Technology overview for waste heat utilisation from data centres

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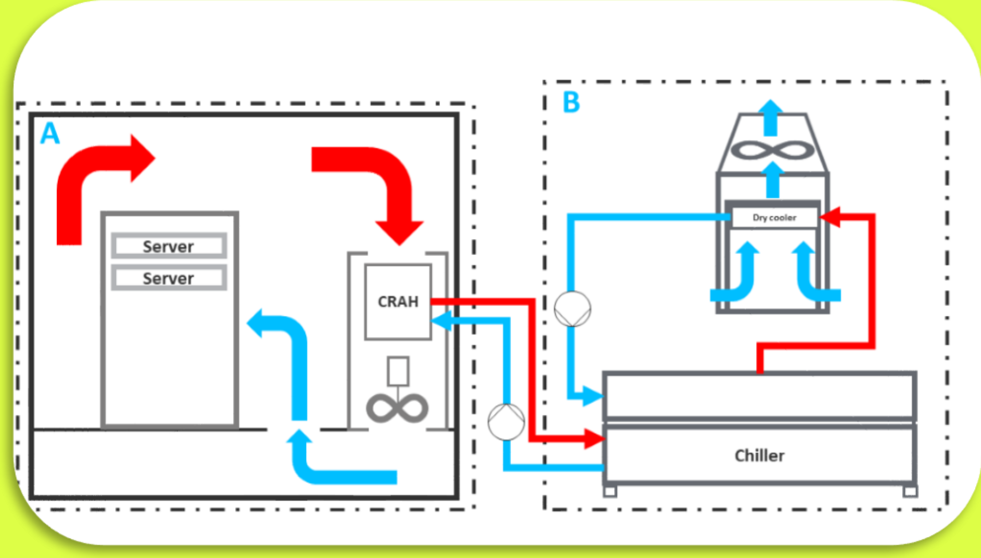
Disclaimer

The technologies for waste heat recovery from data centres contained in this best practice overview are for information purposes only and are intended to serve as suggestions. No guarantee is given for the accuracy or completeness of the information and it is the responsibility of the reader to evaluate and utilise the information in the context of their individual needs and requirements. We accept no liability for any damage or loss that may result from the use of this information. The use of image material for other purposes must be clarified on an individual basis.

Data centre cooling technology

(Level: Server / Rack / Room)

General information on data centre cooling technology



The **cooling of data centres** is made up of two subsystems (A and B). While the *room cooling* system (A) ensures that the waste heat generated during server operation is dissipated (e.g. via recirculating air cooling units), the *cooling infrastructure* (B) provides the necessary cold water (e.g. with compression chillers) and dissipates the excess waste heat to the environment via recooling towers. Within the cooling system, waste heat can be extracted at different temperature levels and from different media flows (e.g. with heat exchangers). CRAH = Computer Room Air Handler;
CRAC = Computer Room Air Conditioning

Air and liquid cooling

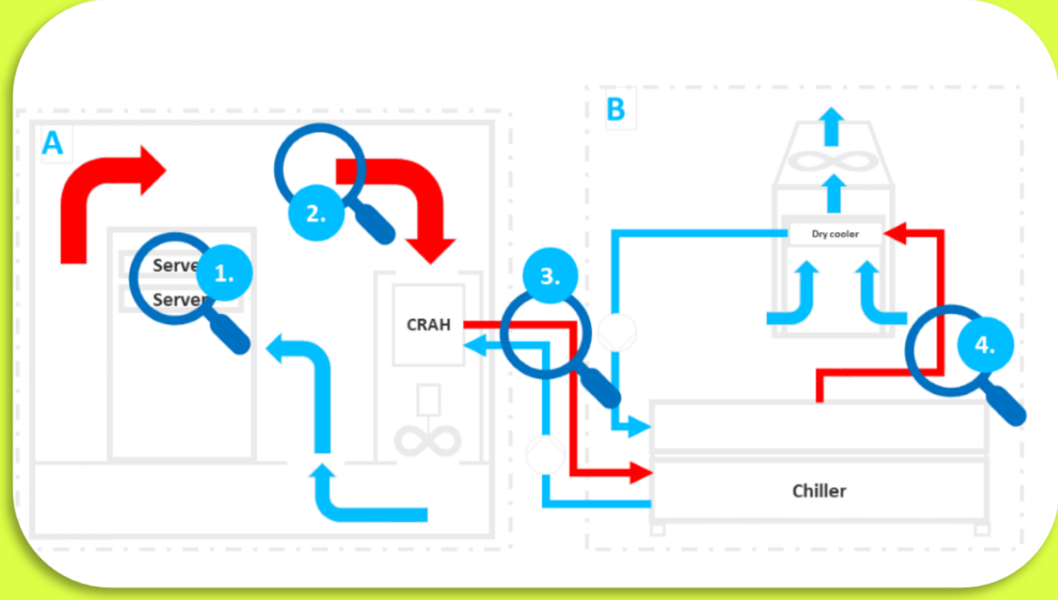
Waste heat collection and removal

20 - 60 °C (Waste heat temperature)

2 - 250 kW_{th}/Rack

Image source: [1]; Source: [2–4]

Where could the waste heat from the servers be extracted?

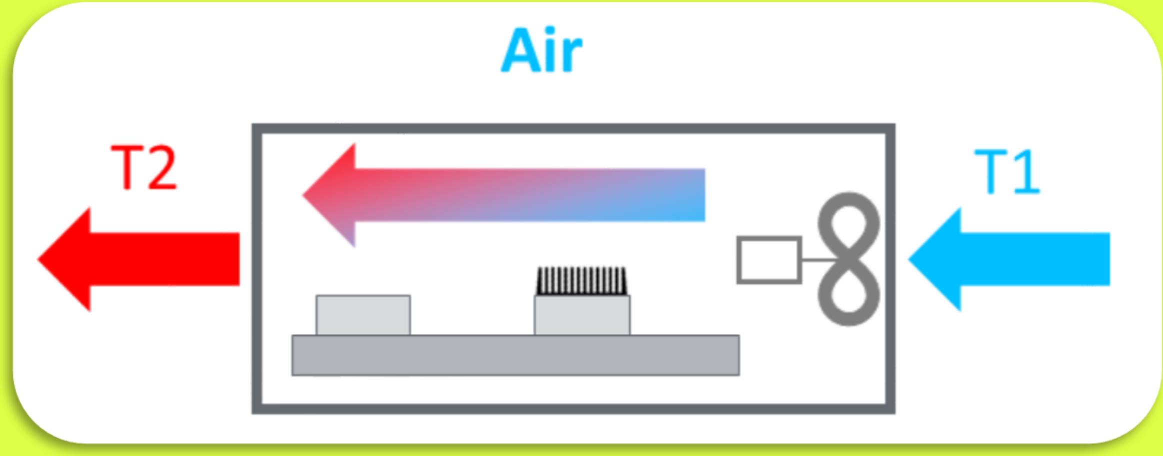


Theoretically, four different approaches can be used to **extract the waste heat**. Depending on the cooling concept, this can take place within the *room cooling* (A) or the *cooling infrastructure* (B). At the same time, this determines the achievable waste heat temperature and the complexity of the technical infrastructure required for extraction. The closer to the heat source the waste heat is captured, the higher its temperature (apart from any temperature increase by means of a chiller). On the other hand, the technical effort required to centrally capture waste heat from all sources decreases.

1. Directly in the server (e.g. thermoelectric generator)
2. Air-X heat exchanger in the hot aisle
3. Cold water / refrigerant (X-water heat exchanger with CRAH / CRAC)
4. Cooling water or extraction integrated in the chiller

Image source: [5]

Air cooling



With **air cooling**, cool air is transported through the server via fans and absorbs the resulting waste heat. In some cases, heat sinks are also installed on individual components for this purpose. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends an inlet temperature of 18 to 27 °C (T1). A temperature increase of up to 15 K takes place via the server. Depending on the configuration (e.g. cold aisle or hot aisle containment), a cooling capacity of up to 12 kWth per rack can be achieved.

The heated air is then cooled by computer room air conditioner (CRAC) or computer room air handler (CRAH) units.

CRAC / CRAH

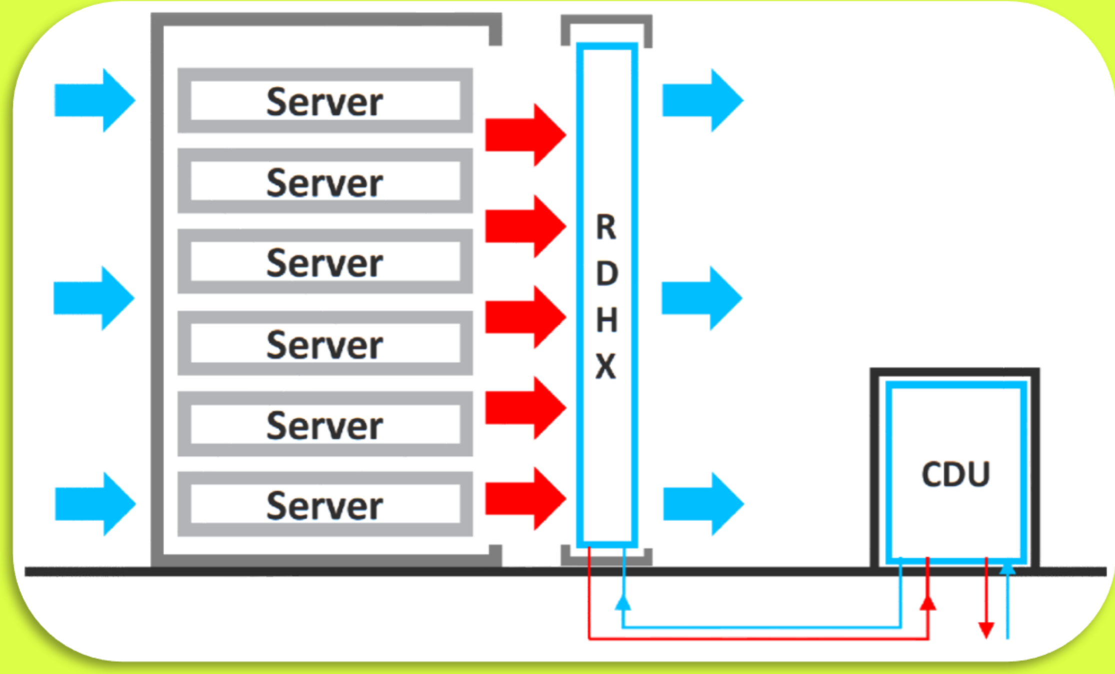
Waste heat capture and removal

20 - 40 °C (Waste heat temperature)

< 12 kW_{th}/Rack

Image source: [6]; Source: [7–15]

Indirect liquid cooling



Indirect liquid cooling involves a combination of air and water cooling. Room air is supplied to the servers and heats up. An air-water heat exchanger is located at the rear of the servers, through which the heated air is forced to flow. This is cooled to room temperature by the cold water flowing through it. The so-called "Rear Door Heat Exchanger" (RDHX) is available in two versions: passive and active. In the second case, additional fans are installed in the rear wall, thereby enabling a higher cooling capacity. A major advantage is the direct transfer of waste heat into the cold water circuit, especially in contrast to computer room air handler units.

Cooled rear doors

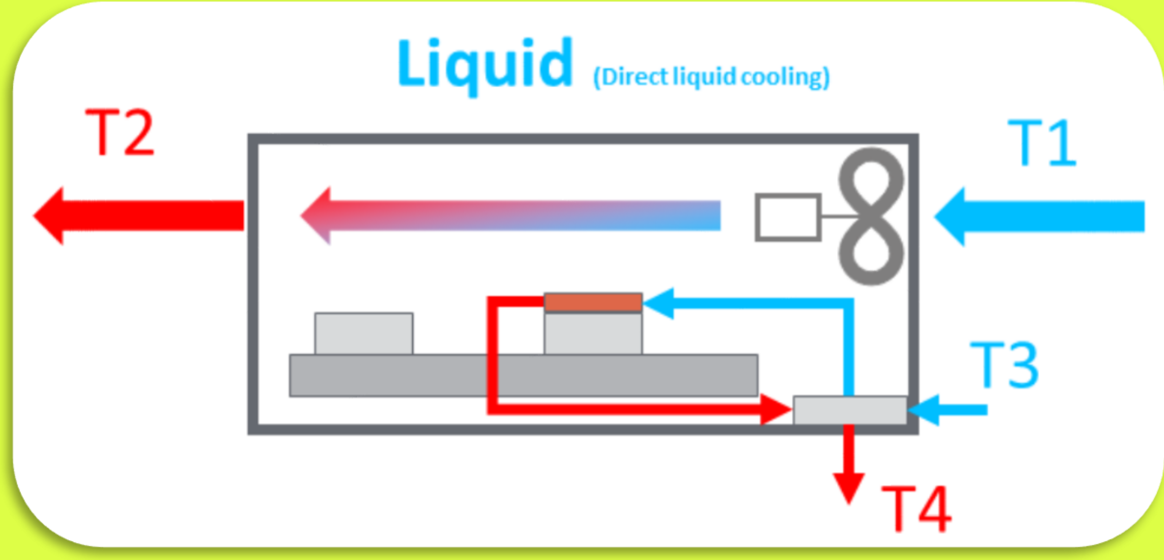
Waste heat capture and removal

20 – 30 °C (Waste heat temperature)

15 – 55 kW_{th}/Rack

Image source: [16]; Source: [3]

Direct liquid cooling

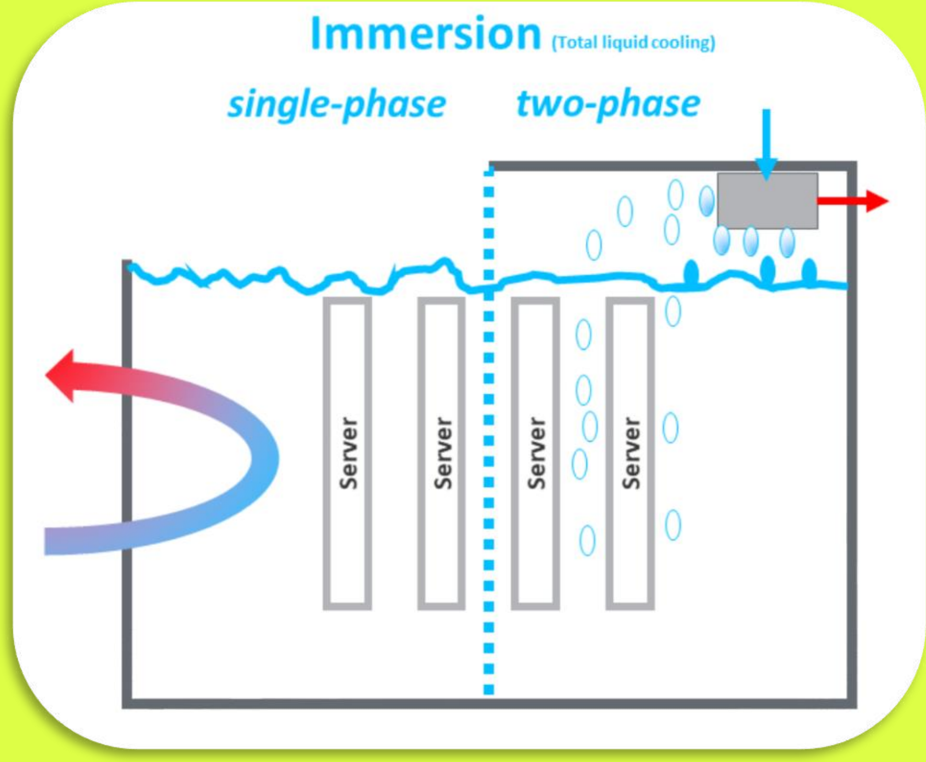


Direct liquid cooling also involves a combination of air and liquid cooling. The components to be cooled (especially CPU and RAM) are fitted with cold plates through which liquid flows. In this way, between 60 and 90 % of the waste heat can be absorbed in the liquid. Single-phase (e.g. water) or two-phase media can be used as the cooling medium. ASHRAE recommends an inlet temperature of 17 (W17) to over 45 °C (W45 and W+). At the same time, the temperature increase via the server components is around 10 K. The remaining waste heat load is dissipated via an air flow.

- Cold plates
- Waste heat capture and removal
- 30 - 60 °C (Waste heat temperature)
- < 80 - 200 kW_{th}/Rack

Image source: [17]; Source: [14, 15, 18]

Immersion cooling



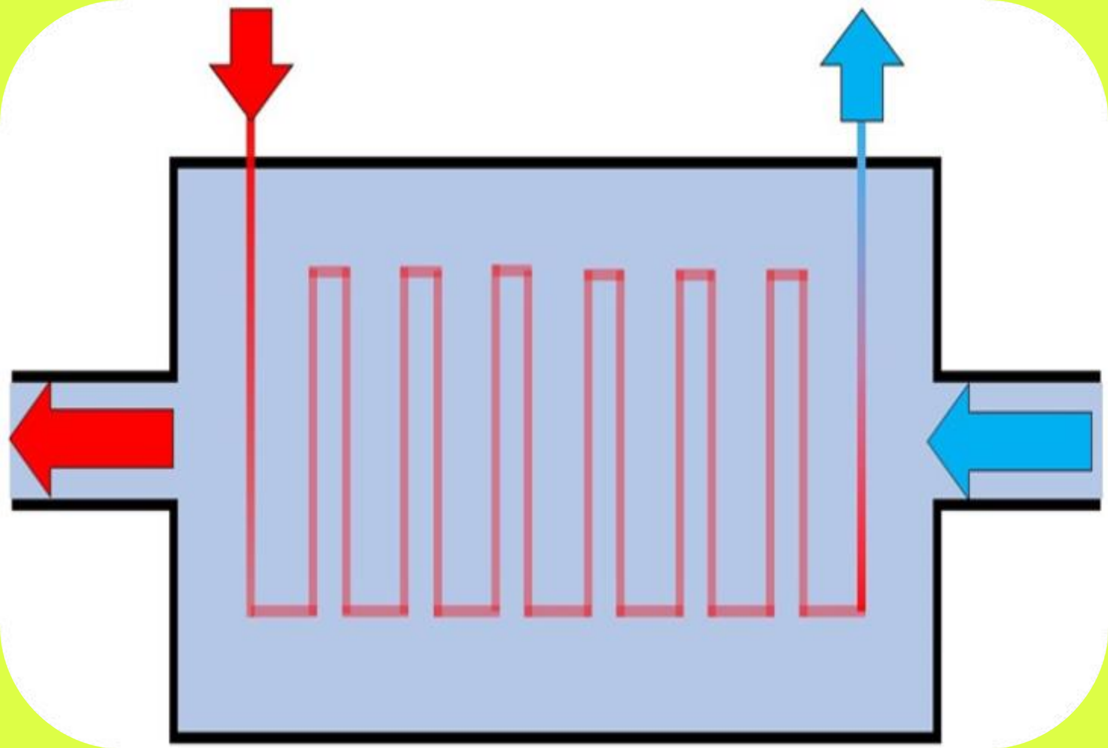
With **immersion cooling**, up to 100 % of the waste heat generated can be bound in a liquid. In contrast to direct liquid cooling, the entire server is immersed in a cooling liquid. In this case, water can no longer be used, but special electrically non-conductive liquids are required (e.g. mineral oils). A different structure is often used. Tanks can also be used instead of a rack. These can be of open or closed design. Depending on whether a single-phase or two-phase coolant is used, a closed design is required. In this case, the evaporation enthalpy can be utilised.

- Single-phase / two-phase
- Waste heat capture and removal
- 30 - > 60 °C (Waste heat temperature)
- < 250 kW_{th}/Rack

Image source: [19]; Source: [4, 18]

Heat exchanger

General information on heat exchangers



A **heat exchanger** is a device that enables the transfer of thermal energy from one fluid flow to another without the fluid having to come into direct contact with each other. The transferred heat can be utilised for other thermal applications. Compact heat exchangers are favoured for waste heat recovery as they have a higher heat transfer rate and a very low pressure loss for the same volume.

Plate and tube heat exchangers

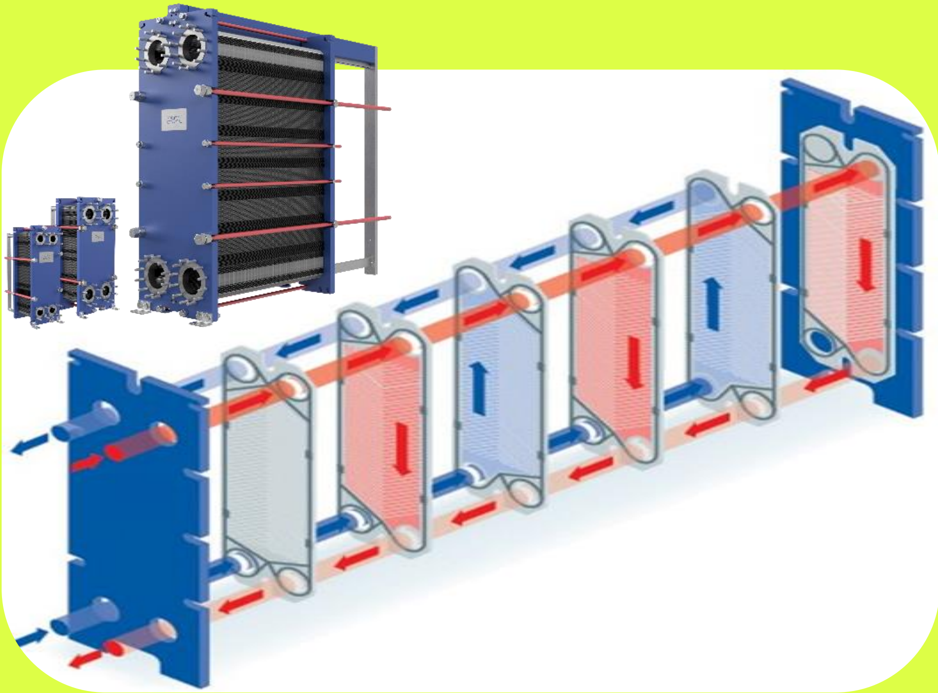
Up to 900 °C (operating temperature)

Heat transfer and recovery

2 kW_{th} – 400 MW_{th}

Image source: [6]; Source: [7–13]

Plate heat exchanger



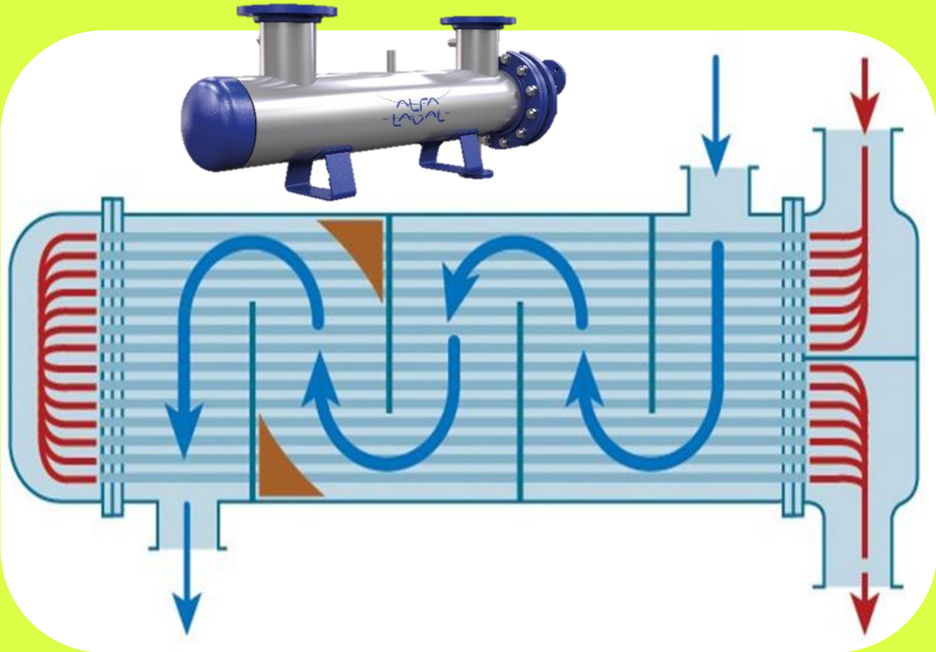
A **plate heat exchanger** is a type of heat exchanger that uses metal plates to transfer heat from one fluid to another. Plate heat exchangers consist of a series of thin, corrugated, moulded metal plates. Each pair of plates forms a complex passageway in which the fluid flows. Plate heat exchangers are generally categorised into two types: brazed and gasketed plates. In plate heat exchangers, the hot fluid flows in alternating chambers in one direction and the cold fluid flows in other alternating chambers, but in the opposite direction to the hot fluid.

Up to 900 °C (operating temperature)

2 kW_{th} – 400 MW_{th}

Image source: [20]; Source: [10–13, 21, 22]

Shell and tube heat exchanger



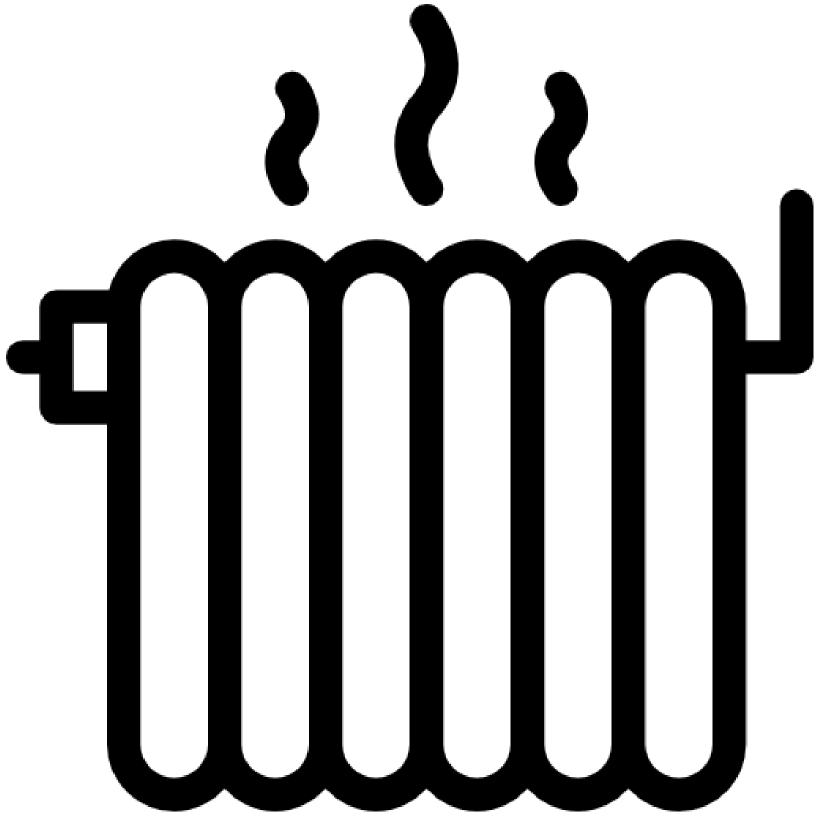
Shell and tube heat exchangers are one of the most commonly used types of heat exchanger. A shell and tube heat exchanger consists of a shell side and a tube side, with one liquid medium flowing through the shell side and another flowing through the tubes. Shell and tube heat exchangers are suitable for high-pressure operation as they are very robust.

Up to 300 °C (operating temperature)

2 kW_{th} - 20 MW_{th}

Image source: [20]; Source: [10–13, 21, 22]

Heat pump



General information on heat pumps

A **heat pump** takes thermal energy from a source with lower temperatures and, together with the operating energy used (usually electricity), upgrades it to a higher temperature. Heat pumps are often used to upgrade the temperature of waste heat from (air-cooled) data centres.

With the help of a heat pump, the waste heat from a data centre can be brought to a temperature level of 60 °C and higher. Multi-stage heat pumps are also possible, with which a significantly higher temperature level of > 150 °C can be achieved.

Air-to-water, water-to-water and high-temperature heat pumps

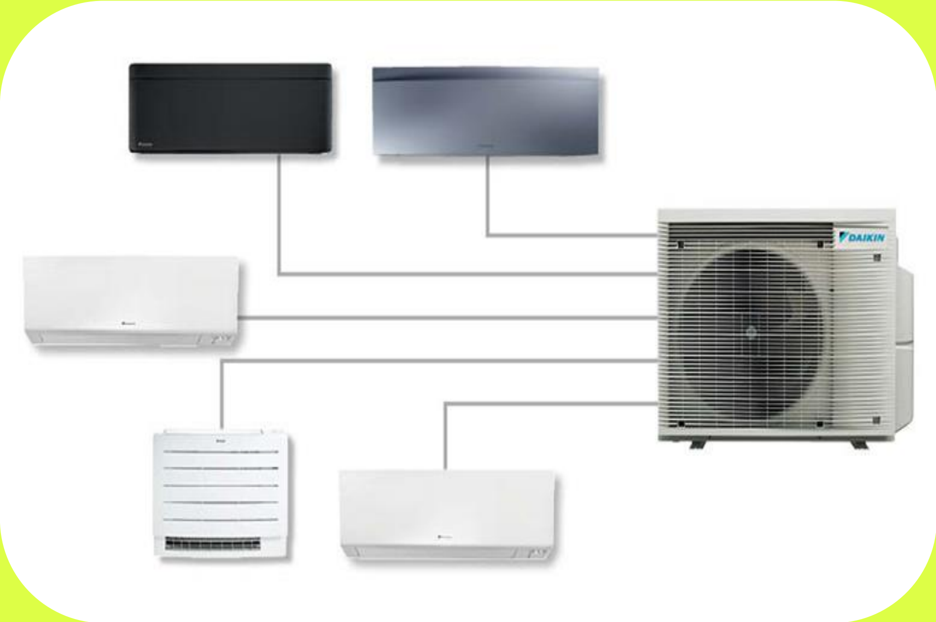
Heating and cooling

30 – 150 °C (Sink temperature)

< 10 kW_{th} ... 70 MW_{th}

Image source: [23]; Source: [24–30]

Air-to-air heat pump



Air-to-air heat pumps utilise the air as a source of thermal energy in heating mode. An air-to-air heat pump system can usually also be used for cooling purposes by reversing the process and extracting heat from the air in the room. In terms of waste heat utilisation in data centres, the air-to-air heat pump cools the server room and can use this as a heat source for heating purposes. In this process, the heat is transferred from an air source to an air sink with a temperature lift.

Image source: [31]; Source: [32–37]

Air-to-water heat pump

Air-to-water heat pumps extract thermal energy from an air source to heat water. The heated water can be used to provide space heating or other applications.

Image source: [38]; Source: [32–37]

Water-to-water heat pump

A **water-to-water heat pump** is a type of heat pump that transfers heat between two streams of water (a source and a sink). It is able to utilise the thermal energy present in the water to provide both heating and cooling.

< 100 °C (Sink temperature)

< 10 MW_{th}

Image source: [39]; Source: [37, 40–44]

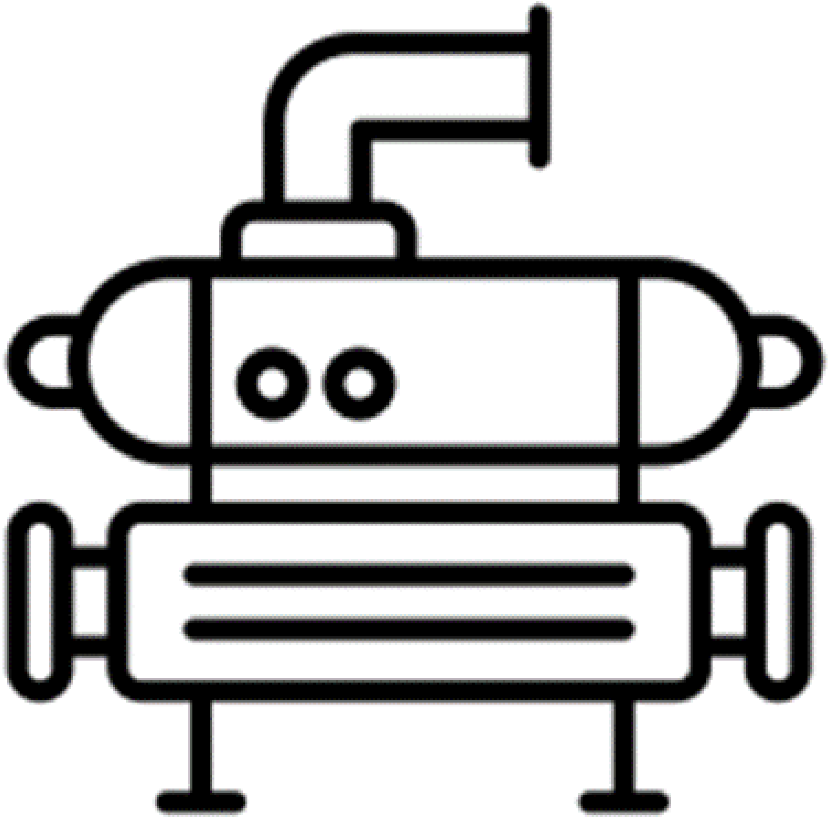
High-temperature heat pump

High-temperature heat pumps are a technology for upgrading heat sources to a particularly high temperature level. On the one hand, they can provide heat at a higher temperature level (> 100 °C) than conventional heat pumps and, on the other hand, they can absorb heat from higher temperature sources. Water, brine, exhaust air or waste water in a temperature range between 17 and 65 °C are generally used as the heat source.

65 - > 130 °C (Sink temperature)

Image source: [45]; Source: [37, 40–43]

Chiller



General information on chillers

Chillers are devices that are used to cool rooms or processes. For this purpose, they provide cold water which is heated by the room or process heat. They then extract heat from the heated cold water and, after raising the temperature, the waste heat is released into the environment via recoolers. Standard chillers typically have a condenser temperature of around 40 °C.

A heat exchanger for heat recovery can be integrated into the chiller. On the other hand, in contrast to classic mechanical refrigeration, waste heat can also be used as drive energy for chillers of the absorption and adsorption type. In this way, waste heat can be utilised to provide cold water.

- Compression, absorption or adsorption chiller
- Cooling generation and waste heat utilisation
- ~ 40 °C (Condenser temperature)
- 15 kW – 15 MW (Cooling capacity)

Image source: [46]; Source: [15, 47–51]

Compression chiller

Compression chillers (CC) are most frequently used in refrigeration supply systems and have the largest market share. They can be used for both cooling and freezing. A refrigerant is vaporised and then condensed again in a cycle. A core component is the refrigerant compressor, for which various designs (screw, turbo, piston and scroll compressors) are used. As a rule, the condenser is cooled with air or water. However, waste heat can also be extracted via the cooling water or an integrated heat exchanger.

Screw, turbo, piston and scroll compressors

~ 40 °C (Condenser temperature)

10 kW – 8 MW (Cooling capacity)

Image source: [52]; Source: [51]

Absorption chiller

Absorption chillers (AbC) require a drive temperature of at least 70 to 95 °C. However, the waste heat generated in the data centre does not usually reach this temperature - not even with liquid-cooled servers. This is also the biggest challenge for this technology. In this case, a drive can only be provided by interposing a heat pump. Instead of an electrically driven compressor, a thermal drive is provided by a sorption process. The refrigeration process consists of two interconnected circuits (refrigerant and solvent circuit).

LiBr/H_2O or NH_3/H_2O AbC

70 - 180 °C (Drive temperature)

10 kW – 20,5 MW (Cooling capacity)

Image source: [53]; Source: [25, 28, 49, 51, 54, 55]

Adsorption chiller

In contrast to an absorption chiller, an **adsorption chiller** (AdC) requires a lower drive temperature and utilises a solid sorbent such as activated carbon, zeolite or silica gel. In addition, the process is discontinuous and consists of two phases: the adsorption and desorption process. A drive temperature of 55 - 100 °C is sufficient. This means that liquid-cooled servers can also be used as a heat source. In contrast to the CC, only cooling is possible.

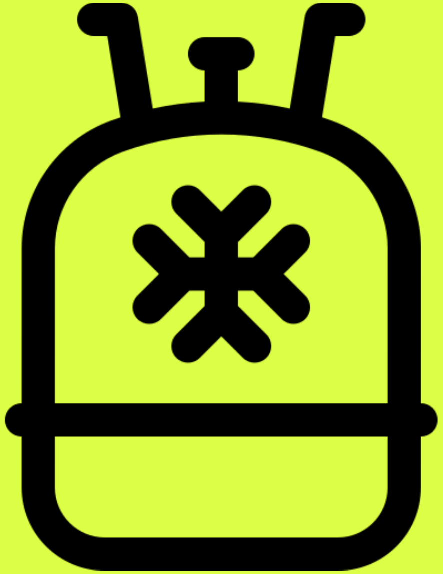
55 - 100 °C
(Drive temperature)

10 kW – 1 MW
(Cooling capacity)

Image source: [56]; Source: [25, 28, 51, 57, 58]

Additional section on refrigerants

General information on refrigerants



Refrigerants are used in both chillers and heat pumps. A compact overview of the most common refrigerants, including their thermophysical properties, can be found in [59]. The following refrigerants are mainly used in the EU today:

- ***Partially halogenated fluorocarbons*** (HCFCs), e. g. R134a
- ***Partially halogenated unsaturated fluorocarbons*** *or* ***olefins*** (HFO) e. g. R1234yf
- ***Ammonia*** (R717)
- ***Carbon dioxide*** (R744)
- ***Hydrocarbons*** (KW), e. g. Propan R290
- ***Water*** (R718); comparatively few systems to date
- Mixtures of the previously mentioned refrigerants, e.g. R404A or R507

The basic **international agreements** are:

- The **Montreal Protocol** of 1987, which regulates the production and consumption of ozone-depleting substances (ODS) → EU Regulation 1005/2009
- the **Paris Climate Change Agreement** of December 2015, which regulates the reduction of greenhouse gases (GHG) as a follow-up agreement to the **Kyoto Protocol**
- the **Kigali Amendment** to the Montreal Protocol, which was adopted in 12/2016 and places the measures to reduce HFCs under the Montreal Protocol.

An overview of the EU regulation on fluorinated greenhouse gases can be found at [60]. The **EU F-Gas Regulation** 2024/573, which comes into force on 11 March 2024, is intended in particular to incentivise the use of alternatives instead of F-gases. The quantities of hydrofluorocarbons (HFCs) placed on the market in the

EU will continue to be gradually reduced. From 2050, the permitted quantity will be set at zero. In addition, new bans on placing on the market will be issued for the following installations, among others:

- Stationary refrigeration systems (see Annex IV No. 4 and 5 b + c)
- Stationary chillers (see Annex IV No. 7 b - d)
- Stationary air conditioning systems and heat pumps (Annex IV No. 8 b - e and 9 b - f)

A **suitable refrigerant** should have the following **characteristics**:

- ➢ Good thermodynamic properties
- ➢ Good chemical stability, good miscibility with oil
- ➢ Good physical properties
- ➢ No or only low environmental impact
- ➢ Good availability

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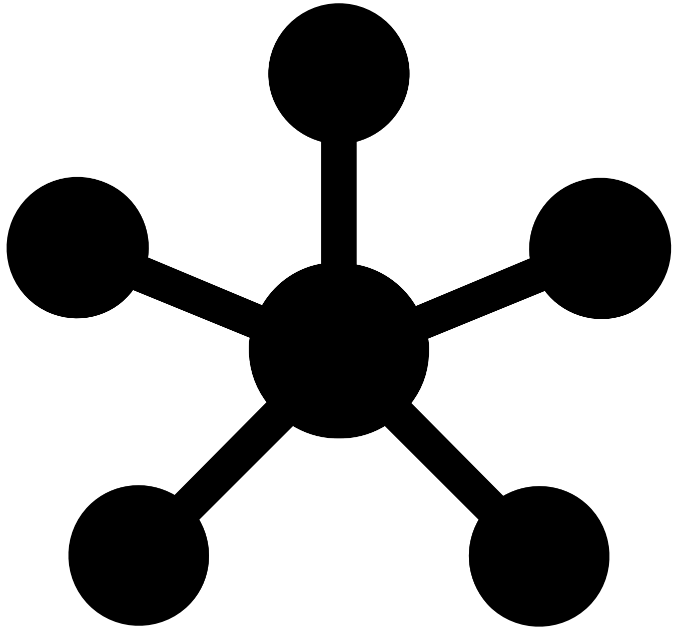
An **overview** including **detailed profiles** can be found at [61] in relation to **natural refrigerants** such as ammonia, carbon dioxide, hydrocarbons, ammonia dimethyl ether and water. Depending on the performance range, the following refrigerants are used in heat pumps.

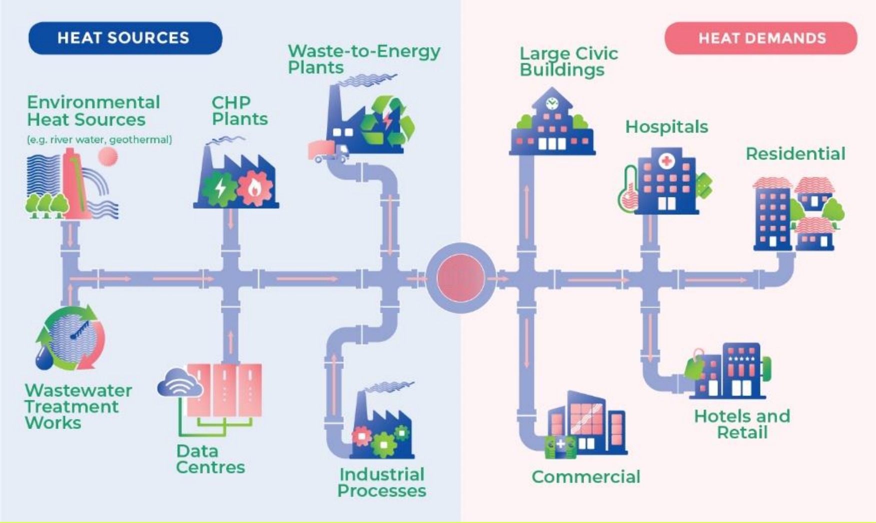
Large heat pumps: carbon dioxide (R744), propane (R290), ammonia (R717), ammonia/dimethyl ether (R723).
Medium to *large performance range*: ammonia.
Medium to *small cap performance acity range*: Non-halogenated and fluorinated refrigerants.

Image source: [62]; Source: [59–61, 63]

Heating network



General information on heating networks



A **heating network** distributes heat via a network of pipes that transport either hot water or low-pressure steam from central systems and heat generation units to residential, commercial and industrial buildings. A distinction is made between local and district heating, whereby the transition between the two is fluid and depends on the spread and size.

The waste heat from data centres is rarely warm enough (~ 20 to 35 °C) to be fed directly into conventional heating networks. Conventional district heating systems are supplied with heat from combined heat and power (CHP) plants or heating plants. Waste heat from industry or data centres can also be fed in. Depending on the flow temperature, a temperature increase is required.

Heating networks from the 1st to the 5th generation

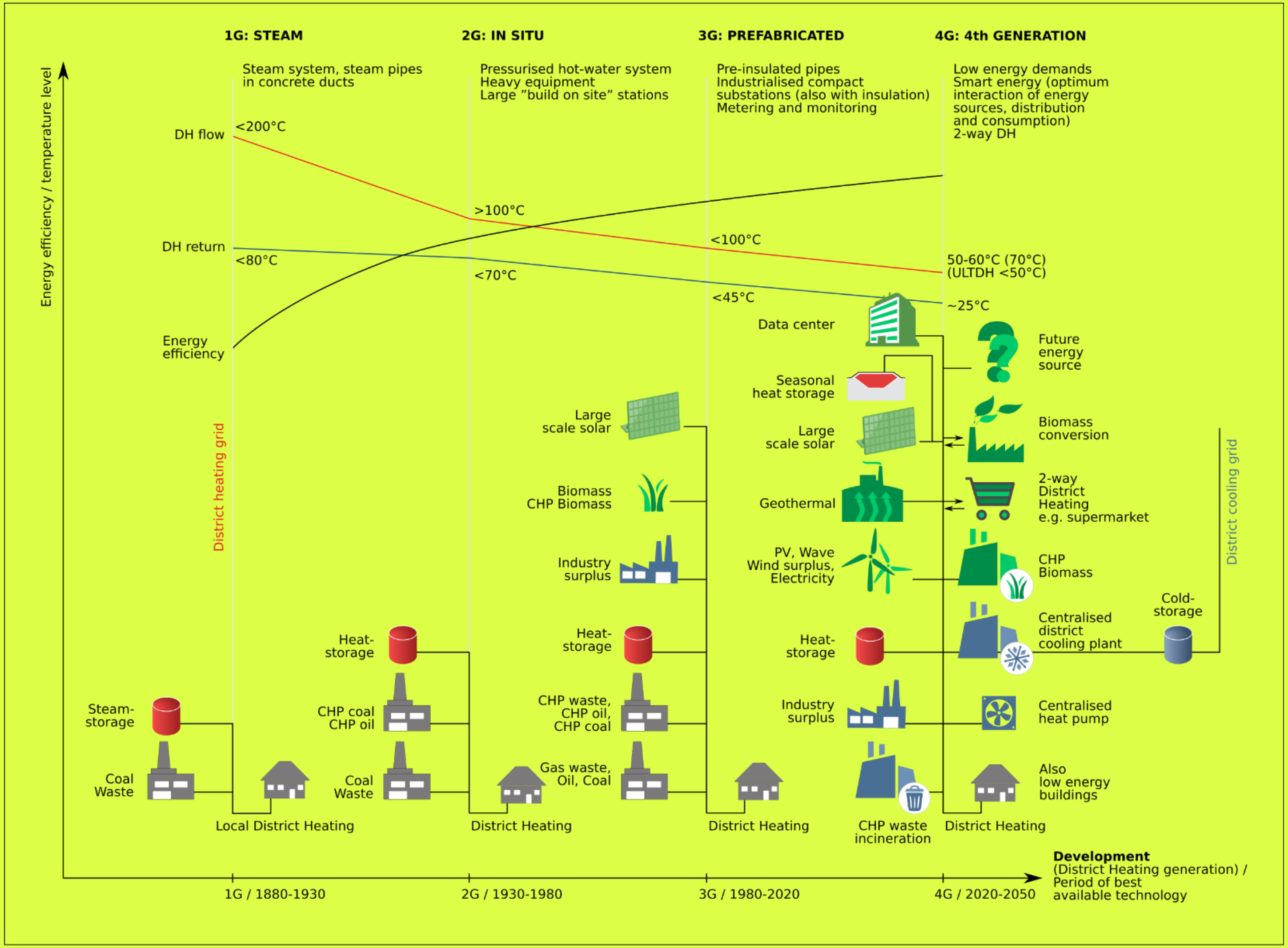
Supply of space heating, hot water and process heat and integration of waste heat

15 - 200 °C (Supply temperature)

n. s.

Image source: [64]; Source: [28, 65–68]

First generation heating network



The main feature of the **first generation** of district heating systems was that the heat was transported using steam, as this is a good transport medium due to its high heat capacity. It was obtained, for example, from boilers or steam power plants that did not run in condensing mode and therefore had steam at a high temperature. Typical steam temperatures are up to 200 °C and pressures up to 20 bar.

< 200 °C (Supply temperature)

n. s.

Image source: [69]; Source: [70–72]

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Second generation heating network

The main feature of the **second generation** district heating system is that the heat is transported by pressurised, superheated water with temperatures of over 100 °C. Second generation district heating was predominant from the 1930s to the 1980s. The distribution network usually consisted of two steel pipes, a supply pipe and a return pipe. The boilers were fuelled with coal, waste and oil. Combined heat and power generation was also introduced in order to save primary energy. One difference to the steam-based systems of the first generation was the centrally arranged circulation pumps, which ensured a sufficient head of water in the distribution network and enabled heat to be extracted at the point of consumption.

≥ 100 °C (Supply temperature)

n. s.

Source: [70–72]

Third generation heating network

The main feature of the **third generation** district heating system is the use of material and labour-saving components in combination with generally lower temperatures (< 100 °C). The third generation was developed in the 1970s after the two oil crises led to oil shortages. The third generation heating networks are also known as "Scandinavian" district heating technology. This system utilised coal, biomass and waste as energy sources, with some also using geothermal and solar energy.

< 100 °C (Supply temperature)

n. s.

Source: [73–77]

Fourth generation heating network

With **fourth generation** or low-temperature district heating, the flow temperature can be below 50 °C and the return temperature close to 20 °C. This would enable smaller heating networks to be highly efficient, whereby lower quality heat could be utilised more efficiently. With flow temperatures below 50 °C, some of the waste heat from data centres can be fed directly into this network without a heat pump, especially from data centres with modern cooling technologies that enable high waste heat temperatures.

< 70 °C (Supply temperature)

n. s.

Source: [73–77]

Fifth generation heating network

The **fifth generation** of district heating distributes heat close to the ambient temperature, minimising heat loss and thus the need for insulation. These are better suited to the lower waste heat temperatures of air-cooled servers. For fifth generation heating and cooling networks, a bidirectional energy flow is particularly important, meaning that connected buildings in the network can be heated and cooled simultaneously. The main features are:

- The energy is distributed at a low temperature level and is not suitable for direct utilisation.
- Decentralised heat pumps are used with the heating network as a low-temperature heat source.
- The heat supply integrates waste heat and renewable energies at low temperatures.
- The same infrastructure can be used for heating and cooling.

< 50 °C (Supply temperature)

n. s.

Source: [75–77]

References

Literature

[2] D. Huang, C. Yang und B. Li, „Rack-Level Cooling and Server-Level Cooling“ in *Data Center Handbook: Plan, Design, Build, and Operations of a Smart Data Center*, H. Geng, Hg., 2 Aufl. Newark: John Wiley & Sons Incorporated, 2021. [Online]. Verfügbar unter: 227–237

[3] B. Dürr, *IT-Räume und Rechenzentren planen und betreiben: Handbuch der baulichen Maßnahmen und Technischen Gebäudeausrüstung,* 2. Aufl. Erkrath: Verlag Bau+Technik, 2018.

[4] 3M, „Two-Phase Immersion Cooling: A revolution in data centre efficiency“, 2015. https://multimedia.3m.com/mws/media/1602994O/novec-immersion-cooling-article-english.pdf. (Aufgerufen: 3. Oktober 2023).

[7] S. Mavridou, G. C. Mavropoulos, D. Bouris, D. T. Hountalas und G. Bergeles, „Experimental Studies On Performance Parameters Of Finned Tube Heat Exchanger For Waste Heat Recovery“, *Applied Thermal Engineering*, Jg. 30, 8-9, S. 935–947, 2010, doi: 10.1016/j.applthermaleng.2010.01.003.

[8] O. Khayal, „Fundamentals of Heat Exchangers“, 2019.

[9] Y. Luo, J. Andresen, H. Clarke, M. Rajendra und M. Maroto-Valer, „A decision support system for waste heat recovery and energy efficiency improvement in data centres“, *Applied Energy*, Jg. 250, S. 1217–1224, 2019, doi: 10.1016/j.apenergy.2019.05.029.

[10] E. Edreis und A. Petrov, „Types of heat exchangers in industry, their advantages and disadvantages, and the study of their parameters“, *IOP Conf. Ser.: Mater. Sci. Eng.*, Jg. 963, Nr. 1, 2020. [Online]. Verfügbar unter: https://iopscience.iop.org/article/10.1088/1757-899X/963/1/012027/pdf

[11] energie-experten.org, *Wärmetauscher-Arten & Typen im Überblick.* https://www.energie-experten.org/heizung/heizungstechnik/waermetauscher#c33601 (Aufgerufen 27. März 2024).

[12] R. Cheaytani, „Die Wahl des richtigen Wärmetauschers“, *VirtualExpo Group*, 2019, 2019. https://guide.directindustry.com/de/die-wahl-des-richtigen-waermetauschers/. (Aufgerufen: 27. März 2024).

[13] M. Dehli, *Energieeffizienz in Industrie, Dienstleistung und Gewerbe*. Wiesbaden: Springer Fachmedien Wiesbaden, 2020.

[14] Ashrae, Hg., „2021 Equipment Thermal Guidelines for Data Processing Environments: ASHRAE TC 9.9 Reference Card“, 2021. https://www.ashrae.org/file%20library/technical%20resources/bookstore/supplemental%20files/referencecard_2021thermalguidelines.pdf. (Aufgerufen: 20. Februar 2023).

[15] K. Ebrahimi, G. F. Jones und A. S. Fleischer, „A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities“, *Renewable and Sustainable Energy Reviews*, Jg. 31, S. 622–638, 2014, doi: 10.1016/j.rser.2013.12.007.

[18] L. Brochard, V. Kamath, J. Corbalán, S. Holland, W. Mittelbach und M. Ott, „Cooling the Data Center“ in *Energy-Efficient Computing and Data Centers*, L. Brochard et al., Hg., Newark: John Wiley & Sons Incorporated, 2019, S. 37–63.

[21] R. P. Sarode und P. Wankhade, „Waste Heat Recovery using the Plate Heat Exchanger“, *International Journal for Scientific Research & Development*, 2020. [Online]. Verfügbar unter: https://www.researchgate.net/publication/343650069_Waste_Heat_Recovery_using_the_Plate_Heat_Exchanger

[22] I. A. Fetuga, O. T. Olakoyejo, S. M. Abolarin, J. K. Gbegudu, A. Onwuegbusi und A. O. Adelaja, „Numerical analysis of thermal performance of waste heat recovery shell and tube heat exchangers on counter-flow with different tube configurations“, *Alexandria Engineering Journal*, Jg. 64, S. 859–875, 2023, doi: 10.1016/j.aej.2022.09.017.

[24] D. Harman, „Waste Heat Recovery In Data Centers: Ejector Heat Pump Analysis“. Masterarbeit, Georgia Institute of Technology, 2008. [Online]. Verfügbar unter: https://repository.gatech.edu/server/api/core/bitstreams/cb1bf575-6cd1-4af0-92f0-8ae5990b7584/content

[25] X. Yuan, Y. Liang, X. Hu, Y. Xu, Y. Chen und R. Kosonen, „Waste heat recoveries in data centers: A review", *Renewable and Sustainable Energy Reviews*, Jg. 188, S. 113777, 2023, doi: 10.1016/j.rser.2023.113777.

[26] Smart Cities Information System, „Heat Pump Driven District Heating Systems Solution Booklet", 2019. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_heat_pump_driven_district_heating_systems.pdf. (Aufgerufen: 8. April 2024).

[27] H. Jouhara, N. Khordehgah, S. Almahmoud, B. Delpech, A. Chauhan und S. A. Tassou, „Waste heat recovery technologies and applications", *Thermal Science and Engineering Progress*, Jg. 6, S. 268–289, 2018, doi: 10.1016/j.tsep.2018.04.017.

[28] T. Funke *et al.*, „Utilization of Waste Heat in the Data Center: A white paper by NeRZ in collaboration with eco – Association of the Internet Industry", Berlin, Köln, 2019. https://international.eco.de/topics/datacenter/white-paper-utilization-of-waste-heat-in-the-data-center/. (Aufgerufen: 9. April 2024).

[29] Agora Energiewende und Fraunhofer IEG, Hg., „Roll-out von Großwärmepumpen in Deutschland. Strategien für den Markthochlauf in Wärmenetzen und Industrie.", 2023. https://www.ieg.fraunhofer.de/content/dam/ieg/deutsch/dokumente/ver%C3%B6ffentlichungen/Rollout_Grosswaermepumpen_Angora_Fraunhofer%20IEG.pdf. (Aufgerufen: 19. März 2024).

[30] D. Hochwarth, „Fernwärme: Größte Wärmepumpe der Welt heizt 100.000 Dänen ein", *ingenieur.de - Jobbörse und Nachrichtenportal für Ingenieure*, 19. Juni 2023, 2023. https://www.ingenieur.de/technik/fachbereiche/energie/fernwaerme-groesste-waermepumpe-der-welt-heizt-100-000-daenen-ein/. (Aufgerufen: 1. April 2024).

[32] C. Montagud-Montalvá, E. Navarro-Peris, T. Gómez-Navarro, X. Masip-Sanchis und C. Prades-Gil, „Recovery of waste heat from data centres for decarbonisation of university campuses in a Mediterranean climate", *Energy Conversion and Management*, Jg. 290, S. 117212, 2023, doi: 10.1016/j.enconman.2023.117212.

[33] M. Deymi-Dashtebayaz und S. Valipour-Namanlo, „Thermoeconomic and environmental feasibility of waste heat recovery of a data center using air source heat pump", *Journal of Cleaner Production*, Jg. 219, S. 117–126, 2019, doi: 10.1016/j.jclepro.2019.02.061.

[34] R. Nandhini, B. Sivaprakash und N. Rajamohan, „Waste heat recovery at low temperature from heat pumps, power cycles and integrated systems – Review on system performance and environmental perspectives", *Sustainable Energy Technologies and Assessments*, Jg. 52, S. 102214, 2022, doi: 10.1016/j.seta.2022.102214.

[35] Y. Jang, D. Lee, J. Kim, S. H. Ham und Y. Kim, „Performance characteristics of a waste-heat recovery water-source heat pump system designed for data centers and residential area in the heating dominated region", *Journal of Building Engineering*, Jg. 62, S. 105416, 2022, doi: 10.1016/j.jobe.2022.105416.

[36] Robert Bosch GmbH, *Brine, air, water: Heat pump technology explained.* https://www.bosch-presse.de/pressportal/de/en/brine-air-water-heat-pump-technology-explained-259638.html (Aufgerufen 9. April 2024).

[37] J. F. Urchueguía, M. Zacarés, J. M. Corberán, Á. Montero, J. Martos und H. Witte, „Comparison between the energy performance of a ground coupled water to water heat pump system and an air to water heat pump system for heating and cooling in typical conditions of the European Mediterranean coast", *Energy Conversion and Management*, Jg. 49, Nr. 10, S. 2917–2923, 2008, doi: 10.1016/j.enconman.2008.03.001.

[40] E. Hervás-Blasco, E. Navarro-Peris, F. Barceló-Ruescas und J. M. Corberán, „Improved water to water heat pump design for low-temperature waste heat recovery based on subcooling control", *International Journal of Refrigeration*, Jg. 106, S. 374–383, 2019, doi: 10.1016/j.ijrefrig.2019.06.030.

[41] K. Hamid *et al.*, „Potential evaluation of integrated high temperature heat pumps: A review of recent advances", *Applied Thermal Engineering*, Jg. 230, S. 120720, 2023, doi: 10.1016/j.applthermaleng.2023.120720.

[42] C. Arpagaus, „From Waste Heat to Cheese", 2019. https://waermepumpe-izw.de/wp-content/uploads/2020/05/190800-Arpaguas-HPT-Magazine-2-2019.pdf. (Aufgerufen: 9. April 2024).

[43] J. Jerez Monsalves, C. Bergaentzlé und D. Keles, „Impacts of flexible-cooling and waste-heat recovery from data centres on energy systems: A Danish case study", *Energy*, Jg. 281, S. 128112, 2023, doi: 10.1016/j.energy.2023.128112.

[44] S. Ortner *et al.*, „Analyse des wirtschaftlichen Potenzials für eine effiziente Wärme- und Kälteversorgung: Beitrag zur Berichtspflicht EnEff-RL, Artikel 14 Anhang VIII", Dessau-Roßlau, 2021. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2021-08-05_cc_54-2021_effiziente_waerme-kaelteversorgung.pdf. (Aufgerufen: 28. Februar 2023).

[47] J. Stenea, G. Eggena, O. Ø. Smedegårda, K. Vagnildhauga und E. Selvåg, „Combined Liquid Chiller and Heat Pump Systems for Data Centre Cooling with High-Temperature Heat Recovery“, 2017. https://etkhpcorderapi.extweb.sp.se/api/file/1592. (Aufgerufen: 22. Oktober 2023).
[48] R. N. Avery, C. Booth, W. Livingston und W. Lopp, “Utilization Of Data Center Waste Heat For Heat Driven Engine,” US 8,522,569 B2.
[49] A. Haywood, J. Sherbeck, P. Phelan, G. Varsamopoulos und S. K. Gupta, „Thermodynamic feasibility of harvesting data center waste heat to drive an absorption chiller“, *Energy Conversion and Management*, Jg. 58, S. 26–34, 2012, doi: 10.1016/j.enconman.2011.12.017.
[50] Trane Klima- und Kältetechnisches Büro GmbH, *Kältemaschinen: von 15 – 15.000 kW zur Deckung des Kühlbedarfs*. https://trane-roggenkamp.de/kaeltemaschinen.html#:~:text=von%2015%20%E2%80%93%2015.000%20kW%20zur%20Deckung%20des%20K%C3%BChlbedarfs&text=Wir%20bieten%20Ihnen%20luft%2D%20und,wir%20Ihr%20Ansprechpartner%20in%20Bayern. (Aufgerufen 10. April 2024).
[51] D. Schmidt, C. Goetschkes und C. Pollerberg, „Kältetechnik in Deutschland: Steckbriefe zu Kältetechnologien“, Oberhausen, 2020. https://www.umsicht.fraunhofer.de/content/dam/umsicht/de/dokumente/referenzen/flexkaelte/K%C3%A4ltetechnik_in_Deutschland-Steckbriefe_zu_K%C3%A4ltetechnologien.pdf. (Aufgerufen: 10. April 2024).
[54] R. Sweetser, „Develop & Demonstrate an Advanced Low Temperature Absorption Chiller Module“, 2011. https://www.energy.gov/eere/amo/articles/advanced-low-temperature-absorption-chiller-module-integrated-chp-system. (Aufgerufen: 9. April 2024).
[55] L. Amiri, E. Madadian, N. Bahrani und S. A. Ghoreishi-Madiseh, „Techno-Economic Analysis of Waste Heat Utilization in Data Centers: Application of Absorption Chiller Systems“, *Energies*, Jg. 14, Nr. 9, S. 2433, 2021, doi: 10.3390/en14092433.
[57] R. Gupta und I. K. Puri, „Waste heat recovery in a data center with an adsorption chiller: Technical and economic analysis“, *Energy Conversion and Management*, Jg. 245, S. 114576, 2021, doi: 10.1016/j.enconman.2021.114576.
[58] P. Ruch *et al.*, „Sustainable data centers and energy conversion technologies“, 2017. https://etkhpcorderapi.extweb.sp.se/api/file/1655. (Aufgerufen: 24. Oktober 2023).
[59] F. Flohr, „D4.1 Thermophysikalische Stoffwerte gebräuchlicher Kältemittel“ in *Springer Reference Technik, VDI-Wärmeatlas*, P. Stephan et al., Hg., Berlin, Heidelberg: Springer Berlin Heidelberg, 2019, S. 511–530, doi: 10.1007/978-3-662-52989-8_22.
[60] Umweltbundesamt, *EU-Verordnung über fluorierte Treibhausgase*. https://www.umweltbundesamt.de/themen/klima-energie/fluorierte-treibhausgase-fckw/rechtliche-regelungen/eu-verordnung-ueber-fluorierte-treibhausgase#aktuelles (Aufgerufen 15. April 2024).
[61] Umweltbundesamt, *Kältemittel*. https://www.umweltbundesamt.de/themen/klima-energie/fluorierte-treibhausgase-fckw/natuerliche-kaeltemittel-in-stationaeren-anlagen/kaeltemittel-start#das-richtige-kaltemittel-ist-klimafreundlich (Aufgerufen 15. April 2024).
[63] Umweltbundesamt, *Wärmepumpen*. https://www.umweltbundesamt.de/themen/klima-energie/fluorierte-treibhausgase-fckw/natuerliche-kaeltemittel-in-stationaeren-anlagen/anwendungen/waermepumpen (Aufgerufen 15. April 2024).
[65] M. Wahlroos, M. Pärssinen, J. Manner und S. Syri, „Utilizing data center waste heat in district heating – Impacts on energy efficiency and prospects for low-temperature district heating networks“, *Energy*, Jg. 140, S. 1228–1238, 2017, doi: 10.1016/j.energy.2017.08.078.
[66] P. Huang *et al.*, „A review of data centers as prosumers in district energy systems: Renewable energy integration and waste heat reuse for district heating“, *Applied Energy*, Jg. 258, S. 114109, 2020, doi: 10.1016/j.apenergy.2019.114109.
[67] Z. He, T. Ding, Y. Liu und Z. Li, „Analysis of a district heating system using waste heat in a distributed cooling data center“, *Applied Thermal Engineering*, Jg. 141, S. 1131–1140, 2018, doi: 10.1016/j.applthermaleng.2018.06.036.
[68] E. Oró, P. Taddeo und J. Salom, „Waste heat recovery from urban air cooled data centres to increase energy efficiency of district heating networks“, *Sustainable Cities and Society*, Jg. 45, S. 522–542, 2019, doi: 10.1016/j.scs.2018.12.012.
[70] Danfoss, *Different generations of DHC*. https://www.danfoss.com/en/about-danfoss/articles/dhs/district-energy-generations-explained/ (Aufgerufen 15. November 2023).
[71] J. E. Thorsen, O. Gudmundsson und M. Brand, „Distribution of district heating: 1st Generation“, 2020. https://assets.danfoss.com/documents/57292/BE346042889071en-010101.pdf. (Aufgerufen: 10. November 2023).

[72] J. E. Thorsen, O. Gudmundsson, M. Brand und A. Dyrelund, „Distribution of district heating: 2nd Generation", 2020. https://assets.danfoss.com/documents/57294/BE343939708434en-010101.pdf. (Aufgerufen: 10. November 2023).
[73] J. E. Thorsen, O. Gudmundsson, M. Brand und A. Dyrelund, „Distribution of district heating: 3rd Generation", 2020. https://assets.danfoss.com/documents/57302/BE346234898141en-010101.pdf. (Aufgerufen: 10. November 2023).
[74] J. E. Thorsen, O. Gudmundsson, M. Brand und A. Dyrelund, „Distribution of district heating: 4th Generation", 2020. https://assets.danfoss.com/documents/57293/BE343939535432en-010101.pdf. (Aufgerufen: 10. November 2023).
[75] Danfoss, *Comparison of 4th vs. 5th generation district heating.* https://infogram.com/1prdyye0n03yn0cg2xyjjlg1x5um7r1we2j?live (Aufgerufen 10. November 2023).
[76] H. Lund *et al.*, „Perspectives on fourth and fifth generation district heating", *Energy*, Jg. 227, S. 120520, 2021, doi: 10.1016/j.energy.2021.120520.
[77] V. Mikler, „District Energy 101", 2017. https://www.integralgroup.com/wp-content/uploads/2017/06/IntegralGroup_District-Energy-101.pdf. (Aufgerufen: 16. November 2023).

Image sources

[1] B. Ott, „Schematische Darstellung eines möglichen Kühlungssystems für ein Rechenzentrum: Eigene Darstellung", Stuttgart, 2024.
[5] B. Ott, „Schematische Darstellung der möglichen Abwärmeauskopplungsoptionen eines Rechenzentrums anhand des Kühlungssystems: Eigene Darstellung", Stuttgart, 2024.
[6] B. Ott, „Schematische Darstellung eines Wärmeübertragers: Eigene Darstellung", Stuttgart, 2024.
[16] B. Ott, „Schematische Darstellung eines Serverschranks mit einer gekühlten Rückwand: Eigene Darstellung", Stuttgart, 2024.
[17] B. Ott, „Schematische Darstellung einer direkten Flüssigkeitskühlung mit Kühlplatten: Eigene Darstellung", Stuttgart, 2024.
[19] B. Ott, „Schematische Darstellung der ein- und zweiphasige Immersionskühlung: Eigene Darstellung", Stuttgart, 2024.
[20] Alfa Laval, *Wärmetauscher*.
[23] Oschner, *Großwärmepumpen: Wärmepumpen für die Industrie Industriewärmepumpen für große Leistungen.* https://www.ochsner.com/de-de/ochsner-produkte/waermepumpen-fuer-grosse-leistungen/ (Aufgerufen 9. April 2024).
[31] Daikin, *Multisplit-Klimaanlage.* https://www.daikin.at/de_at/produktgruppen/luft-luft-waermepumpe/multisplit.html (Aufgerufen 8. April 2024).
[38] Vaillant, *Luft/Wasser-Wärmepumpe aroTHERM plus.* https://www.vaillant.de/heizung/produkte/luft-wasser-warmepumpe-arotherm-plus-194816.html (Aufgerufen 11. März 2024).
[39] Combitherm, *Wärmepumpen.* https://www.combitherm.de/produkte-und-loesungen/waermepumpen/ (Aufgerufen 11. März 2024).
[45] Combitherm, *Hochtemperatur-Wärmepumpen* (Aufgerufen 11. März 2024).
[46] MTA, *Kältemaschine wassergekühlt.* https://www.mta.de/anwendungen/prozesskuehlung/kaltwassersatz-wassergekuehlt/aquarius-g-456-1934-kw/ (Aufgerufen 11. März 2024).
[52] ENGIE Refrigeration, *QUANTUM-Air-Kältemaschinen.* https://www.engie-refrigeration.de/de/kaelte/quantum-air-kaeltemaschinen (Aufgerufen 15. April 2024).
[53] Hitachi, *CGN/CW Series.* https://www.hitachiaircon.com/ranges/chillers/waste-heat-absorption-chiller-gene-link (Aufgerufen 10. Oktober 2023).
[56] Fahrenheit GmbH. Mail, 2024.
[62] Flaticon.com, *Kältemittel.* https://www.flaticon.com/de/kostenloses-icon/kaltemittel_5098190 (Aufgerufen 15. April 2024).
[64] HeatNet NWE, *Examples of heat supply and demand in North-West Europe.* https://guidetodistrictheating.eu/wp-content/uploads/2020/01/HeatNet-NWE_Examples-of-heat-supply-and-demand-in-North-West-EU_Web.jpg (Aufgerufen 3. Mai 2024).
[69] Andol und Mrmw, *Generations of district heating systems.* https://de.m.wikipedia.org/wiki/Datei:Generations_of_district_heating_systems_EN.svg (Aufgerufen 3. Mai 2024).

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