A white paper from

European Data Centre Association's

Technical Committee

An Introduction to Data Centre Heat Reuse

EUROPEAN DATA CENTRE ASSOCIATION

www.eudca.org

Rond-point Robert Schuman 9 – 1040 Bruxelles – Belgique

Contents

Abstract

It is known that a data centre is a system that, for the continuous operation of IT equipment, requires cooling 24 hours a day, 365 days a year. From a thermo-dynamic point of view, this means that a data centre dissipates a quantity of heat that varies according to the computational load and, in most cases, to the external temperature conditions. However, this happens continuously throughout the year, without interruptions.

The recovery and exploitation of this quantity of heat may prove to be convenient: certainly, from an energy and sustainability standpoint; sometimes it is also from an economic point of view.

This white paper aims to give an overview of what heat reuse is, how it can be used, when it's worth using it and what the current regulatory and legislative initiatives that support or mandate it are.

Heat reuse defined

Heat reuse (also known as heat reclaim or heat recovery) refers to the practice of capturing and reusing the waste heat rejected by the IT equipment and cooling systems within a data centre. Data centres are known for producing a significant amount of heat (nearly 100% of the electricity consumed by the servers is dissipated into heat) because of the operation of servers, networking equipment, storage devices. All these are kept at an optimal operating temperature by the cooling systems which, by definition, reject the same amount of heat or even higher, when a compressed vapour refrigerating cycle is used.

Instead of allowing this waste heat to be dissipated into the environment (mainly outdoor air or cooling water), heat reuse systems can be implemented to recover and re-purpose this excess heat for other useful applications. If the excess heat wasn't recovered, a significant amount of electricity would be consumed to meet the heating needs of the area. The captured heat can be used for various uses, such as space heating, water heating, industrial processes, electricity generation, agricultural applications, and livestock breeding.

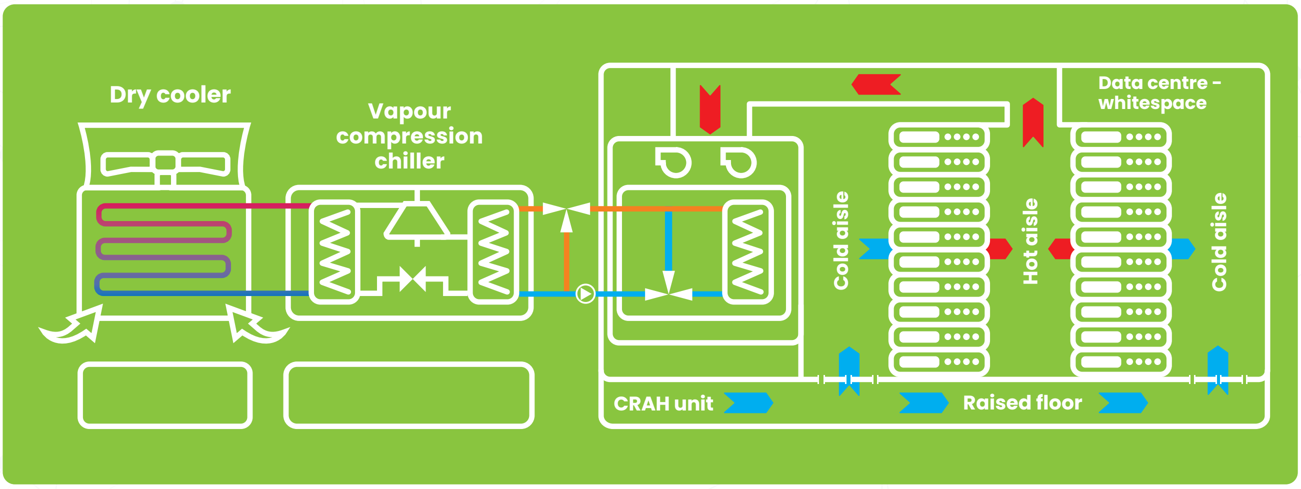
Most of the time the temperature level at which data centre heat is recovered is not high enough for the above-mentioned purposes, so a system to elevate the recovered heat may be needed.

Once the amount of electrical energy absorbed by the IT equipment is reduced to its minimum, then a well-designed heat reuse system not only improves the energy efficiency of the facility but also contributes to sustainability efforts by reducing the overall energy consumption and green-house gas emissions associated with traditional heating and cooling methods.

Heat reuse defined (continued)

According to Euroheat and Power,[1] the EU's total forecasted heat demand by 2025 will be 1850 TWh/year and a key role could be played by abundant, renewable and climate-neutral new heat resources in meeting these needs. By that time, these new heat sources are likely to exceed the EU's heat demand and provide more than 2000 TWh/year of heating capacity. Among them, waste heat from data centres at 25-35°C is in the 4th position (221 TWh/year, targeting 12% of heating demand) just after mid-temperature industrial waste heat at 55°C (540 TWh/year), waste heat from sewage water at 8-15°C (442 TWh/year) and low-temperature industrial waste heat at 25°C (240 TWh/year).[2]

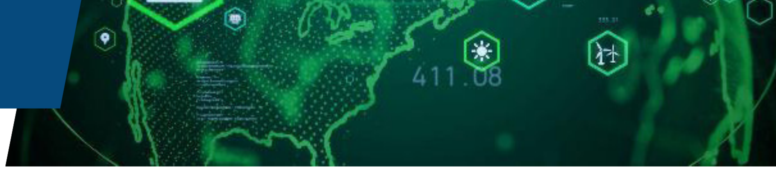
There are 997 data centres in the EU-28 that are located within 2 km of a district heating network, generating more than 75 TWh/year of accessible excess heat per year.



Example of a vapour compression chiller (water-cooled through a Dry-Cooler) providing chilled water to indoor CRAHs

[1] www.euroheat.org

[2] Aalborg University



Main purposes of heat reuse and applications

Heat reuse systems have emerged as a sustainable solution to harness the thermal energy generated by data centres. The primary aim is to improve overall energy efficiency, reduce operational costs, and contribute to more environmentally friendly data centre infrastructure. These systems capture and repurpose the excess heat, converting it into a valuable resource for various purposes:

1. **Space Heating:** heat recovery can be used to heat nearby buildings (homes, offices, etc.) during colder months. This can reduce the need for traditional heating systems, thus saving energy at territory level and reducing operating costs, not only for the data centre operator but for the end user as well. Heat can be piped or distributed through a district heating system.

2. **Industrial Processes:** heat can preheat water for industries that require hot water as part of their manufacturing or production processes. Many industrial operations, such as cleaning and sterilization, require high-temperature water.

3. **Domestic Water Heating:** the heat can be reused to preheat water for domestic use, such as showers and sinks in the data centre itself or nearby buildings.

4. **Electricity Generation:** In some cases, Organic Rankine Cycles (ORC) can be adopted to produce electrical energy using heat rejection from data centres when it is available at elevated temperatures (>80°C).

5. **Cooling:** Absorption chillers can provide cooling for the data centre itself or for nearby buildings. These types of cooling units use heat to drive the absorption process mainly of ammonia/water or lithium bromide (LiBr) and provide cooling through the evaporation of the refrigerant used.

6. **Agricultural Applications:** In agricultural or horticultural settings, heat can be reused to maintain greenhouse temperatures or even to grow algae that can absorb CO_2 from the atmosphere[3].

7. **Breeding:** Dairy cow breeding needs hot water for cleaning and warm drinking water to increase milk production.

8. **Other uses:** swimming pools, field heating, seawater desalination, wood drying, fish farms.

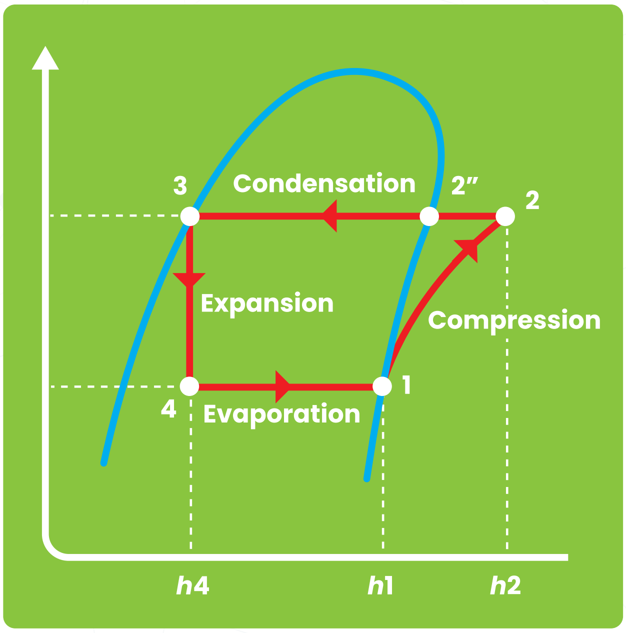
[3] www.theagilityeffect.com/en/article/in-germany-a-new-generation-of-carbon-neutral-datacentres/

How to recover heat from a data centre

There are many ways of providing cooling to a data hall within a data centre, thus there are different ways to recover heat and make it available for the above-mentioned purposes. The easiest and most common way to implement a heat reuse system is to apply it to a chilled water (CW) cooling system. Here follow the most common layouts and related heat recovery systems.

A CW cooling system is based on a water chiller (air-cooled or water-cooled) which provides chilled water to indoor units (mainly CRAHs, fan walls or air handling units). These indoor units then grant the needed cooling capacity reaches, with the needed airflow, to the servers.

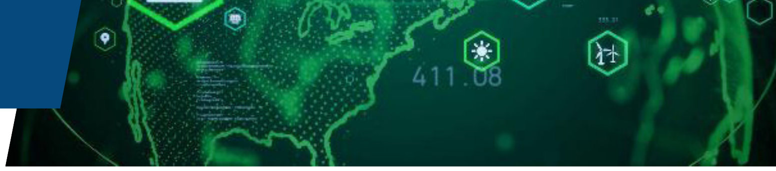
The way heat is rejected out of the data hall is through the condensing phase in the thermodynamic reverse cycle of the chiller. As a rule of thumb, the amount of heat the chiller rejects equals the cooling capacity (h1 – h4) plus the amount of electrical energy consumed by the compressors (h2 – h1). The temperature level at which waste heat is recovered depends on the condensing temperature (T3) of the chiller itself, so it depends on the type of chiller (air-cooled or water-cooled) and on the ambient conditions (ambient air temperature or cooling water temperature). In some cases, a water-cooled chiller is coupled to a cooling tower or a dry cooler, so the condensing temperature is back again related to the ambient air temperature. The higher the outdoor ambient air temperature, the higher the heat recovery temperature.



p-H diagram of a vapour compression cycle

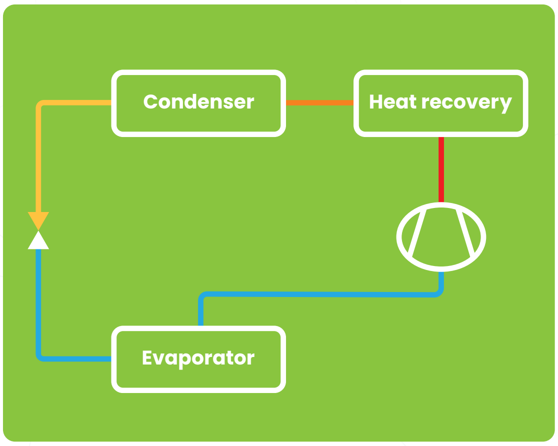
It is understood that, whenever the outdoor air temperature is too low, then the heat recovery temperature level may be too low, as well as the amount of energy recovered. When this occurs, a water-to-water heat pump should be added to the system to integrate what's missing in terms of temperature level and in terms of kWh of thermal energy.

When a chiller is used, heat from the data hall can be recovered using either a desuperheater (in series between compressor and condenser) or a total heat recovery system (an additional condenser, in parallel to the main one), both to be implemented within the chiller itself. What are the pros and cons of these two solutions?



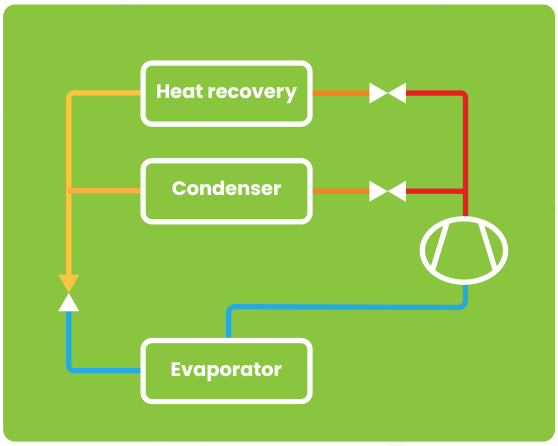
How to recover heat from a data centre (continued)

	DESUPERHEATER	TOTAL HEAT RECOVERY
PROS	Cheap solution	Recovers 100% of the heat rejection
	Simple to manage/control	Temperatures can be set-up independently from boundary conditions (ambient)
CONS	Affects unit's performances always (refrigerant pressure drops)	Doesn't work in a free-cooling chillers when in free-cooling mode (compressors off)
	Recovers only 20-30% of the heat rejection	Expensive solution
	Temperatures depends on ambient conditions and on refrigerant type	Chiller is heavier
	Doesn't work in a free-cooling chillers when in free-cooling mode (compressors off)	



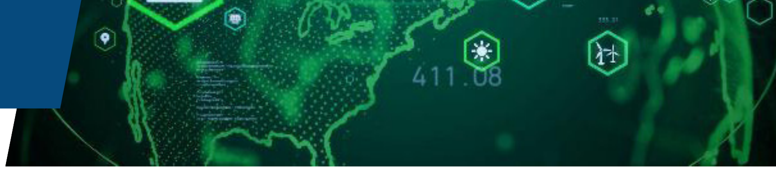
DESUPERHEATER

Heat Recovery system installed in series with the condenser, mainly applied to partial heat recovery schemes (desuperheater)



TOTAL HEAT RECOVERY

Heat Recovery system installed in parallel with the condenser, mainly applied to total heat recovery schemes.



How to recover heat from a data centre (continued)

Another way to get heat recovery in a CW system is to get heat from the pipe leaving the indoor CRAHs. Once the chilled water units have supplied the necessary cooling capacity, the water leaving them and returning to the chiller is "carrying" the heat removed from the data hall. By installing a water/water heat exchanger between the CRAHs and the chiller, this amount of heat can be recovered. According to the type of application for which it will be used, an additional heat pump may be required.

It is well known that high density servers are becoming increasingly popular to meet the processing requirements of applications like Artificial Intelligence (AI). Air-cooled systems are showing their limitations with such applications, and liquid cooling is coming up more frequently as a solution.

As AI and high-performance computing (HPC) are becoming more popular, more high-density servers are deployed. For these high-density applications (>40 kW per rack), air cooling is showing its limits and liquid cooling is emerging as a more effective method for removing heat. Liquid cooling is more likely to deal with higher water (or fluid) temperatures, mainly because of diverse types of chips, resistant to higher temperatures, and for this reason heat recovery could be easier and more convenient than standard air-cooled chips. Excess heat can be easily reclaimed, as mentioned above, by installing a heat exchanger between the liquid cooling appliances and the chiller/dry cooler.

From this perspective, liquid cooling appears to be sustainable and convenient whenever a heat recovery system is combined with it.

Conditions of success of a heat recovery system

Although heat reuse systems in data centres offer many advantages in terms of energy efficiency and sustainability, there are some limitations that should be considered when designing and implementing such systems.

Heat Reuse and Demand Matching

One of the biggest challenges is balancing the heat demand of the environment with the availability of waste heat from the data centre.

Data centres can generate excess heat during times of low heating demand, resulting in a reduced opportunity for useful heat reuse. This is what happens during summertime when outside temperatures are higher. In these conditions, an air-cooled cooling unit rejects a larger quantity of heat into the ambient air, and at a higher temperature level. Depending on the type of heat demand, this excess heat may result in being more than needed and the difference is then rejected and dissipated.

In contrast, during peak heat rise times, the data centre may not generate enough waste heat to meet demand. This is the case during wintertime when Free-Cooling systems are mostly activated to save energy while providing cooling to the IT equipment. In the most energy efficient situation from a cooling standpoint the

Conditions of success of a heat recovery system (continued)

waste heat is as much as the heat rejected by the servers and its temperature level is quite close to the air leaving the servers. To cover peak heat demands, a heat pump is needed and, according to its type, specific values of temperatures can be reached.

Also, Colocation data centres have little control over the IT deployment and heat generation, therefore the availability of the heat to a heat network can be an issue and must be taken into consideration.

Distance and Infrastructure

The proximity of suitable structures or facilities that can use recovered heat determines whether heat reuse is practical, due to the significant upfront CAPEX required to install district heating net-works. That's the case, for instance, with district heating, whose temperature of the fluid entering the pipes depends on the pipe length, when they are not well insulated: the longer the pipes – thus the longer the distance between the data centre and the user buildings – the higher the temperature of the heat recovery must be. And, of course, the longer the pipes, the higher the investment expenses.

It can also be difficult to adapt existing structures/ buildings to accommodate heat reuse equipment, due to architectural barriers. Moreover, with existing (old) buildings and high-temperature radiant systems, the temperature of the heat recovery is required to be at a higher level (>60°C).

Costs

Installing a heat reuse system can require a significant upfront investment in infrastructure such as heat exchangers, piping, and control systems. In some cases, a water-to-water heat pump may be required, to increase the temperature level of the heat recovered. A business plan/justification should be prepared before implementing such a solution.

Ultimately, initial CAPEX must be compared to running costs and it must be carefully evaluated whether the energy required to recover and reuse waste heat can offset the energy savings achieved through heat recovery. Sometimes heat waste can be sold to specific users, generating revenues, and contributing to a quicker return of the investment and a payback time.

The size of the data centre, and thus the heat reuse system size, plays a significant role in cost evaluation and in the break-even point calculation.

In general, the cost of the additional electricity could considerably downgrade the financial balancing, thus making the operation unattractive whenever high temperature applications are considered. One of the keys for success is to develop low temperature networks or usage, when possible.

Regulatory and Environmental Scenarios

Local regulations and environmental concerns increasingly call for the assessment

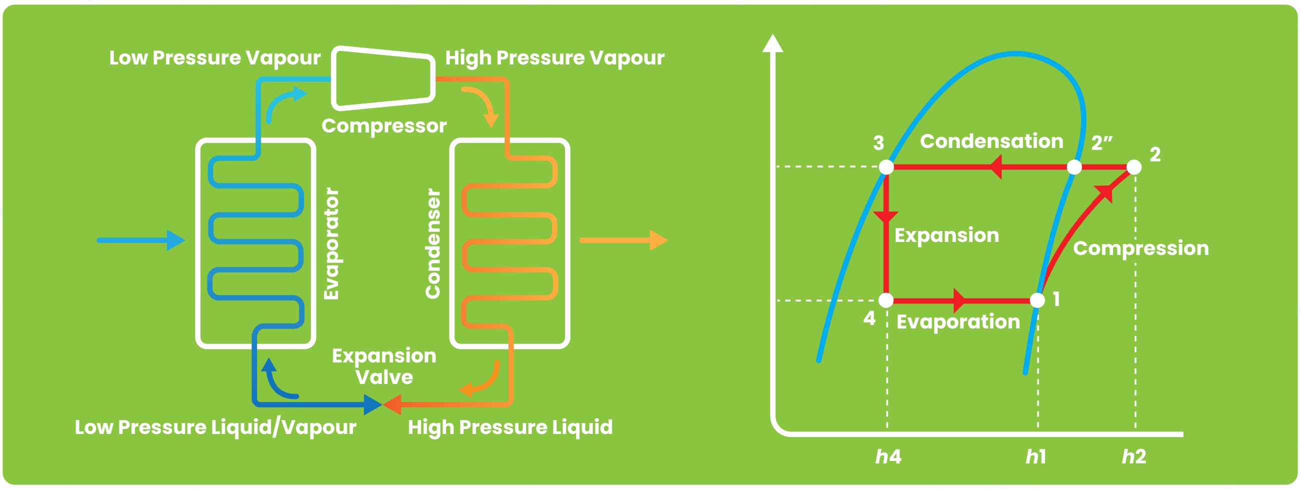
Conditions of success of a heat recovery system (continued)

of the feasibility of exporting heat from data centres. In Germany for example, the Energy Efficiency Act was introduced into law in September 2023 and sets requirements on data centres of a given size to demonstrate compliance with regulations requiring the export of heat. "Energy efficiency standards will also be introduced for new data centres, which will be obliged to utilize waste heat and to make economical use of cooling system power. Efficiency requirements are also being introduced for existing data centres[4]".

Heat reuse and environmental sustainability

A heat reuse system for a data centre is considered sustainable from different standpoints, primarily because it brings more energy efficiency in supplying cooling and heating at the same time. In simple words, heat recovery captures and reuses waste heat that would otherwise be dissipated into the environment. By considering both cooling and heating effects and the related power consumption, it's easy to understand that "energy efficiency ratio" of the whole system is much higher than the EER of the cooling system alone.

Visually and with some simplifications:



Vapour compression circuit and related p-h diagram representation

[4] www.bundesregierung.de/breg-en/news/the-energy-efficiency-act-2184958

Heat reuse and environmental sustainability (continued)

The efficiency of the cooling system that provides cooling to the data centre is measured comparing the cooling effect (line 1-4) and its power consumption (line 1-2) in the metric called EER - Energy Efficiency Ratio. If a heat pump was used to provide cooling to a space heating system, working under the same temperature conditions, then its efficiency would be defined with its COP-coefficient of performance by the ratio of the heating effect (line 2-3) and its power consumption (line 1-2). The two systems are consuming the same amount of electrical energy to supply either cooling or heating.

By considering the full system, providing both cooling and heating at the same time, then it would still be using the same electrical energy (line 1-2) but providing a lot more thermal energy that is the sum of cooling and heating (line 1-4 + line 2-3).

By using waste heat from a data centre for heating purposes such as space heating and hot water production, reliance on traditional heating systems which often use fossil fuels or electricity, is reduced. This may result in significant energy savings and a reduction in carbon footprint, depending on different scheme designs, locations, applications, etc. Overall, this decreases in demand for energy helps reduce greenhouse gas emissions associated with electricity generation.

Metrics for heat recovery systems

It is known that the most popular metric to evaluate the energy efficiency of a data centre is PUE – Power Usage Effectiveness (Ref. EN 50600). Specifically, PUE measures the ratio of the total electrical power consumed by a data centre to the power consumed by the IT equipment within the data centre.

Its definition reads as follows: PUE is a dimensionless metric that represents the efficiency of a data centre's energy usage. It is calculated by dividing the total facility energy consumption by the energy consumption of the IT equipment.

PUE = Total Facility Energy Consumption / IT Equipment Energy Consumption

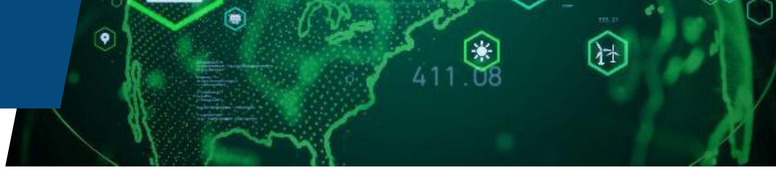
Where Total Facility Energy Consumption includes all the energy consumed by the data centre facility, such as cooling systems, lighting, power distribution, and other auxiliary equipment and IT Equipment Energy Consumption refers to the energy used by the data centre's core IT equipment, which includes servers, storage devices, and networking gear.

Lower values indicate better energy efficiency.

A PUE of 1.0 means that all energy consumed is used by IT equipment only, no energy is used for cooling or other non-IT functions. In practice, the PUE value is usually greater than 1.0 and the goal is to minimize PUE as much as possible to improve energy efficiency and reduce operating costs.

The average power usage effectiveness (PUE) ratio for a data centre in 2020 is 1.58[5].

[5] https://journal.uptimeinstitute.com/data-centre-pues-flat-since-2013/



Metrics for heat recovery systems (continued)

But PUE doesn't consider heat recovery in any way. When a heat recovery system is implemented in a data centre, then it's useful to understand its efficiency and effectiveness. The most used metrics are HRE – Heat Recovery Efficiency and ERE – Energy Reuse Effectiveness.

HRE = (Recovered Heat Output / Total Waste Heat Input) × 100%

ERE = (Total Facility Energy Consumption – Energy Reuse) / IT Equipment Energy Consumption

HRE measures the percentage of waste heat that is successfully captured and utilized by the heat recovery system: the higher HRE, the greater the efficiency in utilizing waste heat. HRE specifically evaluates the efficiency of heat recovery systems in capturing and repurposing waste heat.

While **HRE** focuses exclusively on heat recovery processes, **ERE** accounts for other types of energy recovery. **ERE**[6]

is counting how much the energy reuse is effective. The energy from the data centre that is used in another location and reduces the energy the site would need to buy, procure, or generate, can be accounted for in this metric.

Moreover, there is an additional metric that is internationally recognized as a standard and defined as per EN 50600: **ERF** – Energy Reuse Factor. Apart from primary energy consumption, some data centres reuse their energy for different purposes, creating a secondary energy consumption opportunity. And this is measured by **ERF**, which determines the share of the total energy consumption that is reused.

ERF = Energy Reuse / Total Facility Energy Consumption

EU policy framework on data centres and reuse heat

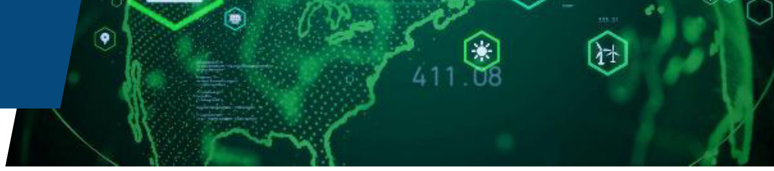
At the European level, the energy policy debate has largely focused on reducing the use of fossil-fuel-based energy sources, and towards renewable sources such as wind, solar, and hydrogen. Recently, the EU has begun looking into waste heat reuse to be added to the mix of renewable energy resources. As part of this, the potential of reusing data centres' excess heat, has been directly included in the revision of EU legislation such as Renewable Energy and Energy Efficiency Directives.

Most recently, in December 2022, a study was launched by the European Commission to examine the **study** on optimization of synergies between data centres and energy systems, including on the feasibility of heat reuse. In the 2023 edition of the **EU Code of Conduct for Data Centre Energy Efficiency** data centres are recommended to evaluate the potential of their waste heat reuse and to take into consideration when choosing a location for new facilities.

Moreover, at the legislative level, more binding requirements are being set.

Under the revised **Energy Efficiency Directive (EED)**, data centres with a total rated energy

[6] ERE: A metric for measuring the benefit of reuse energy from a data centre – The Green Grid – Rev.2010-0



EU policy framework on data centres and reuse heat

(continued)

input of 1MW and higher, in all member states, will be required to utilize their waste heat or other waste heat recovery applications unless they can prove it is economically or technically unfeasible. The requirement will become applicable once the member states transpose this requirement into national law. However, the examination is not required if the data centre waste heat will be directly connected to a district heating network or other networks in the surrounding area. Moreover, other legislative initiatives, such as the revised **Renewable Energy Directive** and revision of the **Energy Performance of buildings directive**, aim at incentivizing the uptake of district and heating systems across Europe, and explore potential sources of waste heat, including data centres, to feed into district heating networks and heat up zero-emissions buildings.

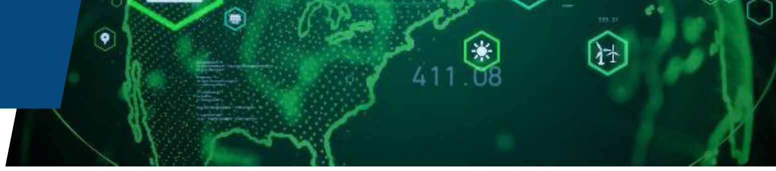
The new requirements set at the European level will also influence the regulatory framework in member states, and some national governments are already taking action and going beyond the minimum requirements of the EED by requiring data centres to provide a portion of their waste heat to local district heating networks.

For instance, in Germany, the Energy Efficiency Act introduced in 2023 new requirements for data centres of a given size to demonstrate compliance with regulations requiring the export of heat.[7] Even outside the EU, other states are following the EU model. For example, in the United Kingdom, the government presented a proposal for a legislation in 2023 making the release of building per-mits to new data centres in heat network zones, conditional upon their connection into existing or planned heat networks.[8]

While this demonstrates increased attention at the policy level for the potential reusability of waste heat from data centres and acknowledgement of the role that data centres could play as a low-cost source of heat in district heating and cooling systems, this is not always accompanied by adequate consideration for the technical challenges the uptake of excess heat reuse still faces.

[7] www.bundesregierung.de/breg-en/news/the-energy-efficiency-act-2184958

[8] www.gov.uk/government/consultations/proposals-for-heat-network-zoning-2023/heat-network-zoning-consultation-summary



Links to other resources

More information about this and related topics are available on EUDCA website.

Coming next will be new publications on liquid cooling, technical guidelines on how to conduct feasibility studies for heat reuse in your data centres, and a six-level maturity model on heat reuse.

Circular energy is going to be a big topic for EUDCA in 2024. Together with other industry actors, many EUDCA members are currently working to identify industry-based targets for circular energy and heat reuse under the Climate Neutral Data Centre Pact (CNDCP). For more information, please visit the CNDCP website.

Author

Alessandro Zerbetto (Vertiv)

Reviewers

Tanja Gutgesell, Benoit Ploux (Vantage)

Noah Nkonge, Billy McHallum (Equinix)

Marie Chabanon, Linda Lescuyer (Data4)

Steven Parker (Global Switch)