Ahead of the Expected

The Future of Data Centers : Energy Efficiency and Waste Heat Potential

WHITE PAPER

The Future of Data Centers

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An Energy-Efficient Cooling System

An Energy-Efficient Cooling System for Data Centers

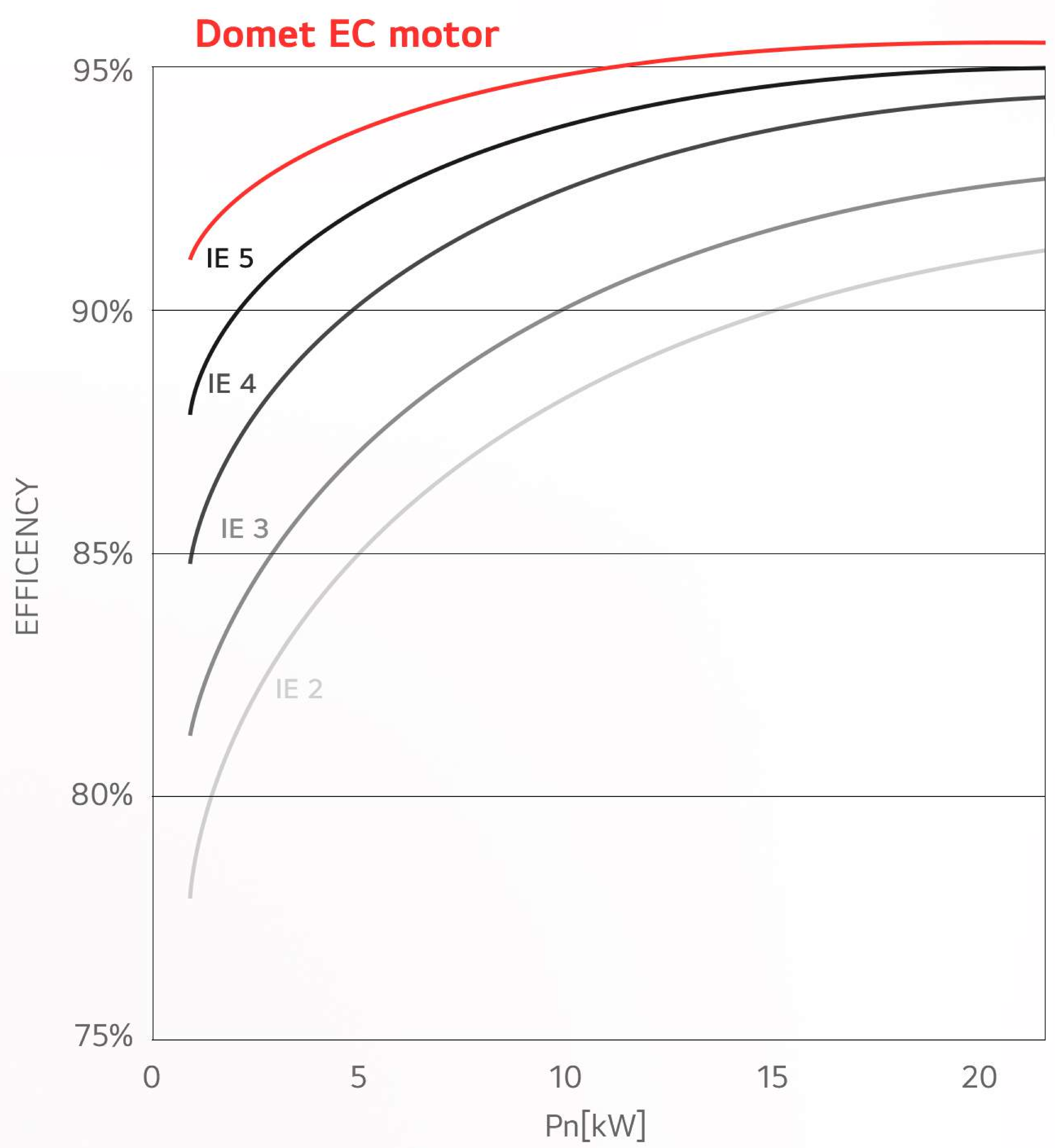
With the launch of AI solutions like OpenAI's ChatGPT, hundreds of millions of users have adopted AI almost overnight, making these models an integral part of our daily lives. Nearly every industry is exploring new AI capabilities to streamline processes and enhance outcomes.

Data centers hold a unique position in this evolving digital landscape, both enabling and benefiting from AI applications. Training and running AI models require vast computational power and data storage. To sustain our technology-driven world, both existing and future data centers must offer these crucial capabilities. This increasing demand means that data centers themselves must leverage AI and other emerging technologies to deliver services that are more efficient, secure, and effective.

However, data centers already account for 1.5% of global electricity consumption, and according to the Data Center Trends 2023 report, demand is expected to grow by 15% annually. As computing resource consumption continues to rise, concerns about sustainability are intensifying, making energy efficiency a key challenge. Since cooling systems alone consume approximately 40% of a data center's power, implementing sustainable cooling solutions is crucial.

Modern data centers must efficiently and eco-consciously manage the excessive heat generated by IT equipment. As data centers grow in size and complexity, a hybrid approach combining air and liquid cooling is essential to achieving optimal energy efficiency and sustainability.

Air Cooling



[Fig. 1] EC Motor Efficiency Rating

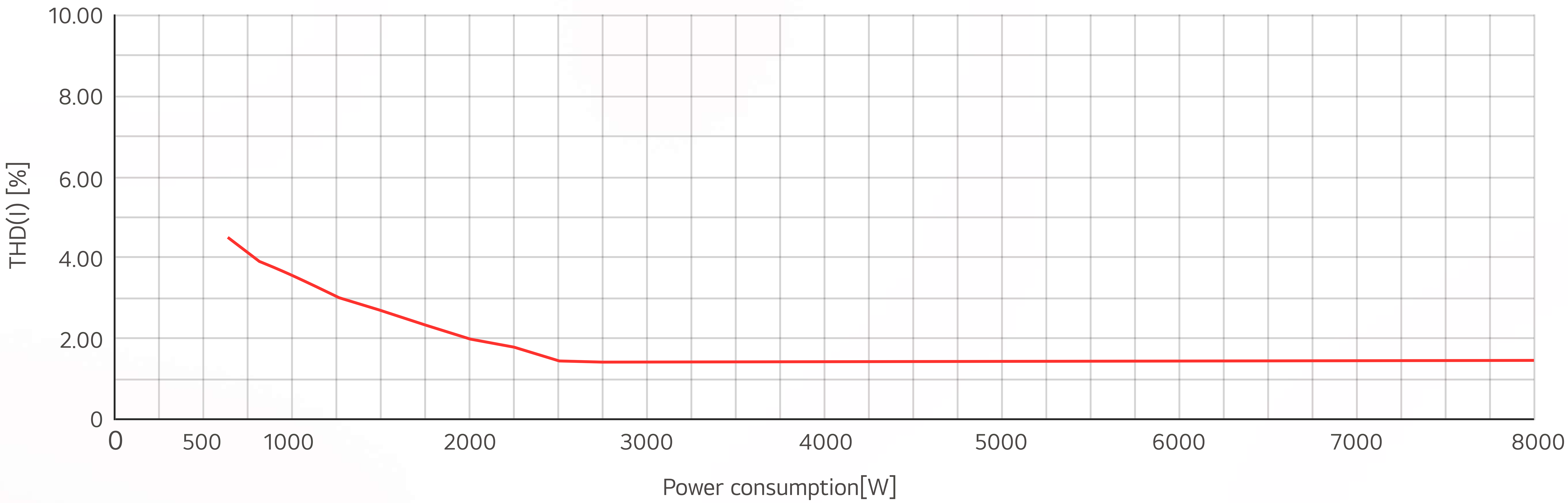
Air cooling is the most traditional method cooling method for data centers, where air is circulated around IT equipment to dissipate heat. To support this cooling process, Fan Wall Units or Coil Wall Units are used.

A Fan Wall Unit is a modular system where fans and coils are arranged horizontally to maximize cooling capacity. Meanwhile, a Coil Wall Unit, designed for small to mid-sized applications, has a vertically-positioned fan and coil to minimize space usage.

One of the key advantages of air cooling is its reliable performance and versatility across various types of data centers. To enhance energy efficiency in air cooling systems, high-efficiency turbo chillers, free cooling, and high-performance Fan Wall Units are incorporated.

The primary source of energy consumption in Fan Wall Units and Coil Wall Units comes from EC (Electronically Commutated) fans, which include a fan wheel, an EC motor, and a drive unit. As shown in Figure 1, multi-EC fans certified with an IE5 efficiency rating or higher outperform single fan motors in terms of energy efficiency. Additionally, this configuration enhances system reliability by providing redundancy, allowing continued operation even if a fan fails.

Current Harmonics

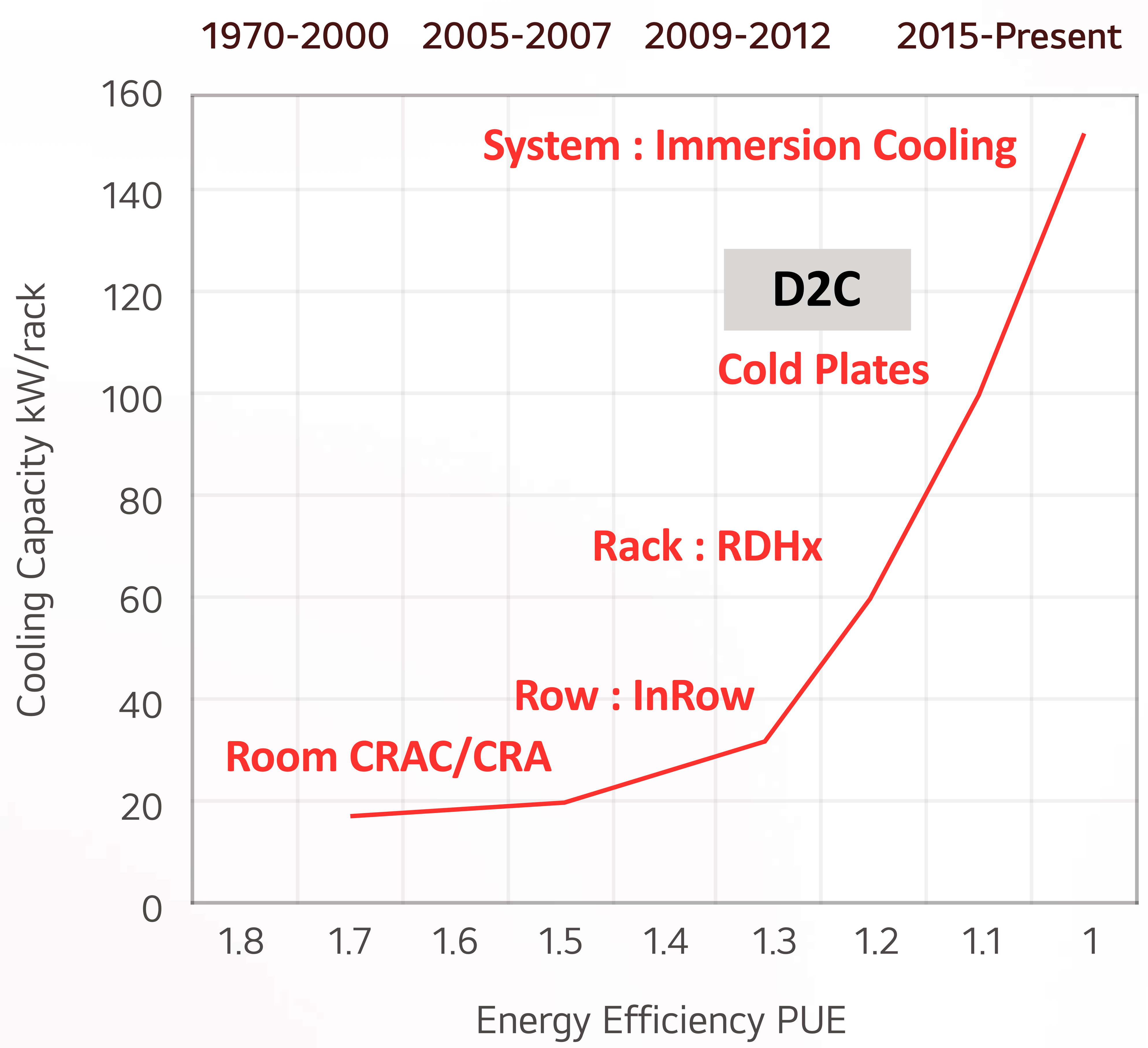


[Fig. 2] Harmonic Distortion Rate THDi (%)

The drive unit includes an active harmonic filter, which keeps the total harmonic distortion (THDi) below 5% during operation. As illustrated in Figure 2, this results in lower harmonic distortion at nominal load, which helps prevent motor overheating, failures, and reduced lifespan. Furthermore, lower THDi enhances power factor correction and overall power quality, reducing power losses and contributing to energy savings.

For data halls housing low-to medium-density IT equipment, using high-efficiency components like these is essential to maximizing energy efficiency.

The Rise of Liquid Cooling Technology



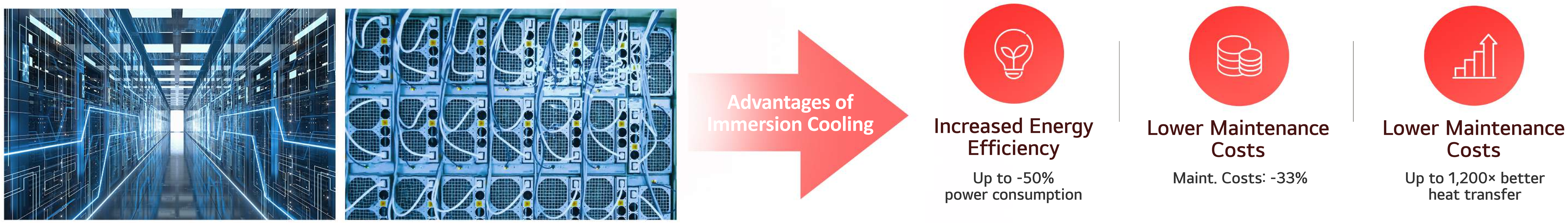
[Fig. 3] Cooling Capacity and PUE by Data Center Cooling Method

Source : GRC

Most data centers in operation today rely on traditional room-based air cooling to manage server heat. While air cooling will continue to be the dominant method for low-power-density data centers, it is no longer a viable cooling solution for AI-driven data centers where power densities exceed 50kW per rack. Figure 3 illustrates how the heat dissipation per rack and Power Usage Effectiveness (PUE) vary depending on the cooling method used. When rack power consumption surpasses 50kW, liquid cooling technologies such as Rear Door Heat Exchangers (RDHX), Cold Plate cooling, and immersion cooling become essential for effective heat management.

RDHX enhances air-cooling efficiency by circulating coolant through a heat exchanger mounted on the back of the server rack, allowing for close-proximity cooling. Since liquid flows at the rear of the server rack, RDHX can be categorized as a liquid cooling solution. Cold Plate cooling, also known as direct-to-chip (D2C) cooling, attaches metal plates with microchannels directly to high-power GPU or CPU chips, allowing coolant to flow through and maximize forced convection. D2C cooling can handle rack power densities close to 100kW. When even greater cooling capacity is required, immersion cooling becomes necessary. This technique submerges entire servers in a non-conductive liquid, allowing for direct heat transfer, significantly improving cooling efficiency.

Immersion Cooling Data Centers



[Fig. 3] Advantages of Immersion Cooling Technology

Liquid cooling offers a significant advantage over air cooling by providing higher cooling capacity per rack. Additionally, it helps maintain a lower Power Usage Effectiveness (PUE)—a key metric that measures data center energy efficiency by dividing total power consumption by the power used for IT equipment (with values closer to 1 indicating greater efficiency).

For comparison, traditional air-cooled data centers typically have a PUE of around 1.5. In contrast, RDHX (Rear Door Heat Exchanger) systems can bring this down to 1.1–1.3, while direct-to-chip (D2C) cooling achieves even better efficiency, with PUE values between 1.05 and 1.2. Immersion cooling takes efficiency further, reducing PUE below 1.1, and in the case of two-phase immersion cooling, which uses phase change, reports show incredibly low values around 1.02.

A lower PUE translates directly to reduced energy consumption, making immersion cooling up to 50% more energy-efficient compared to air cooling. Additionally, maintenance costs can be reduced by approximately 33%.

Another key benefit of liquid cooling is the ability to operate at higher coolant temperatures compared to air cooling. According to ASHRAE guidelines, the recommended air temperature for traditional air cooling systems ranges between 18-27°C, with return air temperatures typically staying below 35°C.

In contrast, liquid cooling systems offer superior thermal efficiency, allowing coolant temperatures to be maintained at higher levels. In immersion cooling, for example, return temperatures can reach close to 50°C. The ability to sustain higher coolant return temperatures opens up new possibilities for reusing the waste heat generated by data centers.

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Waste Heat Utilization Technology in Data Centers

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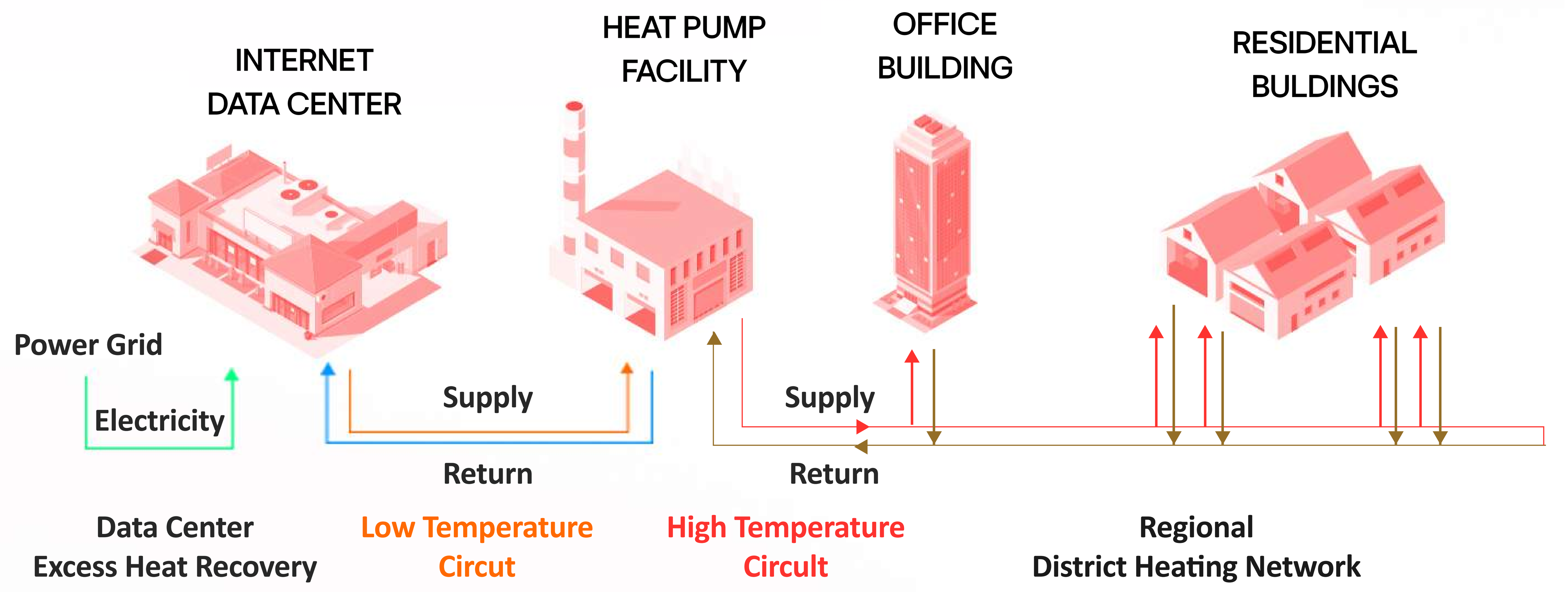

Source: Keskin and Soykan, Energy Conversion and Management(2022) 254, 115211.

Data Center Waste Heat Recycling

District Heating	Agriculture(Greenhouse)
Supplies waste heat to district heating systems for residential building heating	Provides a stable year-round heat source for greenhouses
Swimming pool	**Dehydration(Drying)**
Maintains consistent swimming pool temperatures with data center waste heat	Is used for drying wood pellets, coffee beans, etc.

[Fig. 4] Classification of Data Center Waste Heat Utilization Technologies

Most of the electrical energy consumed by IT equipment in data centers is released in the form of heat. When this waste heat is discharged directly into the atmosphere or rivers, a heat exchanger is used to lower its temperature to minimize environmental impact. In a way, this results in a double waste of energy, making technologies that repurpose waste heat increasingly important from an economic perspective. Many countries are already utilizing waste heat from data centers in various ways (see Fig. 4), with the most common method being the supply of waste heat to district heating systems. It is also used to provide heat for greenhouses, swimming pools, or industrial processes.

Looking at specific cases, global IT companies are seeing both economic benefits and carbon emission reductions by supplying waste heat from their data centers to nearby district heating systems. These companies have established many data centers in Northern Europe, where the cool climate is advantageous for cooling, and the demand for heating remains high throughout the year.

Meta operates a data center in Odense, Denmark, where it plans to supply 100GWh of waste heat annually to the local district heating network. Apple also runs a data center in Viborg, Denmark, powered entirely by renewable energy while providing hot water for district heating. Amazon has reduced 1,400 tons of CO_2 emissions by supplying hot water to the Dublin, Ireland region, while Microsoft, in partnership with Fortum, has launched a project in Finland to provide heating for 250,000 people, cutting 400,000 tons of CO_2 emissions.

There are also numerous cases of waste heat being used in agriculture. Equinix, a leading colocation data center provider, has built a greenhouse on the roof of one of its data centers, supplying waste heat to maintain optimal temperatures inside the greenhouse. Research suggests that supplying waste heat to greenhouses can achieve 66% energy savings compared to using propane heaters. The Olympic swimming pool in Saint-Denis, Paris, for the 2024 Olympic Games, received 28°C waste heat from the nearby Equinix PA10 data center. A heat pump then heated it to 65°C, enabling efficient pool temperature regulation.

In the UK, the startup Deep Green has demonstrated cost savings and carbon reduction by recovering heat from immersion cooling and supplying it to swimming pools, reducing boiler fuel costs. Industrial applications also leverage waste heat, particularly in drying processes where the waste heat temperature is relatively low. EcoDataCenter in Sweden exemplifies this approach by integrating wood-based construction and running entirely on renewable energy (75% hydro, 25% wind). The company repurposes its waste heat for drying wood pellets, further reinforcing its commitment to sustainability.

These examples show how waste heat generated by data centers can be repurposed in a variety of ways. While waste heat is mostly used for heating applications, in areas where heating demand is inconsistent, it is more effective to implement technologies that allow waste heat to be used for both heating and cooling.

For instance, during the summer months, waste heat from data centers can be redirected to cool nearby buildings or even help reduce the cooling energy consumption of the data center itself. If an existing data center relies on air cooling, but a newly expanded facility adopts liquid cooling, the heat expelled from the liquid cooling system can be used to generate chilled air. This can then be used for air cooling in the original data center, optimizing overall energy efficiency.

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Conclusion

As high-density hyperscale data centers continue to expand, the importance of thermal management and cooling technology has never been greater. With the rise of AI, data center capacity and energy consumption will only continue to grow, making the management and utilization of massive heat output both a challenge and an opportunity.

To cool highly integrated server racks, advanced liquid cooling technologies such as D2C (Direct-to-Chip) cooling and immersion cooling are competing for dominance. At the same time, there is increasing focus on how to effectively use the waste heat produced by liquid cooling systems. Successfully advancing energy-efficient liquid cooling and waste heat recovery solutions will be crucial to ensuring the long-term sustainability of the data center industry—turning today's challenges into tomorrow's opportunities.

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Reference

SAREK

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