Can an AI Chatbot Help Heat Your House?
Exploring Data Center Waste Heat Recovery Opportunities

Guidehouse: Mark Umland, Bill Goetzler , Blake Lajiness, Jim Young (Formerly)

ABSTRACT

Data centers are rapidly growing in number, size, and density to accommodate artificial intelligence (AI) and machine learning models, and modern cloud computing systems. Besides computing, cooling of the computer chips and server racks accounts for the greatest share of a data center's energy consumption. While data center designers and operators have increased cooling efficiency in recent years, data centers generate an enormous amount of heat which is generally rejected to the ambient environment. While this heat rejection occurs at data centers, residential, commercial, and industrial facilities are burning fossil fuels or using electricity to provide space, water, and process heating. How can we best harness waste heat from data centers and reduce overall energy consumption?

In this paper, we discuss the potential for data center heat recovery for use by nearby buildings, the target building applications, necessary technologies at the facility and system level, and the key challenges for each configuration. Key considerations include data center design, supply and load temperatures, facility proximity, available thermal distribution networks, high temperature booster heat pumps, and business models. We highlight successful examples of waste heat recovery from data centers in the US and Europe and discuss successful policies to support feasibility studies and installations. Lastly, we summarize the key issues that require further stakeholder involvement to expand data center heat recovery in the U.S. In this paper, we concludes that data center heat recovery can be meaningfully used given certain technical conditions, particularly with supportive policies.

Introduction

Data centers have become a critical backbone of the modern economy, enabling cloud computing, artificial intelligence (AI), machine learning, streaming media, financial services, and an expanding array of digital applications. Over the past decade, data center capacity in the U.S. has expanded rapidly, and growth is accelerating as AI workloads drive higher computing intensity and power density. Hyperscale facilities exceeding hundreds of megawatts are increasingly common, while colocation and enterprise data centers continue to proliferate in metropolitan regions. Northern Virginia, Phoenix, Dallas, and Atlanta are now global data center hubs, and many secondary markets are experiencing similar growth.

This rapid expansion has created a growing set of challenges for utilities, municipalities, regulators, and communities. Data centers are comprised of servers, network equipment, cooling, power distribution systems, security, and firefighting facilities, and they have large, relatively inflexible electrical loads that can strain local electrical grids. To support this infrastructure growth and increased demand, utilities rates may increase for data centers as well as residential, commercial, and industrial customers. In many regions, data centers also consume large amounts of water, particularly where cooling towers are employed. Local communities have raised concerns related to land use, noise from mechanical equipment, visual impacts, and the concentration of industrial-scale facilities in residential or mixed-use areas, in addition to the electrical and water usage issues (Chan 2023). As data center development increasingly intersects with broader decarbonization goals, questions are also emerging around indirect and direct emissions impacts and how these facilities can align with state, local, and utility climate objectives.

Despite these concerns, data center growth is expected to continue. Digital services are deeply embedded in today's economy, and demand for computing is projected to continue rising for decades. A recent Guidehouse Insights report projected the global market revenue for data center thermal management will grow from $8.7 billion in 2023 to $27.4 billion in 2032, with North America projected to be the largest global market (Guidehouse Research 2025). The critical question for policymakers, utilities, and data center operators is therefore how their impacts can be managed more effectively and how their presence can deliver shared benefits to host communities. Various strategies already being pursued by data center designers and operators to mitigate negative impacts where feasible. They include energy efficiency improvements within the data center, customer-sited distributed energy resources (DERs), on-site or contracted clean generation, grid-interactive load management, alternative cooling approaches that reduce both energy and water use, and waste heat recovery.

Waste heat recovery represents a particularly underutilized opportunity. Nearly all the electrical energy consumed by IT equipment is ultimately converted to heat. Despite significant advances in heat capture and rejection efficiency (e.g., improved air management, liquid cooling), most data centers still discharge substantial amounts of low- to medium-grade heat into the surrounding environment. Meanwhile, nearby residential, commercial, institutional, and industrial buildings consume large amounts of energy, often from fossil fuels, to meet space heating, domestic hot water, and process heating demands. This raises a fundamental question: How can waste heat from data centers be harnessed to reduce overall energy consumption, lower emissions, and provide benefits beyond the data center fence line?

The potential scale of this opportunity is significant. Many data centers operate continuously at high load factors, producing a steady and predictable stream of thermal energy throughout the year. In contrast, building heating demands are often seasonal and variable, but they remain substantial across campuses, industrial facilities, district energy systems, and dense urban areas. When data centers are located near compatible thermal loads, such as multifamily housing, office buildings, hospitals, universities, industrial plants, or district heating networks, waste heat recovery can offset consumption of conventional heating fuels, reduce peak heating demand, and improve overall system efficiency. In some configurations, recovered heat can be further heated using high-temperature heat pumps or repurposed for cooling via absorption chillers, further expanding the range of viable applications.

Despite this promise, data center heat recovery remains relatively rare in the U.S., particularly when compared to parts of Europe where district energy infrastructure and supportive policy frameworks are more prevalent. A combination of technical, economic, and institutional barriers has limited adoption. These include mismatches between data center heat rejection temperatures and building heating requirements, the cost and complexity of thermal distribution infrastructure, uncertainty around capital costs and ownership models, and challenges aligning incentives among data center operators, utilities, building owners, and local governments. Water use considerations also play an important role: while some heat recovery configurations can reduce overall water consumption by displacing evaporative cooling, others may introduce tradeoffs that must be carefully evaluated on a site-specific basis.

Retrofit considerations create additional complexity. While integrating heat recovery into new data center developments may be more straightforward (i.e., allowing for coordinated planning of cooling systems, site layout, and nearby thermal loads), most existing data centers were not designed with external heat reuse in mind. Understanding when and how heat recovery systems can be retrofitted into operating facilities, without compromising reliability or uptime, is therefore a critical question. Retrofit solutions that leverage modular technologies, minimize operational risk, and align with data center upgrade cycles may be especially important for scaling adoption.

This paper explores the opportunity for waste heat recovery from data centers as a means of addressing multiple challenges associated with data center growth. The focus is not on constraining or discouraging development, but rather on identifying practical pathways to make data center expansion more manageable for energy systems and host communities. By enabling shared benefits, such as reduced emissions, improved energy efficiency, lower heating costs for nearby buildings, and more productive use of existing infrastructure, heat recovery can promote a more integrated approach to data center planning.

The following sections examine the technical characteristics of data center cooling and heat rejection, the thermal demands of potential end-use applications, and the technologies needed to connect available heat with compatible loads. Configurations for direct building connections, campuses, and district energy systems, including the role of heat pumps and heat-activated cooling technologies are discussed. The paper also evaluates key implementation challenges related to proximity, temperature compatibility, water use, capital costs, stakeholder alignment, and retrofit opportunities. Finally, the paper presents case studies and identify potential roles for utilities, governments, data center operators, and other stakeholders.

Heat Recovery Opportunity

Data center cooling solutions involve two interrelated functions to maintain IT system performance: first, transferring heat from the IT equipment and secondly, transferring heat from the data center to a heat sink. The list below highlights the variety of heat transfer solutions for these two data center cooling functions in use today. Data center operators and their engineering teams optimize the selection of the IT cooling and heat transfer solutions to match the data center's operating needs, climate, local resources, utility rates, and other parameters. For example, data centers in colder regions can utilize the colder ambient air as the primary cooling solution either directly or through water-side economizers and require minimal mechanical cooling. On the other hand, data centers in hot and/or humid regions require significant mechanical cooling and may look to more advanced solutions to minimize their operating cost. Furthermore, the industry is moving towards liquid-based cooling solutions either in total or in hybrid with air-cooled methods to accommodate higher power densities and heat loads within servers and racks. Immersion cooling is another emerging technology for high performance computing facilities that involves placing the IT equipment directly within a dielectric fluid and then using liquid cooling solutions to reject the heat. More novel cooling methods (e.g. spray cooling) are under consideration for future generations of high performance AI data centers.

Heat Transfer from IT Equipment

- Passive thermosyphons and heat pipes
- Forced air cooling
- Liquid cooling (rear door, direct-to-chip)
- Immersion cooling (single and two-phase fluids)

Heat Transfer from Data Center to Sink

- Ambient air (air-cooled chillers and condensers, cooling towers for water-cooled chillers and evaporative coolers, free cooling economizers)
- Geothermal (ground, water aquifer, nearby body of water)
- Heat recovery for heating applications (district heating, building heating)
- Heat recovery for cooling applications (absorption / adsorption chillers)

For data center heat recovery, the primary factors that determine the viability of a potential heat recovery project are first whether there are sufficient loads inside or outside of the data center to utilize the available waste heat and secondly, whether a contractual relationship can be established between the data center and the outside parties. The economic value of the waste heat must be sufficiently high for both the data center and the facility to overcome the cost and complexity of delivering the recovered heat for a usable purpose. At rejection temperatures of 120-160 ºF, we move beyond 'low-grade' waste heat that requires energy-intensive boosting, into thermal energy that may be used directly. This temperature bracket may align with engineering reality, but the efficiency calcs of the deployed system needs careful consideration. Otherwise, the data center will default to using conventional heat rejection strategies and the facility will use conventional heating and cooling solutions.

Table 1. Temperature Ranges for Data Center Heat Recovery Opportunities

Data Center Heat Rejection (Return) Temperatures	Facility Heating Temperatures
• Air cooling solutions 70-95 °F (20-35 °C) • Liquid cooling 85-120 °F (30-50 °C) • Direct-to-chip liquid and immersion cooling 120-160 °F (50-70 °C)	• Building space heating: 95-160 °F (35-70 °C) • Building water heating: 120-140 °F (50-60 °C) • Absorption cooling: 175-250 °F (80-120 °C) • District energy hot water supply loops: 120-160 °F (50-70 °C), steam systems higher temperature • Industrial processes: 175-300 °F (80-150 °C) and higher

Representative and rounded values

Table 1 highlights the typical heat rejection temperatures and operating profiles for data centers, as well as operating temperatures for a range of heating applications.

- The most straightforward applications would be those where the data center's waste heat is supplied at a similar temperature to the end-use application. Another simpler solution would be for the data center heat recovery to serve as pre-heating energy for the end-use application, such as a district heating utility or campus thermal network. In these cases, the heat recovery system would involve a pipe network, pumps, and heat exchangers to transfer the heat to the outside facility.
- Another straightforward, but lesser used practice would be to use the waste heat from the IT system to provide heat input for absorption or adsorption chillers. Rather than the electrically driven vapor compression cycle used in most cooling and refrigeration applications, heat activated cooling cycles use thermal energy to cyclically move heat across a closed loop system. This strategy can generate chilled water from the waste heat, often with additional natural gas or other form of heating, to supplement the data center's main cooling systems. A few examples are highlighted below.
- More complex heat recovery situations would be those where there is a temperature imbalance, and the outside facility needs are significantly higher supply temperature. In these situations, industrial heat pumps[1] could raise the temperature of the recovered heat with additional electricity consumption. The industrial heat pumps could be located at the data center, facility, or intermediary location.

Beyond technical feasibility, developing an attractive operating model can be challenging for data center heat recovery applications due to a range of logistical and market challenges. Ultimately, all parties need to see the economic or business benefits from pursuing the data center heat recovery project relative to conventional alternatives.

- Proximity is a major driver for project cost and feasibility, with large facilities located near data centers making the most straightforward case (see Case Studies below). Because pipe networks are required, long distances between the data center and the end-user require more permitting, approvals, external parties, and construction challenges. It is possible to do heat recovery over longer distances, but most examples involve short distances or connect to a wider district energy network because they minimize thermal degradation. There is also a paradox in which the most usable data centers for heat recovery are generally furthers away from residential areas that could use the heat, creating a need to bridge the gap between remote high-grade heat production and urban thermal demand.
- Beyond temperatures, the relative size of the end-user's heating demand and the data center's heat rejection capacity dictate the feasibility for a heat recovery project. For example, a data center's heat rejection load will be much too large for an individual home or even a neighborhood, but also may not be large enough for a nearby campus.
- Even where attractive proximity, temperature, and loads exist, developing the business case between parties can be a major challenge if priorities do not align. For example, a data center operator would not necessarily want to act as a utility to create and maintain a neighborhood district heating network. Furthermore, property developers may not want to delay their building opening or increase construction cost

[1] Industrial heat pumps generally range from 2.5 – 4.0 COP.

to connect with a data center heat recovery loop, especially if the developer does not have a sustainability focus or responsibility for ongoing energy bills.

Table 2 outlines the heat recovery potential for several data center designs and the relative impact for residential home and commercial office facilities, not accounting for technical, market, and logistical constraints. A smaller data center may be able to support 80 homes and a single office, whereas larger hyperscale facilities could support almost 200,000 homes and 2,300 offices. If projected across the estimated base of more than 1,000 hyperscale facilities, this would equate to 200 million homes (>150% of US housing stock) and 2 million office buildings (>200% of US office building stock). Of course, existing data centers may not have suitable proximity to major end-use loads and would face significant cost and challenges retrofitting both the data center and end-use facility to enable waste heat recovery. Furthermore, the heating demands for homes and offices will be highest in the winter months and will vary by region, and the heat recovery output from data centers will be relatively consistent throughout the year. Nevertheless, Table 2 suggests the relative scale of the opportunity before accounting for feasibility constraints, such as temperature mismatch, distribution losses, and seasonal non-coincidence. Even if only 10% of the projects are viable, the opportunity is on the scale of millions of homes or thousands of office buildings.

Table 2. Hypothetical Data Center Heat Recovery Potential Using 10% Recovery Assumption

Data Center Type (Size, IT Load, Annual Waste Heat Potential)	Number of Potential Buildings Serviced by Data Center Heat Recovery	
	Average Annual Space and Water Heating Demand	
	49 MMBtu/yr per home	4,220 MMBtu/yr for 200 kSF building
Enterprise (30 kSF, 100 kW IT Load, 3,883 MMBtu/yr)	80	1
Co-Location (100 kSF, 10 MW, 388,271 MMBtu/yr)	8,000	90
Hyperscale (500 kSF, 250 MW, 9,706,785 MMBtu/yr)	200,000	2,300

RECS 2020 US Average Per Home Space Heating + Water Heating Consumption (EIA 2024)
CBECS 2018 US Average Per SF Space Heating + Water Heating Consumption for Office (EIA 2022)
Waste heat potential assumes cooling design factor of 1.3 of IT load[2], 8760 hr/yr operation
Does not consider seasonality of space heating load relative to data center waste heat potential

In addition to waste heat recovery from IT loads, electricity generation systems at the data center site present another opportunity for heat recovery. Most data centers have backup diesel, propane, or natural gas generators to maintain operations during electrical grid outages, but these are run infrequently. Many larger data centers under construction today are creating the

[2] Assumption that for every 1 kW of electrical IT load, there is 0.3kW of waste heat.

data center's electrical generating needs "behind the meter" at the data center site. This strategy can support regional electricity capacity growth and grid stability, and potentially expedite the operating date of the data center where utility electricity and/or natural gas connections may be delayed. Various generation technologies are under consideration today that could offer waste heat recovery potential, including engine, turbine, fuel cell, and small modular nuclear solutions. The waste heat from IT and electrical generation could be combined to support on-site and off-site thermal loads.

Key Challenges for Market Adoption

Adoption of advanced data center heat-recovery faces numerous challenges. This section reviews several critical barriers facing manufacturers, operators, and other stakeholders.

- Economics and efficiency
- System architecture and integration
- Fluctuating loads for some facilities and data sharing issues
- Uncertainty around immersion cooling
- Standards and performance metrics
- Workforce

Economics are perhaps the most significant barrier to implementing data center heat recovery. The initial capital investment required for advanced heat-recovery infrastructure, such as specialized piping, heat exchangers, and integration with district energy networks, can be substantial, especially when compared to traditional systems. Operators must also account for additional maintenance costs for the heat-recovery infrastructure, which can be further complicated if multiple organizations are involved. Another critical challenge is the lack of good technical options for heat-recovery systems in data centers, which leads to extended payback periods for operators. Systems struggle to efficiently capture and repurpose low-grade waste heat, resulting in marginal energy savings and limited economic benefit. These financial considerations often deter owners from pursuing heat-recovery options, particularly when the return on investment is uncertain due to fluctuating energy prices, limited local demand for waste heat, and regulatory ambiguity. Consequently, many organizations prioritize conventional cooling approaches that offer predictable costs and operational simplicity. Additionally, the efficiency of heat recovery systems are determined by the temperature delta between the data center's rejection loop and the end-user's supply requirements. To maximize exergy and minimize the parasitic load of booster heat pumps, we must prioritize liquid-to-liquid transfer to ensure effective heat flux across the distribution architecture. Efficiency is central to feasibility because transport losses, pumping energy, and temperature lift can erode the value of recovered heat, impacting net energy savings and energy reuse performance.

System architecture, integration, and the development of compatible system designs present significant hurdles for the adoption of advanced data center heat-recovery solutions. One primary challenge is the limited demand for waste heat in the immediate vicinity of most data centers. Since data centers are often located in industrial parks or remote locations far from major population centers, finding nearby users who can utilize the recovered heat is difficult. This geographic separation means that even if a data center can successfully capture low-grade waste heat and the owner wants to implement a heat-recovery system, there may be no viable way to transport it to where it is actually needed. There is also a need to consider the on-site thermal capture infrastructure such as specialized heat exchangers and pump skids as well as the external distribution architecture required to transport that energy to the end-user in terms of both design and cost analysis.

In addition to location-based challenges, fluctuating thermal loads within some data centers further complicate system design. Depending on the design and purpose, some data center operations are characterized by variable workloads that directly impact heat generation and, consequently, the supply of recoverable waste heat. This variability leads to mismatches between when heat is available and when it is needed, making it difficult to align supply and demand profiles. As a result, the reliability and efficiency of waste heat-recovery systems can be unpredictable, limiting their appeal for both operators and external stakeholders that are considering investments in district energy integration or combined heat and power applications. Due to limited data sharing, insufficient real-time monitoring, lack of workload-aware control strategies, and privacy concerns surrounding operational data from data centers, it is difficult to assess solutions. The absence of mature digital twins, hardware-in-the-loop testing, and validated AI-driven control frameworks slows deployment and increases perceived operational risk. There is also an issue of seasonality. When homes and communities need heating the most, there is much less cooling needed in data centers, meaning very little useful rejected heat when it is needed the most. This fundamental mismatch limits the functionality of heat recovery.

As we look towards the future, many advanced cooling approaches that are best suited for heat recovery due to their higher operating temperatures, particularly immersion cooling and spray cooling, face gaps in long-term reliability data under real-world operating conditions. There is limited validated performance at scale, insufficient maximum heat flux handling in some configurations, and uncertainty around durability over the full lifecycle of data center equipment. These concerns create risk for operators considering large capital investments in emerging thermal technologies. These concerns will be exacerbated in the context of heat-recovery, as immersion and spray become more common due to increased thermal loads. Developing heat-recovery systems in conjunction with these technologies has been limited. A major adoption challenge is the difficulty of scaling advanced cooling technologies across existing data center footprints. Immersion cooling systems, in particular, present barriers related to system weight, heat flux density, and facility structural constraints. Retrofitting operating data centers is more complex and costly than in new construction, especially when equipment must remain online during upgrades. The lack of standardized, “plug-and-play” retrofit solutions further limits deployment flexibility, and retrofitting a heat recovery system into existing infrastructure is a massive impediment.

The absence of widely accepted standards and performance benchmarks is another critical barrier. Traditional metrics such as Power Usage Effectiveness (PUE) are not sufficient to evaluate advanced cooling systems that include heat-recovery. While alternative metrics such as Total Energy Use Effectiveness (TUE), Information Technology Usage Effectiveness (ITUE), and energy recovery factors are options, no consensus exists on universal adoption, implementation, or climate normalization. This lack of standardization complicates technology comparison, procurement decisions, and regulatory alignment.

There are also significant workforce barriers. Advanced cooling systems with heat-recovery require specialized skills for installation, operation, and maintenance. Gaps in training, operational experience, and service infrastructure can increase downtime risk and total cost of ownership, particularly for edge and modular deployments in remote or harsh environments.

In summary, the widespread adoption of advanced data center heat-recovery designs faces a complex set of obstacles, including high upfront costs, technical limitations, integration challenges, and the absence of uniform standards. Other factors, such as variable demand for waste heat, evolving cooling technologies, unpredictable workloads, and gaps in workforce expertise, further complicate implementation. Addressing these barriers will require coordinated efforts involving technology development, workforce training, and regulatory alignment to unlock the full potential of sustainable data center cooling solutions.

Roles for Different Stakeholders

Enabling the adoption of more heat recovery in data center cooling systems requires a coordinated, multi-stakeholder approach, as no single entity can overcome the complex technical, economic, and regulatory challenges alone. This issue is highlighted in the case studies summarized in the next section.

- **Utilities** play a pivotal role by developing infrastructure and rate structures that incentivize the integration of heat-recovery systems. By offering targeted incentives and grid support for district heating or cooling networks, utilities can make it more attractive for data centers to supply waste heat to local communities. Additionally, utilities can collaborate with data centers to pilot innovative grid-balancing strategies that align with the variable nature of both heat and power demand. They must take a proactive approach since, as discussed in the previous section, geographical limitations for heat recovery are a major issue that needs to be addressed early in the development process.
- **Hyperscale data center owners**, given their scale and influence, are uniquely positioned to drive industry-wide adoption of heat-recovery solutions. By investing in research, pilot projects, and large-scale deployments, these organizations can demonstrate the feasibility and business case for advanced cooling and heat-recovery technologies. They can also foster industry collaboration by sharing operational data and best practices, and by advocating for the standardization of performance metrics that capture the full value of heat-recovery systems. This is especially relevant for these stakeholders, as enabling waste heat recovery offers numerous benefits that with widespread implementation, could help mitigate some negative publicity associated with data center growth.
- **Manufacturers** are essential in advancing the technical capabilities of heat-recovery systems. They must focus on innovating robust, scalable, and cost-effective solutions that address the unique constraints of data centers, such as high heat flux densities, variable loads, and retrofit requirements. Manufacturers can also support heat recovery adoption by developing plug-and-play modules, providing comprehensive training programs for installers and operators, and collaborating with digital twin and AI developers to enable more reliable, workload-aware control systems.
- **Government agencies** have a critical role in shaping the regulatory and policy environment that supports heat-recovery adoption. By establishing clear standards or offering tax incentives, or creating a dedicated government agency, governments can

reduce market uncertainty and/or lower barriers for investment. Public sector leadership in funding demonstration projects, supporting workforce development, and facilitating cross-sector partnerships can further accelerate progress. Non-profit organizations complement these efforts by raising awareness, conducting independent research, and facilitating knowledge-sharing among stakeholders. They can advocate for sustainability goals, help convene industry groups, and support the development of open standards and best-practice guidelines.

Ultimately, more heat-recovery adoption in data centers depends on collective action from all these stakeholders. By working together to address technical, economic, and organizational challenges, they can unlock the environmental and operational benefits of sustainable data center cooling and contribute to broader decarbonization efforts.

Successful Case Studies

Table 3 highlights the wide variety of data center heat recovery projects, including region, ownership type, end-use building type, applications. Common to all of these case studies is the close proximity of the data center heat source and the end-use loads, often being in the same or adjacent facility or connected on the same district heating network. Secondly, each of these projects required close collaboration and partnership between the data center operators, the facility receiving the waste heat, and other local partners. Even in situations where the data center and facilities are owned by the same organization, coordination is needed across departments and all participants must recognize the long-term benefit of the project. Third, most projects involved new construction or major renovations because extensive retrofits may be needed to convert the end-user facility to utilize the data center's waste heat.

The Amazon Headquarters project in Table 3 showcases a successful data center heat recovery project along with the major challenge for expansion. This project featured a sustainability focused end-user with a long-term occupancy expectation and experience with data center design and operations. Nevertheless, Amazon states the project may have a long payback period relative to conventional heating solutions due to the higher capital costs (Amazon 2019). This underscores the challenges that data center heat recovery projects face – even when major technical, organizational, and logistical drivers are favorable, attractive project economics are not guaranteed. In most construction situations, unfavorable upfront and/or lifecycle cost can thwart otherwise successful design solutions.

Table 3. Data Center Heat Recovery Case Studies

Project Details (Reference)	Description	Key Success Factors
Tallaght District Heating, Dublin Ireland New District Heating System Codema 2026	• The Tallaght District Heating Scheme, developed by Codema and South Dublin County Council, is Ireland's first large-scale district heating network and has been operational since 2023. • The district heating system uses waste heat from nearby Amazon data centers to supply public buildings and TU Dublin Tallaght. • Operated by the council-owned nonprofit Heat Works, the project has the potential to expand to hospitals, housing, and other local buildings in the future.	• Close proximity between data center and end-use load owned by different parties • Partnerships between the supportive community and the data center owners (i.e., Amazon) • Enabling policy frameworks and support from the federal government of Ireland • Diverse funders and project partners
Amazon Headquarters Seattle, WA New Construction Office Complex Amazon 2019	• Heat recovered from a downtown telecommunications data center is piped to the neighboring central energy plant serving a 5 million sq.ft. office complex • The plant increases the 65F incoming water to 130F for the building's space heating through the use of electric heat recovery chillers •	• Close proximity between data center and end-use load owned by different parties • Development of a new district energy facility and network • End-user represented a large technology corporation with sustainability commitments • New construction office could be designed around the data center heat recovery solution
Silicon Valley Initiative, San Jose CA New Construction Multifamily Community PG&E 2025	• A new net-zero community would pair 3 data centers with up to 4,000 multifamily homes where the heat recovered from the data center would support a district energy system serving the surrounding buildings. • Construction on the community is expected in 2026 with the first data center coming online in 2027	• Close proximity between data center and end-use load, developed by the same partners • Development of a new district energy facility and network • Strong engagement with local utility and city officials on how to use data center projects to build housing and enhance communities • Community will include a mix of new construction and adaptive reuse to connect with the district energy facility.

Project Details (Reference)	Description	Key Success Factors
National Laboratory of the Rockies (NLR), Golden CO Research Labs and Office Facility NLR 2026	• NLR's High-Performance Computing (HPC) user facility captures waste heat from a liquid-cooled supercomputer to heat the facility's process hot water loop. • The recovered heat supports space heating and snow melting at the HPC facility, but also connects to the wider campus heating loop to serve other buildings as well.	• Close proximity between data center and end-use loads, owned by the same organization • Hydronic system design within buildings and hot water loops across the research campus • Research organization with a strong mission to evaluate emerging technologies and achieve very low PUE (< 1.04) for supercomputer
Syracuse University Green Data Center, Syracuse NY Data center and office building NYSERDA 2015	• Constructed in 2011, gas-fired microturbines generate electricity for the 12 kSF data center and the recovered heat from the exhaust stream provides space heating and cooling to the facility and adjacent 70 kSF office building. • The waste heat provides the thermal input for two absorption chillers that generate the chilled water for cooling the data center and office spaces.	• Close proximity between data center and end-use loads, owned by the same organization • New construction data center designed to provide thermal connection to older office building • Research organization with a strong mission to evaluate emerging technologies and achieve energy and emissions savings

Conclusions and Next Steps

Heat recovery in data centers offers significant potential to enhance sustainability and efficiency. Leveraging waste heat not only reduces environmental impact but also offers tangible benefits to end-users, municipalities, and utility providers. Integrating heat recovery solutions into data center operations can play a pivotal role in advancing energy efficiency, supporting decarbonization goals, and promoting responsible growth within the sector.

To fully realize these opportunities, coordinated action is required among stakeholders, as highlighted by the case studies above and construction planning experts (Spencer 2026). Data center operators should prioritize heat recovery feasibility studies during the planning and construction phases, incorporating best practices and aligning with sustainability certifications such as LEED® and ENERGY STAR®. By preparing a public database of heat recovery projects, industry leaders and policymakers can facilitate knowledge sharing and encourage wider adoption of proven solutions.

Regulators and local governments have a critical role in shaping the regulatory landscape by considering voluntary or required feasibility studies for new data center construction. They can further support these initiatives by offering development incentives, streamlining permitting processes for both data centers and end-use loads, or developing metrics that incorporate heat recovery. Utilities and state energy efficiency programs should explore mechanisms to include heat recovery projects in their incentive eligibility criteria, establishing clear guidelines on how benefits and incentives are distributed among participating parties.

The research, development, and demonstration community is encouraged to advance innovative technologies and solutions that optimize heat recovery systems. Collaboration between academia, industry, and government agencies will be essential to drive progress and validate new approaches. End-users, including building owners and district heating operators, should seek partnerships with data centers to incorporate recovered heat into their operations, thereby reducing energy costs and improving the sustainability profile of their facilities.

In summary, unlocking the value of heat recovery in data centers requires an integrated strategy involving all key stakeholders. By fostering collaboration, incentivizing adoption, and aligning on efficiency standards, the industry can significantly enhance its sustainability and contribute to broader environmental objectives, while also reducing negative perceptions surrounding the industry. The recommendations outlined here provide a roadmap for achieving these goals and ensuring responsible data center growth for the future.

References

Amazon. 2019. "The super-efficient heat source hidden below Amazon's Seattle headquarters." August 20, 2019. https://www.aboutamazon.com/news/sustainability/the-super-efficient-heat-source-hidden-below-amazons-seattle-headquarters

Chan, Rosalie. 2023. "Virginia's 'Data Center Alley' residents say an eerie hum is keeping them up at night." Business Insider. November 27, 2023. https://www.pwcva.gov/assets/2024-09/Data-Center%20Boom%20Leads%20to%20Noise%20Disruptions%20in%20Loudoun%20County%2C%20Virginia%20-%202.pdf

Codema. 2026. Tallaght District Heating Scheme. https://www.codema.ie/our-work/tallaght-district-heating-scheme/

Elwardany, M., Turja, A. I., Hasan, M. M., & Nassif, N. (2026). High-temperature heat pumps for industrial decarbonization: Technologies, integration strategies, and future perspectives. Chemical Engineering and Processing - Process Intensification, 225, Article 110806. https://www.sciencedirect.com/science/article/pii/S025527012600111X

Guidehouse Research. 2025. "Data Center Cooling." June 26, 2025. https://www.guidehouseresearch.com/reportaction/MF-DCC-25/Marketing

National Laboratory of the Rockies (NLR). 2026. High-Performance Computing Data Center Heat Capture and Reuse. https://www.nlr.gov/computational-science/waste-heat-energy-reuse

NYSERDA. 2015. "Microturbine System Provides Electricity, Space Heating, and Cooling." Case Study of Syracuse University Green Data Center.

PG&E. 2025. "PG&E Begins Energy Infrastructure Upgrades to Bring San Jose's Net Zero Community to Life." April 9, 2025 https://www.prnewswire.com/news-releases/pge-begins-energy-infrastructure-upgrades-to-bring-san-joses-net-zero-community-to-life-302424740.html

Spencer, Timothy. 2026. "PAS Quicknotes - Data Center Waste Heat Recovery." American Planning Association's Planning Advisory Service. No. 117. March 2026. https://planning-org-uploaded-media.s3.amazonaws.com/publication/download_pdf/PAS-QuickNotes-117.pdf

Synergy Research Group. (2025, March 19). Hyperscale data center count hits 1,136; average size increases; US accounts for 54% of total capacity. Synergy Research Group. https://www.srgresearch.com/articles/hyperscale-data-center-count-hits-1136-average-size-increases-us-accounts-for-54-of-total-capacity

U.S. Energy Information Administration (EIA). 2022. 2018 Commercial Building Energy Consumption Survey (CBECS) Data. December 2022. https://www.eia.gov/consumption/commercial/data/2018/index.php?view=consumption

U.S. Energy Information Administration (EIA). 2024. 2020 Residential Energy Consumption Survey (RECS) Data. March 2024. https://www.eia.gov/consumption/residential/data/2020/index.php?view=consumption

Acknowledgments

As applicable for a conference paper on data centers, the authors used Microsoft Copilot to support background research, data gathering, and for developing flow between sentences for this paper. The authors reviewed and verified all content, calculations, and citations