Waste Heat Recovery and Utilization Potential from Data Centres in Alberta

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Problem Statement

Alberta is vying to attract C$100 billion in data centre (DC) investment over five years. Already, over 11 GW of DCs have requested grid interconnection, which would more than double the province's average electricity demand. At this scale, the potential for waste heat utilization is in the realm of billions of kw-hours of recoverable energy annually. This research aligns with Alberta's AI DC Strategy which includes promoting sustainable, innovative cooling systems and exploring waste heat capture and utilization.

Research Questions

1. How does ambient temperature affect annual cooling load for data centres operating with identical immersion cooling systems?
2. What are the technical environmental and economic benefits of capturing waste heat from data centres in Alberta?

Literature Review

Immersion Cooling

Rapid increase in chip power density and corresponding thermal density in AI data centres is exceeding the capabilities of conventional air-based cooling systems, which struggle to manage server racks that are over 20 kW each (Ebrahimi et al., 2014; Nadjahi et al., 2018). Today's average power density is approximately 15kw per rack, but it's expected that AI computational workloads will reach over 60kw per rack (Kleyman, 2024). A solution to these high heat density chips is immersion cooling, which works by fully submerging servers in thermally conductive dielectric fluids, enabling more efficient heat removal at higher temperatures than air-cooled systems (Nadjahi et al., 2018; Wang et al., 2024).

Immersion cooling offers significant energy and water savings compared to air cooling systems. By eliminating or greatly reducing the need for chillers, computer room air handlers, or evaporative cooling towers, immersion systems can reduce cooling electricity consumption by **30–50%** (Nadjahi et al., 2018; Ebrahimi et al., 2014). Moreover, water consumption is nearly eliminated in immersion-cooled facilities, which is a major difference from evaporative cooling (Haghshenas et al., 2023).

Waste Heat Recovery

Data centres ultimately convert nearly all the electricity they consume into heat after data processing (Luo et al., 2019). When conventional air-cooled systems are used, most of this thermal energy is simply released into the atmosphere. However, when a facility uses immersion or other forms of liquid cooling, much of that heat can be captured in a concentrated form. Liquid cooling directly transfers thermal energy from servers into a circulating fluid, which can leave the DC at temperatures high enough for productive use—around 60 °C. At this temperature, the heat can be applied directly to many space heating applications without the need for temperature boosting from heat pumps.

Methodology

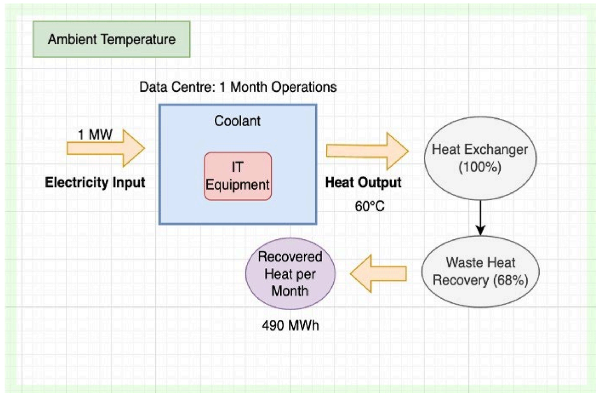
The calculations below were used to determine the amount of electricity consumed per hour by the immersion cooling system, based on ambient outdoor temperature. Annual energy consumption was compared across eight locations in Canada and the US.

1. $PUE(T) = PUE_{Base} + \alpha \cdot \max(T_{ambient} - T_{threshold}, 0)$
2. $PUE(T) = 1.05 + 0.0006 \cdot \max(T_{ambient} - 22, 0)$
3. $P_{cooling} = (PUE(T) - 1) \cdot 1\ MW$
4. $E_{cooling}$ (per hour) $= P_{cooling} \cdot 1hr$

Assumptions

- Threshold Temperature: 22°C
- Base Power Usage Effectiveness (PUE): 1.05
- α = 0.0006

Assumptions and System Boundary



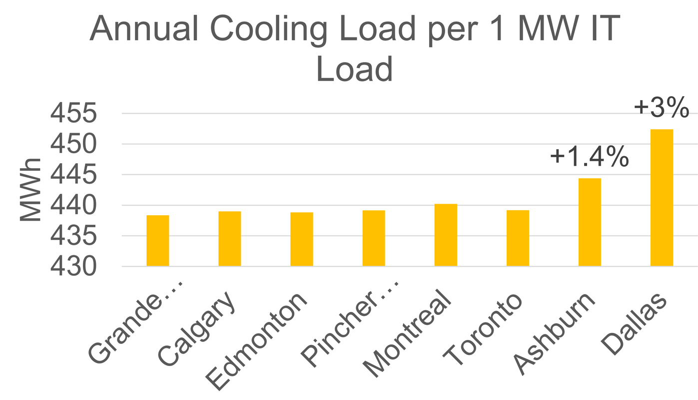
- Functional Unit: 1 MW IT Load
- Recovery Efficiency: 100%
- Transfer Efficiency: 68%
- Waste Heat/ Month: 489.6 MWh
- Coolant Outlet Temperature: 60°C

Every 1 MW of IT load will produce 490 MWh of recoverable waste heat per month. The block flow diagram above shows 1 MW of input of electricity, coolant exiting the servers at 60°C, and flowing through the heat exchanger and transfer (or recovery) systems.

Results & Interpretation

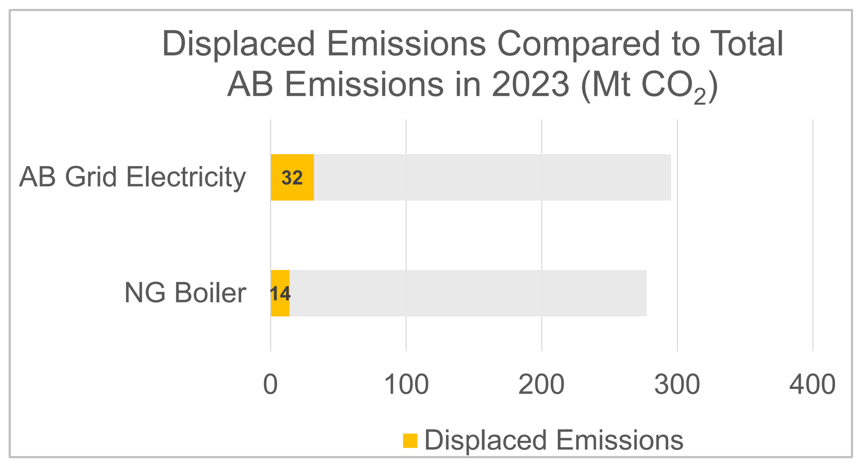
Research Question 1: Energy Required for Cooling

The graph below shows cooling load across all eight locations in the study. Dallas has the highest demand, at approximately 3% above the lowest demand location. The results indicate that cooler climates reduce the number of hours that active cooling is needed, thereby lowering the total cooling energy use. However, the magnitude of these differences suggests that under the immersion cooling and waste heat capture configuration, location-specific temperature impacts exist but are not a dominant driver of total annual electricity demand.

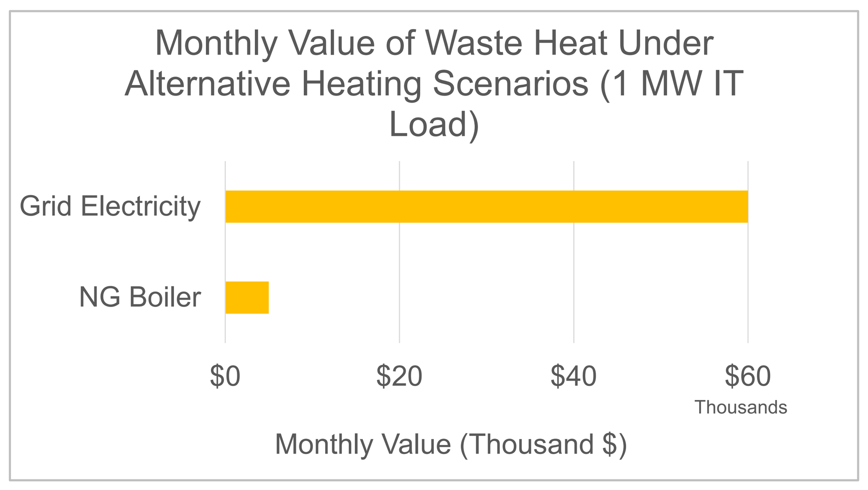


Research Question 2: Economic and Environmental Benefits of WHR

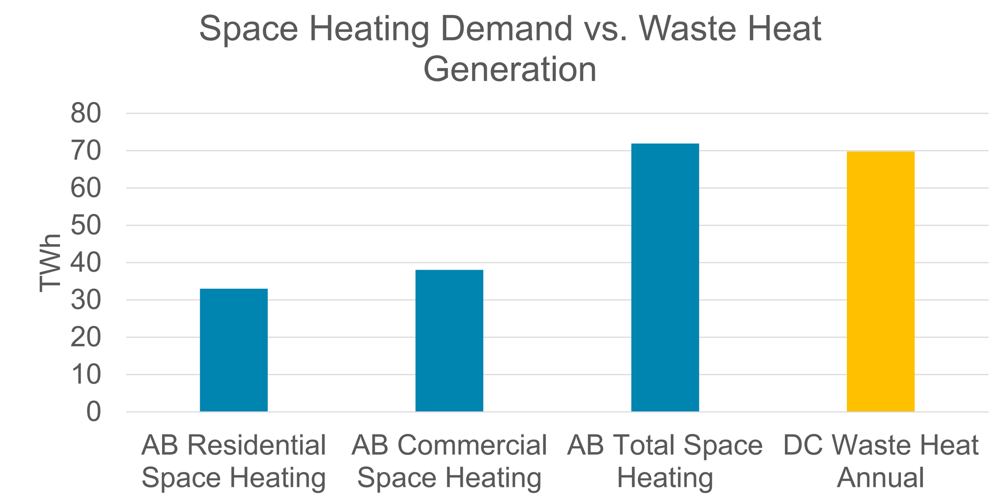
The graph below illustrates the scale of potential emissions reductions if all 11,879 GW of proposed data centres that have applied for grid interconnection in Alberta were to capture and reuse their waste heat. If this recovered heat displaced space heating from natural gas boilers, approximately **14 $MtCO_2$ would be displaced annually**, **equal to about 5% of Alberta's total 2023 emissions.**



The economic value of waste heat is based on the cost of providing the same heating service with conventional natural gas boilers or electric heating, using current gas and electricity prices. In practice, the actual value would depend on what an off taker is willing to pay. The graph below shows that if waste heat is used to replace space heating from a natural gas boiler with 90% efficiency, assuming the price of natural gas is $10 per MWh ($2.78 per GJ), it would replace the equivalent of $5,440 per month for every 1 MW of IT load. When scaled up to a 300 MW data centre, this translates to **$1,632,000 per month or over $19M per year**.



Space Heating in Alberta



To maximize waste heat utilization, generation must be aligned with the timing and magnitude of space heating demand. In 2022, Alberta's residential and commercial sectors consumed 33 TWh and 38 TWh of natural gas for space heating, respectively for a combined total of 71.9 TWh across the two sectors (Natural Resources Canada, 2022). The waste heat produced from the 11 GW of planned DCs annually equals 69.8 TWh–approximately equivalent to Alberta's space heating demand. While it would be virtually impossible to use all the waste heat due to the feasibility barriers like infrastructure or seasonal and daily demand matching, the key takeaway is that Alberta's annual demand for space heating provides a strong offtake opportunity.

Conclusion

Results show that under an immersion cooling and waste heat reuse configuration with a threshold for active cooling of 22°C, cooling system **electricity consumption does not vary significantly between locations in Alberta or across Canada.** Results for the second research question demonstrate **that for every 1 MW of IT load, an immersion-cooled DC running 24/7 generates 5875 MWh of recoverable waste heat per year**. By replacing natural gas fired space heating, **this could offset 1175 tCO_2e and be equivalent to $65,280 of fuel costs annually**.

WHR is a meaningful decarbonization opportunity. With appropriate district heating and offtake infrastructure in place, Alberta's data centres could meet a significant share of space heating. Despite this potential, implementation of WHR faces serious hurdles, namely Alberta's limited district heating infrastructure to distribute recovered heat. Seasonal and daily demand matching is another challenge that may reduce utilization rates. There is also significant capital cost associated with heat transmission infrastructure, including pipelines, heat exchangers, and integration with existing systems. Additionally, the market for purchasing recovered heat from DCs is nascent; standardized contractual frameworks and pricing mechanisms are not yet widely established.

Taken together, these findings challenge some assumptions about Alberta's cold climate advantage. Instead, other factors in site selection such as electricity cost, grid capacity, cost of land, fibre network availability, and as this research suggests, the availability and value of waste heat offtake, become more important. This research also presents a compelling case for repositioning DCs not just as energy consumers but as integrated energy assets with digital and thermal value.

Works Cited

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