infrastructure in Technobothnia

- Research and education laboratory for University of Vaasa, Vaasa University of Applied Sciences and Novia University of Applied Sciences
- Serves about 2400 technology students
- Close collaboration with industry
- Place for the future data center research infrastructure
- Combined with existing laboratories: EMC, 5G, Energy, Power systems, Space Data, User experience, etc

Thank You

Happy Valentine's Day

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