WASTE HEAT POTENTIALS FROM LIQUID COOLED DATA CENTRES FOR SUSTAINABLE BUILDING HEATING SOLUTIONS

Xiaoshu Lü [1,2] and Tao Lu [1]

[1] *Department of Electrical Engineering and Energy Technology, University of Vaasa, P.O. Box 700, FIN-65101, Vaasa, Finland*
[2] *Department of Civil Engineering, Aalto University, P.O. Box 11000, 02150, Espoo, Finland*

ABSTRACT: The surge in internet usage has heightened the demand for data centres (DCs) and resulted in significant increases in energy consumption and carbon dioxide (CO2) emissions in the world. Concurrently, buildings are among the largest energy consumers and CO2 emitters. Reducing carbon emissions in both DCs and buildings is crucial for climate change mitigation. This paper proposes innovations in DC waste heat reuse in building space heating tailored to different climate zones. It explores the potential of the latest Edge DCs with liquid cooling technology, where DCs directly contribute to building heating. Highlighting efficient heat exchanger design, we assess and compare DC waste heat recovery strategies for varying climate conditions, aiming to optimise energy efficiency without relying on heat pumps. We assess these strategies and their potential to reduce CO2 emissions. This study bridges gaps in existing literature and offers insights into region-specific applications of DC waste heat reuse in building space heating.

Keywords: data centre waste heat reuse, liquid cooling technology, district heating networks, climate-specific solutions

1. INTRODUCTION

The rapid expansion of internet usage globally has led to a corresponding surge in demand for data centers (DCs), which in turn has significantly increased energy consumption and CO2 emissions. As DCs continue to proliferate, their environmental impact becomes increasingly critical in the context of climate change mitigation efforts (IEA, 2023). Concurrently, The buildings sector, one of the largest energy consumers and CO2 emitters, accounts for over one third of world's energy consumption and emissions (IEA, 2023). Efforts to address these challenges are multifaceted. One promising avenue is the reuse of waste heat generated by DCs to heat buildings, which offers dual benefits of reducing energy wastage and potentially offsetting heating demands in adjacent buildings or district heating (DH) networks (Pakere et al. 2023).

In applying waste heat from DCs to supplement DH networks, preheating is typically needed to meet DH temperature requirements (45–55°C) (Tahiri et al. 2022), often necessitating additional heating devices and power input. Heat pumps (HPs) are often implemented which can upgrade waste heat temperatures, enabling its use in high-grade heating demands and significantly reducing centralized heat production and carbon emissions (Abdurafikov et al. 2017). Case studies have demonstrated substantial energy savings, operational cost reductions, and CO2 emission reductions, highlighting the potential benefits of integrating waste heat recovery systems in DH networks (Ljungdah et al. 2022, Yuan et al.

2023). Pakere et al. (2024) investigated the potential for waste heat recovery from DCs in Latvia, finding that the waste heat generated in 2022 was 51.37 GWh at 65°C, and projecting an increase to 257 GWh by 2050, with 201 GWh being utilized for heating purposes. Oltmanns et al. (2020) studied TU Darmstadt's new data center that uses direct hot-water cooling at 45°C, enabling waste heat to be repurposed for campus heating. Results show that CO2 emissions could be reduced by up to 4% and 20%-50% utilisation of waste heat could be achieved for heating, with the remaining heat dissipated via free cooling. Montagud-Montalvá et al. (2023) adapted Stanford Energy System Innovations' decarbonization plan to Universitat Politècnica de València, focusing on recovering waste heat from a campus data center with consistent cooling demands totaling 1,661,020 kWh annually. A 300 kW polyvalent heat pump is proposed to utilize this waste heat, providing both cooling and heating to several campus buildings, thereby potentially saving 254,106 kWh/year in thermal energy and reducing CO2 emissions by 64,035 kg/year. These findings offer insights for similar projects aimed at decarbonizing large data centers in Mediterranean urban settings. Yuan et al. (2023) reviewed waste heat recovery from various DC sources for applications like heating, cooling, and industrial processes, offering technical, energy, environmental, and economic insights for future research and development.

Recently, Lu et al. (2024) proposed an innovative strategy for the reuse of DC waste heat to buildings that connected to DH networks. Specifically, it explored the potential of Edge DCs equipped with liquid cooling technology, where waste heat from DCs is directly utilized for building heating. Unlike traditional approaches that rely on heat pumps, the proposed strategies emphasessed efficient heat exchanger design and novel heat recovery schemes. Note that due to the skyrocketing growth of artificial intelligence and high computing, liquid cooling is expected to increase steadily. The return temperatures from liquid-cooled racks are higher, offering opportunities for direct use in building space heating, especially in low-temperature district heating (DH) networks. Low-temperature DH networks and low-energy buildings are being promoted across the EU (Open Access Government. 2023).

This paper extends innovative strategies (Lu et al., 2024) for the reuse of DC waste heat to building space heating tailored to diverse climatic conditions. While research has focused on DC waste heat reuse to specific building systems, comprehensive data for buildings is still lacking to inform national and regional policies on energy and carbon reduction. Literature review shows that no study has yet addressed this gap. This study aims to fill this void by exploring the utilisation of DC waste heat across various climatic regions in Finland.

2. MATERIALS AND METHODS

2.1 Data Centre (DC) and Buildings

We investigate a real liquid-cooled DC housed within an office building and connected to a DH network. The DC has an IT capacity of 50 kW with 30 kW dedicated to direct-to-chip cooling and 20 kW to free air cooling. This study focuses on the reuse of 30 kW of liquid-cooled waste heat, which is integrated into the return line of the secondary side of the space heating DH network, see details in Methods section.

The representative office building is assumed to have a floor area of 3000 m² with energy consumption of 95 kWh/m², distributed as follows: ventilation and air-conditioning 45%, envelop 17%, windows 9%, water 2%, floor 1%, and lighting and electricity 27% (LTRS, 2020).

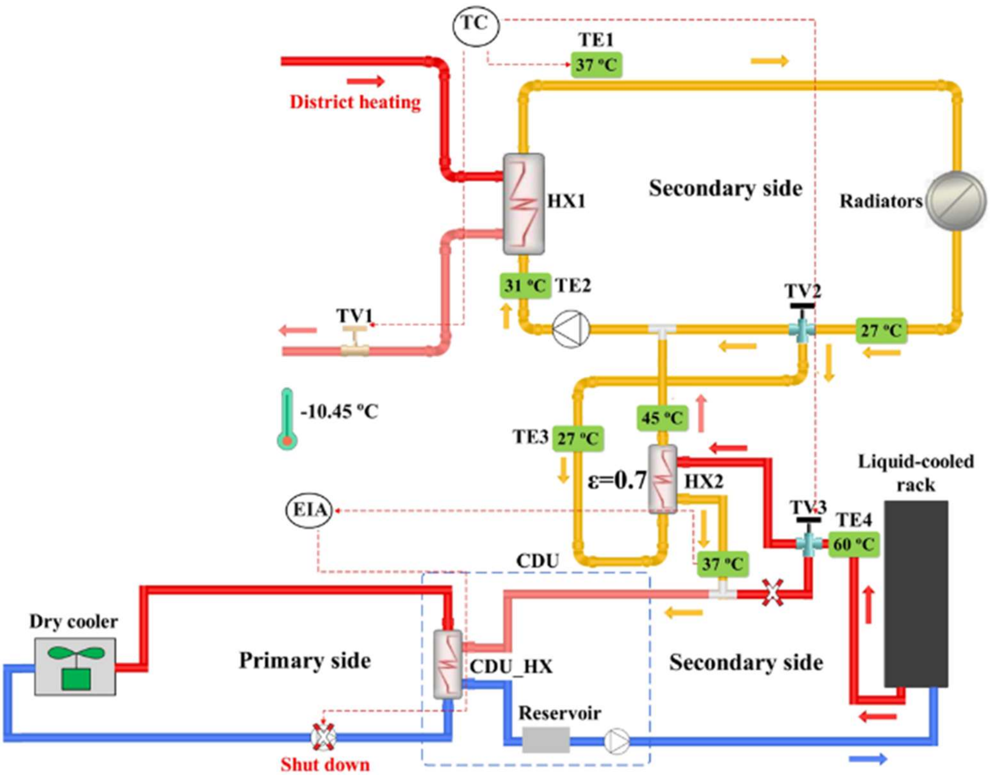
2.2 Methods

2.2.1 Efficiency of waste heat utilisation

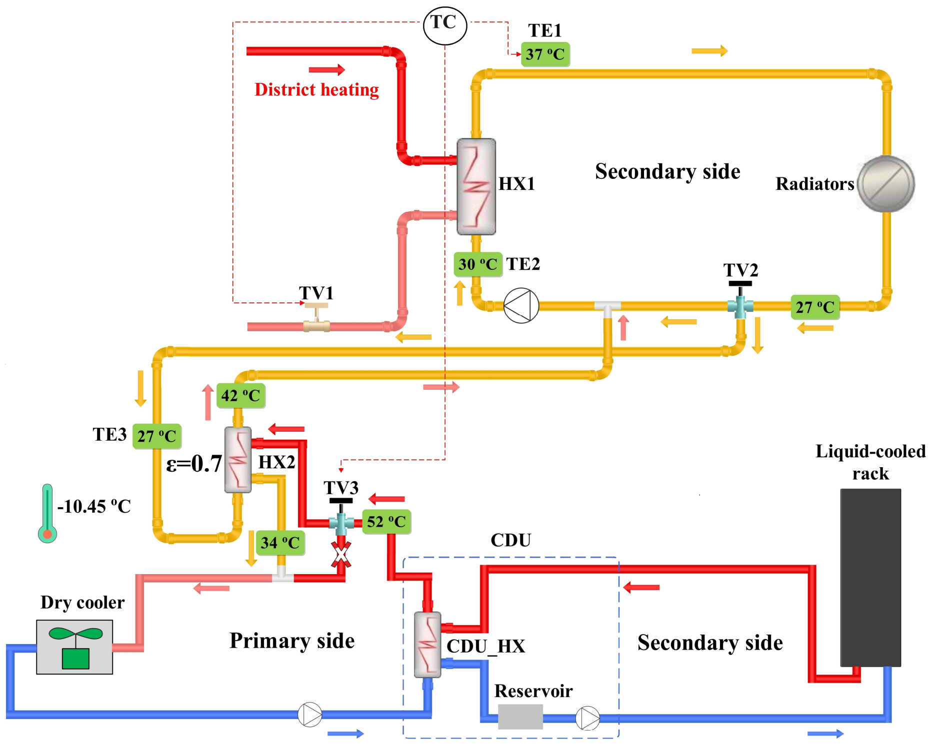
Two innovative connection schemes, S1 and S2, for recovering DC waste heat from either the primary or secondary side of the cooling distribution unit (CDU) are adopted using a liquid-to-liquid heat exchanger. Table 1 illustrates the system parameters and Figure 1 shows the schematic drawings of S1 and S2. Details can be found in the reference (Lu et al. 2024).

Table 1. System parameters for direct-to-chip cooling system.

CDU	**Primary side**
Effectiveness ε = 0.7	Pump's mass flow rate = 1200 kg/h
Pump's mass flow rate = 1000 kg/h	Pump's input power = 0.25 kW
Pump's input power = 0.25 kW	Fluid* specific heat capacity = 3.6 kJ/kg.°C
Coolant* specific heat capacity = 3.91 kJ/kg.°C	
Dry cooler	
Design inlet fluid flow rate = 45 °C	Design air flow rate = 33768 kg/h
Design outlet fluid temperature = 40 °C	Total heat of rejection = 30.8 kW
Specific heat capacity = 3.53 kJ/kg°C	Rated fan power = 1.76 kW
Design ambient air temperature = 35 °C	Designed outlet fluid temperature = 31 °C if ambient temperature ≤ 26 °C; Outdoor temperature + 5 °C, ambient temperature > 26 °C.



(a)



(b)

Figure 1. Schematic drawing for waste heat recovery from either the secondary (a) or the primary (b) side of the cooling distribution unit.

The control center TC adjusts TV1 valve to regulate DH flow through HX1, supplying water temperature TE1 according to DH control curve in Figure 2 (Yu et al., 2023).

- 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.
- Figure 1 (a): EIA: emergency that activates the pump on the primary side if the outlet source temperature of HX2 exceeds 41°C; otherwise, keep it off
- Figure 1 (b): The pump and dry cooler on the primary side must operate continuously.

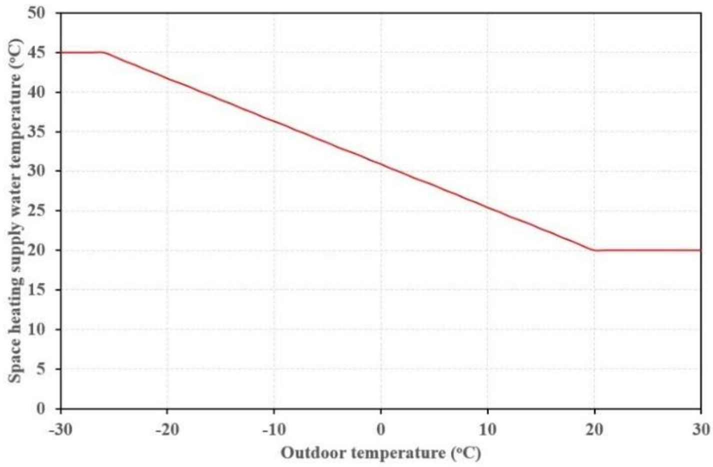


Figure 2. Space heating supply water temperature variations.

2.2.2 The office building in different climates

The space heating network shown in Figure 1 is modeled for four Finnish cities representing different climate zones: Helsinki (average yearly outdoor temperature 7.1°C in 2023), Jyväskylä (4.1°C), Oulu (3.7°C), and Rovaniemi (1.86°C), as illustrated in Figure 3. The 2023 outdoor temperatures are used for modeling, detailed in Lu et al. (2024). This paper aims to investigate the impact of outdoor climate on DC waste heat utilization and CO2 emission reductions.

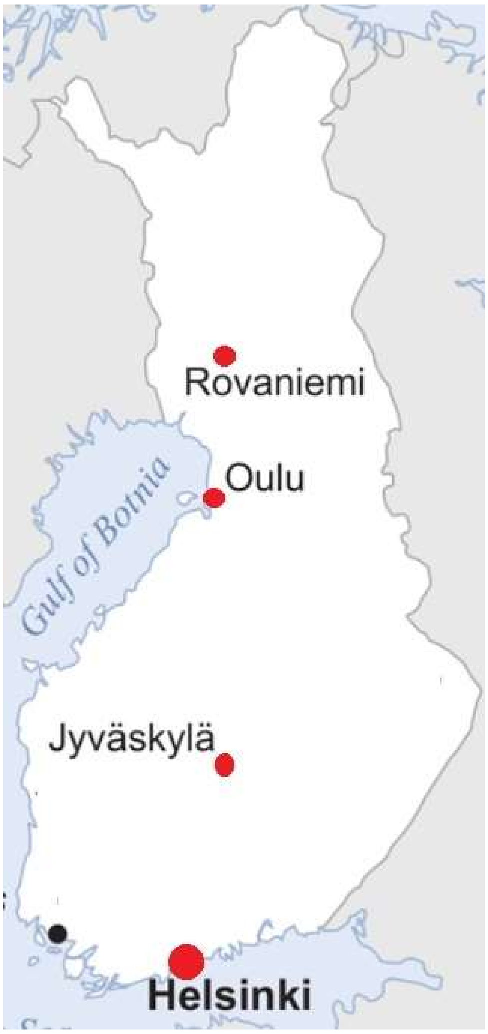


Figure 3. Investigated four Finnish cities.

3. Th RESULTS AND DISCUSSION

3.1 Waste heat utilisation

Figure 4 shows the comparison of DC waste heat utilization in different climate zones in terms of DH savings.

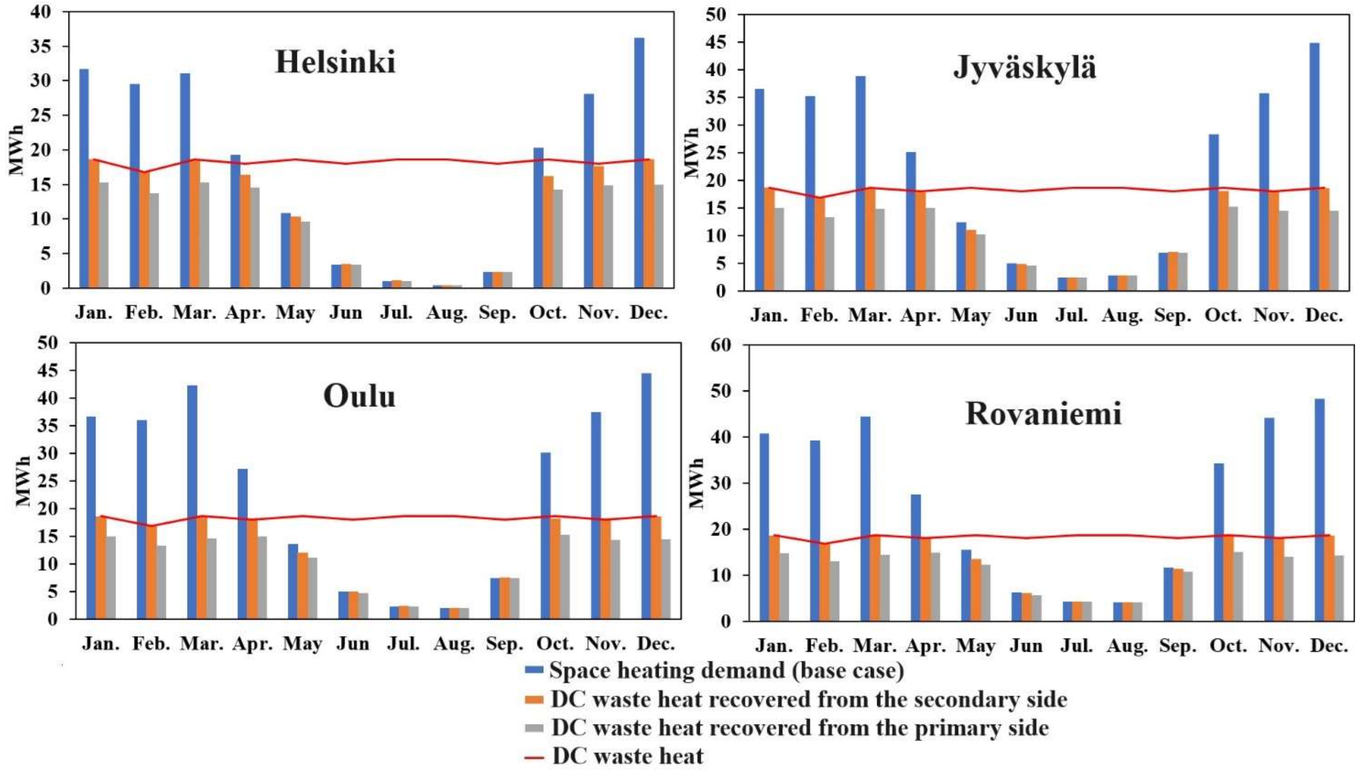


Figure 4. Comparison of waste heat utilisations in different zones.

Figure 4 demonstrates that recovering waste heat from DCs on the secondary side consistently proves more effective than on the primary side across all climate zones due to higher temperatures and greater heat availability. In colder climates, such as Helsinki and Rovaniemi, where heating demand is more pronounced, significantly more waste heat is recovered compared to warmer climates. For instance, in Helsinki, 140 MWh of waste heat is recovered from the secondary side versus 119.5 MWh from the primary side, while in Rovaniemi, these figures increase to 165.78 MWh and 137.4 MWh, respectively. The difference in recovered waste heat between the secondary and primary sides also widens in colder climates, expanding from 21.5 MWh in Helsinki to 28.38 MWh in Rovaniemi, highlighting the efficiency gains in utilizing waste heat for heating purposes. These findings highlight the potential for secondary-side waste heat recovery to not only optimize energy utilization in DC operations but also contribute significantly to reducing energy consumption and environmental impact in colder regions.

3.2 Environmental assessment

Besides waste heat utilisation, we also simulated the carbon reductions for the represetative climate zones. The carbon reduction is estimated based on the reduction from DH and electricity due to the saving from the system, referring to Table 1 and emission factors (Finnish Ministry of the Environment, 2019). Figure 5 illustrates the results.

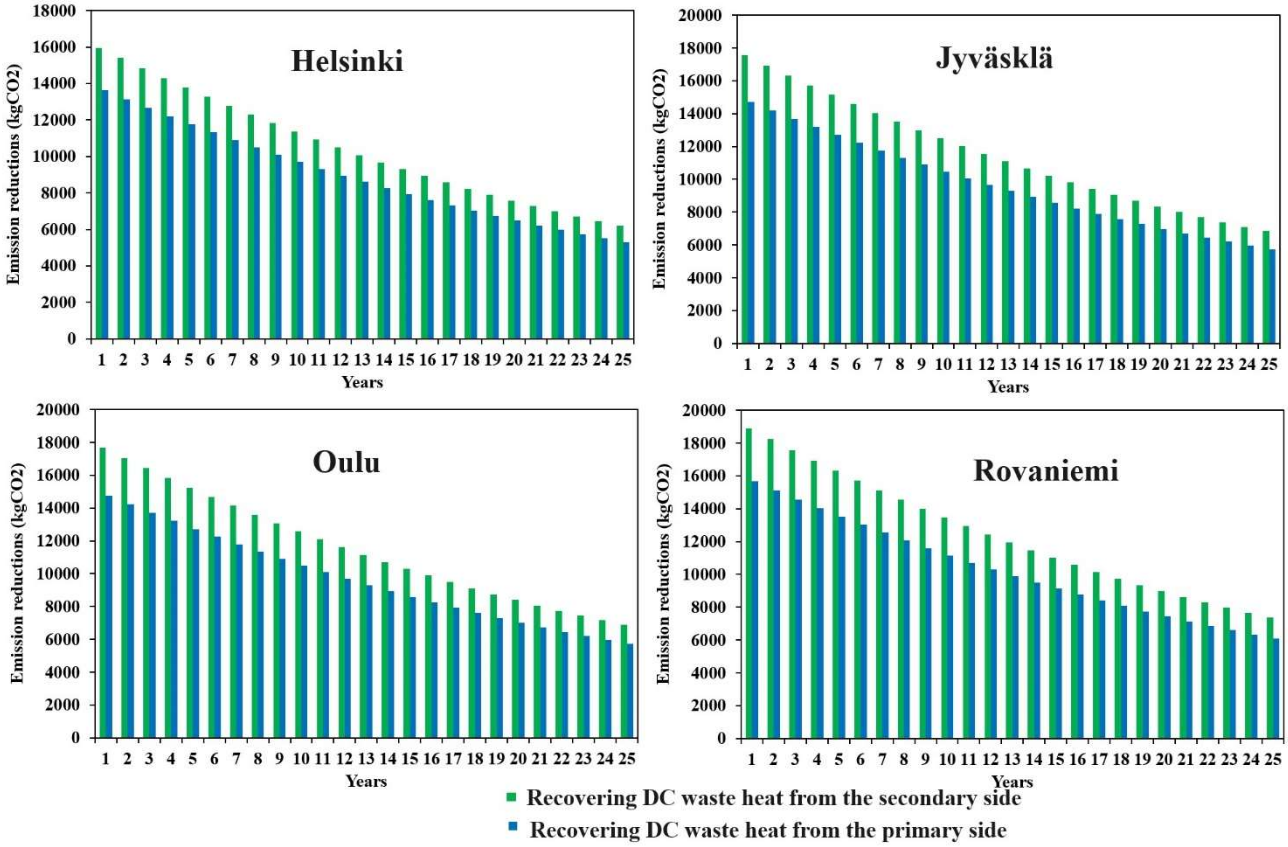


Figure 5. Comparison of carbon emission reduction in different zones.

Figure 5 demonstrates the substantial impact of waste heat recovery from DCs over a 25-year period on reducing CO2 emissions across different cities. In Helsinki, Jyväskylä, Oulu, and Rovaniemi, recovering waste heat from the secondary side results in significant CO2 reductions: 261,108 kg, 287,024 kg, 289,075 kg, and 309,180 kg, respectively. Comparatively, recovering from the primary side leads to lower but still substantial reductions: 222,870 kg, 240,473 kg, 241,163 kg, and 256,251 kg in the same cities. These findings highlight that while both methods achieve greater CO2 reductions in colder climates, choosing the optimal recovery location is critical. For instance, despite Rovaniemi's colder climate, secondary side recovery in Helsinki over 25 years yields a larger reduction in CO2 emissions than primary side recovery in Rovaniemi. This underscores the importance of strategic decision-making in waste heat recovery to maximize environmental benefits across varying climate conditions and geographical locations.

4. CONCLUSIONS

This study highlights the considerable potential of reusing waste heat from DCs for building space heating, particularly through tailored solutions that account for varying climate conditions and the adoption of Edge DCs employing liquid cooling technology. By implementing innovative heat recovery methods and efficient heat exchanger designs, significant improvements in energy efficiency and reductions in CO2 emissions can be achieved without the need for extensive heat pump systems. The research findings stress the importance of adapting waste heat recovery strategies to local climates to maximise their environmental benefits effectively. Moreover, this work addresses a critical gap in the existing literature, providing essential insights that can inform the development of national and regional policies aimed at optimising energy usage and mitigating carbon emissions amidst the expanding DC landscape. The environmental assessment conducted on proposed waste heat recovery schemes emphasises their potential to notably reduce CO2 emissions, improve air quality, and contribute to broader sustainability objectives. These advantages stress the role of innovative energy solutions in combatting climate change and fostering sustainable global development.

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