Open Compute Project

# Reference Designs for Data Center Heat Reuse

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# Copyright info

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## 1. Executive summary

This paper provides reference designs for implementing data center heat reuse systems.

It starts with a business section introducing the different integrations of the heat reuse business into the data center operations. Key stakeholders are identified, emphasizing the importance of collaboration in driving these initiatives forward.

On the technical side, the design of a heat recovery station is discussed, covering critical components, connections, and infrastructure needs - such as power, network, cooling, and security. Special attention is given to the design of loops and cascading systems, as well as retrofitting existing data centers for heat reuse.

The paper addresses challenges of matching heating demand, including seasonality and intraday variations, with technical features that could be considered to cope with these variations. Heat storage solutions and boosting mechanisms, such as heat pumps and boilers, are reviewed. The possibility of converting heat to cooling or power are also covered. The final sections identify key performance metrics and how heat reuse systems could impact them.

In summary, this paper provides a roadmap for organizations looking to implement data center heat reuse, providing technical details needed for it as well as some business considerations. It offers practical insights and strategies for deploying heat reuse systems: improving energy efficiency, while reducing waste, and contributing to broader sustainability goals with intersectoral coupling.

The purpose of the Heat Reuse Reference Design Workstream is to define a set of common features of the basic technical room in a data center for heat reuse purposes and create guidance that engineers, architects and decision-makers might need when designing and developing a data center that facilitates the recovery of excess heat. Topics include:

- Design considerations
    - Components – list of essential hardware
    - Sizing – for allocating space in facility
    - Demarcation point – data center vs heat host considerations
    - Sample drawings, sketches, single-line diagrams
- Other topics
    - Definition of different scenarios at both sides of the demarcation point
    - Business considerations, stakeholders
    - Metrics

## 2. Compliance with OCP Tennets

### Openness

*This document is intended for widespread public use by any person interested in data centers and the reuse of their heat. Its target audience is data center designers looking to evaluate the technical parameters behind a heat reuse project.*

### Efficiency

*Reuse of data center heat not only makes data centers more efficient, but also makes off-takers who use the heat cleaner and more efficient. This white paper objective is to help data center designers to better understand how to reach heat reuse integration potential and what it means from a technical point of view.*

### Impact

*This white paper should be used as a way of self-assessing the design of a data center heat reuse project. The intention is to facilitate developers to close knowledge gaps to make heat reuse projects possible. The knowledge gap has been identified as one of the main barriers so far.*

### Scale

*Project success experiences, especially in Europe, demonstrate data center heat reuse is viable. This white paper shows how a single data center can integrate any small excess heat into a heat reuse project, but also shows how this concept can be scaled up for larger data centers.*

### Sustainability

*Data center heat reuse improves the sustainability of both data centers and end users of data center heat. For data centers, reusing their heat means reducing the amount of electricity needed for cooling and the Scope 2 emissions that may be associated with it. For heat off-takers, data center heat reduces their greenhouse gas emissions because they can replace the use of fossil fuels to produce heat with much cleaner heat. Data center heat reuse may also achieve other sustainability goals such as reduced water use.*

## 3. Introduction

Almost 100% of the energy used by servers in a data center is turned into heat. Heat reuse is defined as the beneficial use of any recovered heat from the data center. To make a data center heat reuse project possible we need a combination of the following (credit: *Data Centers Heat Reuse 101*):

1. A heat host (also referred to as the heat end user, heat offtaker, heat receiver, or heat consumer) nearby the data center area, possibly adjacent to it. If this is not the case, the collaboration of a utility will be needed as medium (or as heat host itself).
2. A temperature level that is interesting for the heat host: optimally the heat will be directly used without transformations.
3. Ideally the heat host and the data center have the same ownership structure; if not, then different entities must be willing to collaborate.
4. Finally, a legislative structure that encourages collaboration.

This paper is part of a series of white papers that the Open Compute Project Foundation Heat Reuse group is publishing. The first white paper, *Data Centers Heat Reuse 101* was published June 2023 and describes why now is the time for heat reuse and what is needed for wide-scale adoption to turn heat from a liability into an asset that potentially can be a source of income and assist in meeting sustainability goals. This paper focuses on reference designs, with a mission to define the basic technical room in a data center for heat reuse purposes. Material has been elaborated based on community-driven input during our monthly Heat Reuse Reference Design Workstream calls.

An important companion document is the *Data Center Liquid Distribution Guidance & Reference Designs* white paper (Revision 1.0 or higher), written by the OCP Advanced Cooling Facilities (ACF) subproject. It provides excellent guidance in the following areas of planning:

- Piping System considerations - sizing estimates for flow rates & velocities, pressure drops, routing, connection methodology, materials of construction
- Reference Design Development - use of building information modeling (BIM) content (including piping system, components, and ITE) to develop planning layout documents
- Cooling loop temperature control, isolation strategies and Thermal Ride Through
- Service Level Agreement (SLA) considerations
- Balancing cost and risk via design consideration, commissioning, and procedures

The Heat Reuse group will be releasing other white papers that focus on the economics and policies around heat reuse. The *Policies to Accelerate Data Center Heat Reuse: Achieving Economic and Climate Change Goals* white paper (Revision 1.0 or higher) provides a nice overview of heat reuse opportunities, along with key challenges, and helpful policies to encourage data center heat reuse.

The Open Compute Project Foundation is an open forum, so please join our regular conversations about heat reuse and share your thoughts, insights, and experiences with the community, start with the following link:

https://www.opencompute.org/projects/heat-reuse

# 4. Business considerations

## Stakeholders

The Net Zero Innovation Hub for Data Centers (referred to as NZIH in this document) put together the Stakeholder matrix map shown in Figure 1. It defines interphase nomenclature spanning from the data center to heat transmission to heat end user, and various stakeholder owners that will likely be involved. Suggested approach is to focus on data center heat distribution, heat recovery station, heat transmission, and heat delivery station areas first.

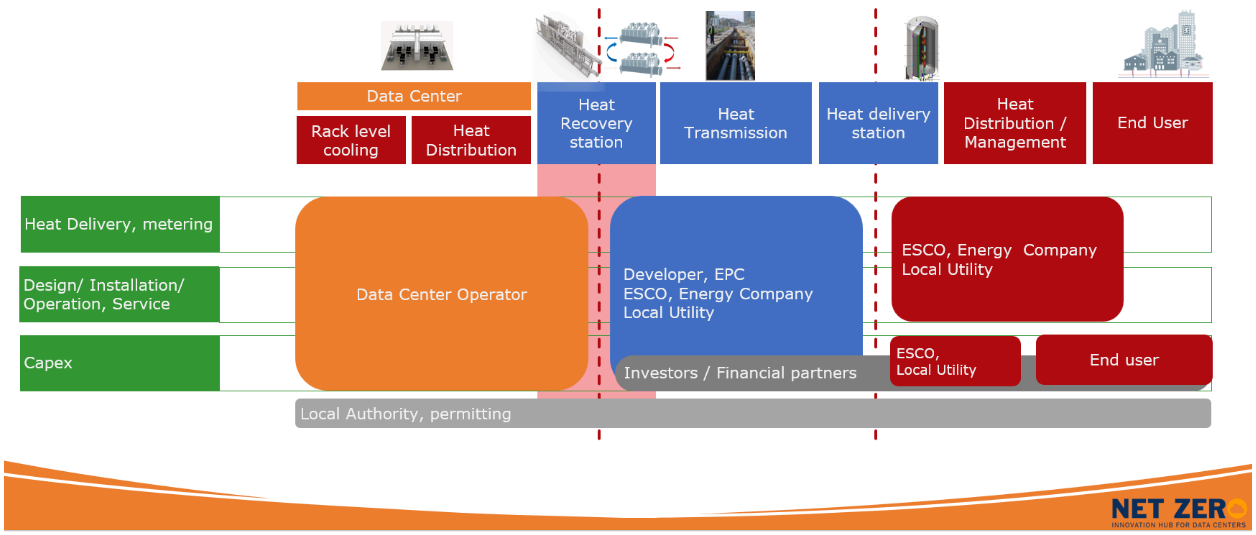


Figure 1 – Stakeholder matrix map (Credit: NZIH)

Note that excess heat is not exclusive to data centers. Other industries have an established track record reusing excess heat that might be of very high quality. Data center excess heat can be >45°C in some cases but in general it will achieve 25°C to 40°C, depending on the IT equipment used and the cooling technology among other factors. There are a variety of applications that can use these heat levels:

- Applications using >45 °C: power-to-X, biogas upgrade plant, district heating return, very high temperature air process
- Applications using 20-45 °C include: open loop geothermal, hydronic process cooling, hydronic process rejection, facility cooling, biogas slurry, high temperature air process, subway exhaust recovery

- Applications using <20 ºC include: wastewater, seawater, recirculation aquaculture, medium temperature air process, medium temperature refrigeration

## Data center heat reuse maturity model

A so-called “maturity model” has been proposed to set the demarcation points according to the involvement of the data center into the business of the delivery of heat. The more involved a data center is into the business of the delivery of the heat, the higher is the maturity of the data center in that business. This should take into account the data center proximity to the offtaker, as well as their maturity level and application. The following table (Table 1) illustrates this concept:

Table 1 – Data Center Heat Reuse Maturity model (Credit: Lex Coors - Digital Realty)

| **Energy reuse maturity model** | **Maturity level 0** | **Maturity level 1** | **Maturity level 2** | **Maturity level 3** | **Maturity level 4** | **Maturity level 5 (disruption B to C)** | **Maturity level 6 (disruption B to C)** |
|---|---|---|---|---|---|---|---|
| **what** | Own usage of the excess heat | Tap off from chilled water or Heat exchanger | Heat pumps inside the data center. | Heat pumps inside the data center | Data center as part of the community heat pumps inside data center | Data center owns the whole cycle from production to delivery Business to Consumer | A large data center community (data center aggregation) under a Mankala model - to avoid kartel - own the whole cycle from production to delivery Business to Consumer |
| **who** | The data center operator | From this point take over by the heat re- use party for direct use or temperature increase | A separate new entity is set by the data center to own the heat pumps and for the re-use party to tap off | Owned by data center operator | Owned by data center operator | Owned by data center operator | Owned by data center operators |
| **heat delivery temperature** | Roughly 30 C of supply water | Roughly 30 C of supply water | 30 C to 70C of supply water | 30 C to 100 C or above | 30 C to 100 C or above | 30C to 100 C or above | 30C to 100 C or above |
| **cost and opportunity** | Heat recovery station materials (piping, valves, controls, heat exchanger, etc.) cost | Heat recovery station materials (piping, valves, controls, heat exchanger, etc.) cost | Heat recovery station materials, any machinery needed to store or transform the heat (higher temperatures, into cooling, etc.). Selling heat to heat offtaker | Heat recovery station materials, any machinery needed to store or transform the heat (higher temperatures, into cooling, etc.). Selling heat to heat offtaker | Heat recovery station materials, any machinery needed to store or transform the heat (higher temperatures, into cooling, etc.). Selling heat to heat offtaker | Heat recovery station materials, any machinery needed to store or transform the heat (higher temperatures, into cooling, etc.). Selling heat to heat offtaker | Heat recovery station materials, any machinery needed to store or transform the heat (higher temperatures, into cooling, etc.). Selling heat to heat offtaker |
| **remarks** | Basic scenario, a "must" for increasing the energy efficiency of the whole data center (heating data rooms, equipment, | Easy, no further impact as all further cost are taken by the re-use party to build the required piping systems, heat pumps and pumping stations | New entity is needed to avoid that the heat pump is owned by operator, increasing the energy needs of the data center and hence its PUE | Cost could involve all piping to the offtakers but, this part can also be taken by them | Cost could involve all piping to offtakers but, this part can also be taken by them | All cost and risk at the operator's side | All cost and risk at the operator's side |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | but also offices, etc.) | | | | | | |

While the primary focus of this document is on the considerations at a data center level to facilitate a heat reuse project, the emphasis of this document is on Maturity level 0 and level 1, to make data center owner/operators aware of the opportunities for heat reuse, and encourage planning for it when designing facilities or updating existing sites. Certainly, any maturity level scenario can be considered; the particularities belonging to scenario 2 and above may require a separate dedicated focus and might be the basis of further work.

The first Maturity levels (level 0), having an in-house usage of the excess heat, seems to be a must in all modern data centers. The recirculation of heat from the cooling system is a common practice in heating, ventilation, and air conditioning (HVAC) systems. The recirculation of excess heat is employed for mixing, in case outdoor temperatures are too low for the ITE, but, in general, the excess heat will be used for non-IT elements in the data center building. A diversion of the excess heat to warm own-controlled spaces, equipment, and nearby white spaces, seems an easy step to start with, without the need to involve external stakeholders and with a potentially low CAPEX impact in the project. The operational savings can be significant. An example of internal usage of the excess heat for the ITE HVAC process is the use of liquid-cooled ITE excess heat to generate cooling power with an absorption refrigeration machine, to cool air-cooled ITE. For more information about this, see the sections below on "Heat to Cooling".

For higher Maturity levels, examples of installations beyond the data room matching the heating demand of heat end users are listed and evaluated in the section below "Matching of the heating demand".

# 5. Design considerations

## General design of the heat recovery station

The essential hardware to transfer heat from the data center to a heat host is a heat exchanger along with associated plumbing to make the connections between the two locations. Metering, valves, and actuators allow for automated controls. The *Data Center Liquid Distribution Guidance & Reference Designs* white paper had a figure showing a concept design for an elevated temperature loop operating with immersion cooling and no chiller plant. Figure 2 and Figure 3 show the modified concepts that add a heat exchanger for heat reuse. Table 2 introduces the different scenarios.

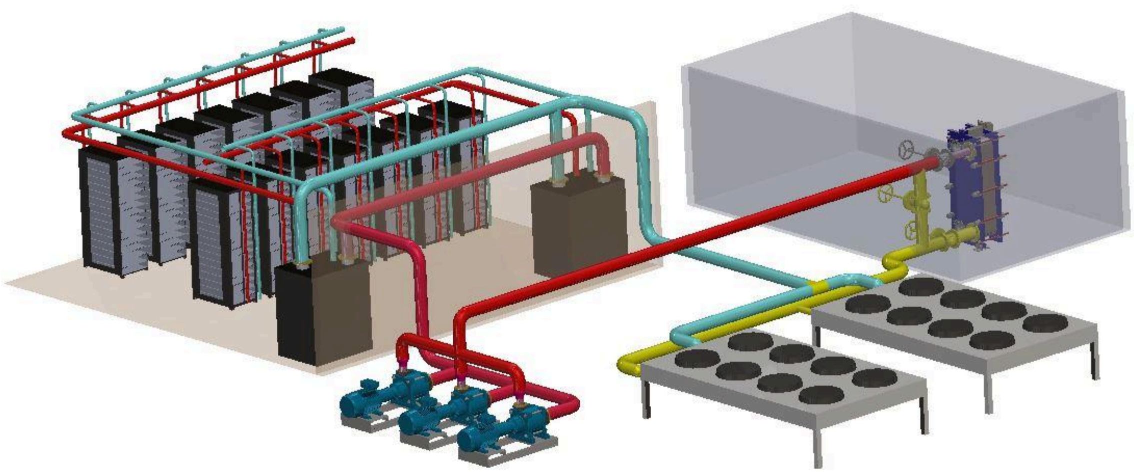

Figure 2 – Scenario 2A: modified concept design of direct-to-chip cooling example with no chiller plant to add heat exchanger for heat reuse (Credit: Binghamton University)

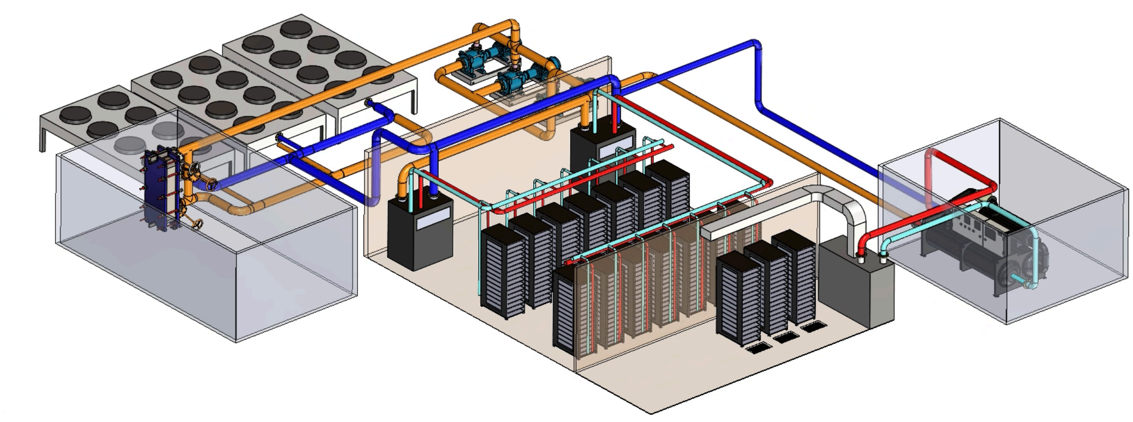

Figure 3 – Scenario 2A: modified concept design of direct-to-chip cooling example with a chiller plant to for heat reuse (Credit: Binghamton University)

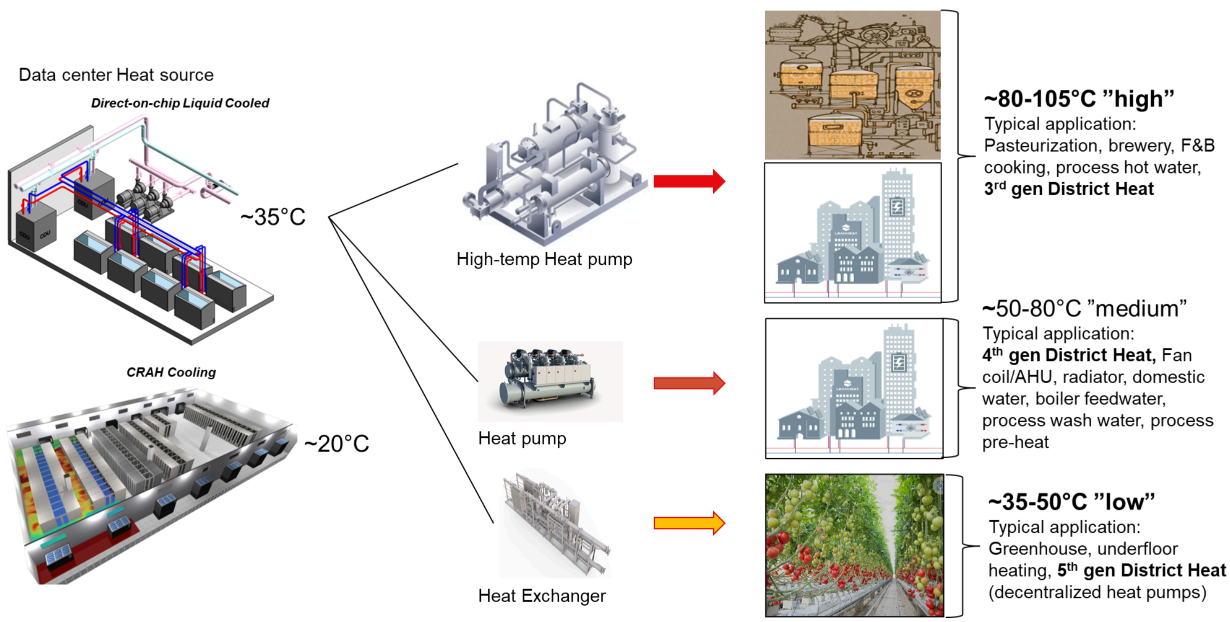


Figure 4 – Heat reuse categories overview (Credit: NZIH)

Table 2 - Scenario combinations

| Scenario | ITE cooling | Facility supply-return temperatures | Heat Storage | Boosting mechanisms |
|---|---|---|---|---|
| 1a | Air cooling (chillers + CRAHs / Fanwalls / RDHx or similar + cooling towers) | supply: 10-20<br>return: 20-30 | No | No |
| 1b | | | Yes | No |
| 1c | | | No | Heat pump |
| 1d | | | Yes | Heat pump |
| 2a | Moderate Temperature Liquid cooling (chillers + D2Chip / Immersion + cooling towers/ dry-coolers) | **supply: 20-30**<br>**return: 30-40** | No | No |
| 2b | | | Yes | No |
| 2c | | | No | Heat pump |
| 2d | | | Yes | Heat pump |
| 3a | High Temperature Liquid cooling, 1-phase or 2-phase (D2Chip / Immersion + cooling towers/ dry-coolers) | **supply: 30-40+**<br>**return: 40-55+** | No | No |
| 3b | | | Yes | No |
| 3c | | | No | Heat pump |
| 3d | | | Yes | Heat pump |

Three base scenarios have been defined based on the cooling method of the ITE:

- **Air cooling (chillers + CRAHs / Fanwalls / RDHx or similar + cooling towers)**: ITE is air cooled but the extracted heat is forced into a liquid. Return temperatures generally will not exceed 30ºC. This base scenario provides the lowest level of temperature for heat offtakers and it is still the most common one. A heat pump integration for this scenario might be, not only beneficial, but highly recommended to enlarge the possibilities of matching with a heat offtaker. Storage could help but it is probably not a game changer. Any other mechanism transforming the heat to power or to cooling cannot be considered for this scenario as of today. Chillers are needed for this scenario, which makes heat reuse a secondary free-cooling mode. Depending on the chosen heat rejection method (dry-coolers / outdoor condensing units), the heat reuse station can be tapped-off at a different point of the cooling system, but generally bypassing the heat rejection loop.

- **Moderate Temperature Liquid cooling (chillers + D2Chip / Immersion + cooling towers/ dry-coolers)**: ITE is cooled with liquid or with a mix of liquid and vapor. Return temperatures will not be generally above 40ºC. This base scenario provides a middle level of temperature for heat offtakers and it is becoming more common for high-density computing. A heat pump integration for this scenario might be beneficial, and recommended to enlarge the possibilities of matching with a heat offtaker. Storage can help buffer differences between the heat supplier and consumer. Any other mechanism transforming the heat to power or to cooling could be considered for this scenario as of today. Chillers are needed for this scenario, which makes heat reuse a secondary free-cooling mode. Depending on the chosen heat rejection method (dry-coolers / outdoor condensing units), the heat reuse station can be tapped-off at a different point of the cooling system, but generally bypassing the heat rejection loop.

- **High Temperature Liquid cooling, 1-phase or 2-phase (D2Chip / Immersion + cooling towers/ dry-coolers)**: ITE is cooled with liquid or with a mix of liquid and vapor. Return temperatures will be above 40ºC and in some cases reach 65ºC. This base scenario provides a high level of temperature for heat offtakers and it is becoming more common for high-density computing, although latest hardware generations often do not accept these high levels of temperatures. A heat pump integration for this scenario might be beneficial, and recommended to enlarge the possibilities of matching with a heat offtaker but might not be needed. Storage can help buffer differences between the heat supplier and consumer. Any other mechanism transforming the heat to power or to cooling can be considered for this scenario and might become very relevant in the near future. Chillers might not be needed for this scenario, but heat reuse still represents a secondary free-cooling mode. The chosen heat rejection method will probably be dry-cooler based, and the heat reuse station will be tapped-off bypassing the dry-cooler loop.

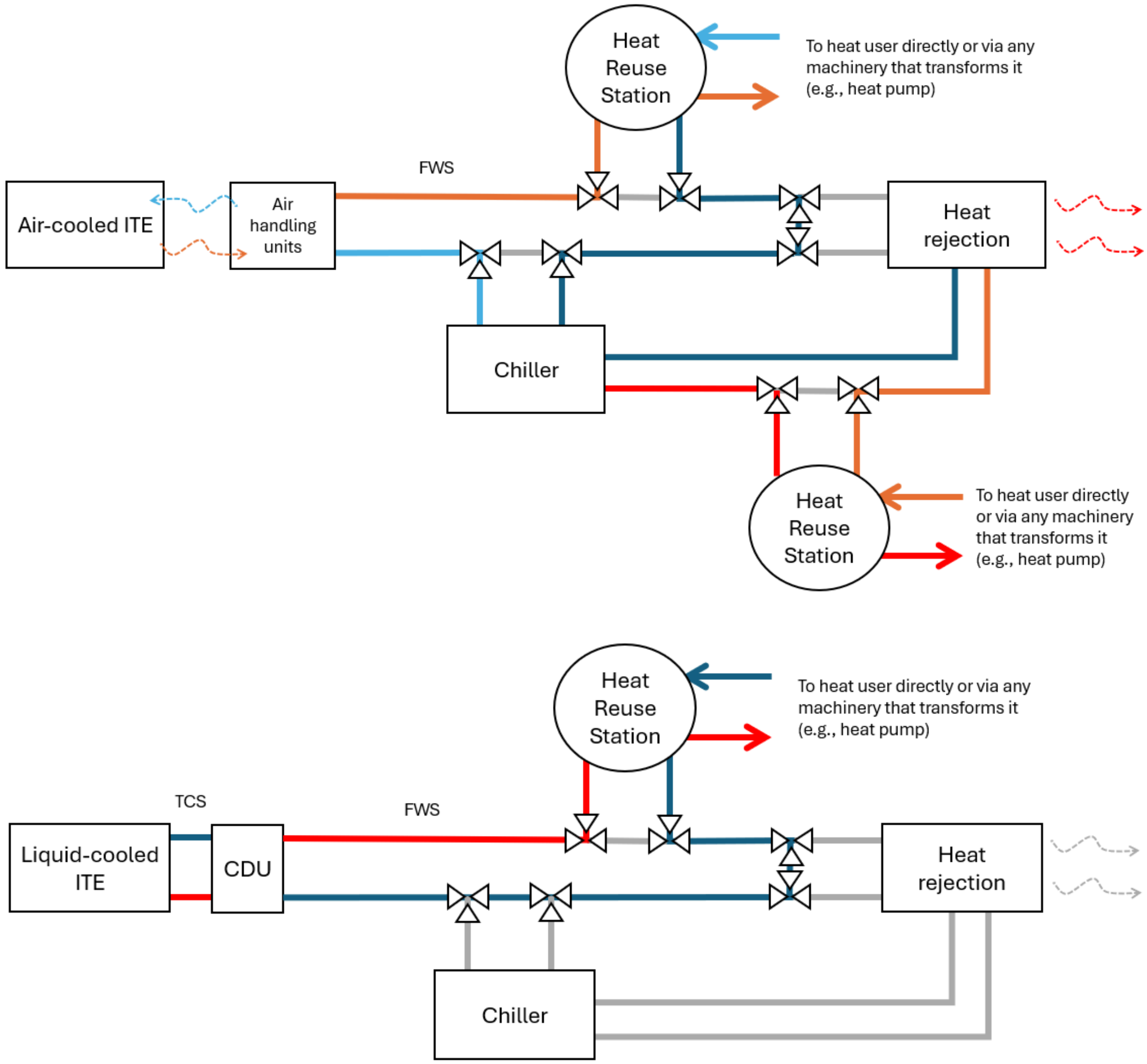


Figure 5 – Suggested schematics of the connection of a heat reuse into different cooling systems scenarios

- Other scenarios that could be considered:
    - **Direct or Indirect-air free cooling**. For these scenarios, the extraction of heat from the data center for a separate heat reuse loop can be challenging, due to the fact that the heat is not forced into a liquid loop so the handling of it, the energy conservation, the heat storage, etc. will be challenging and difficult the business case unless the boundary conditions are given (neighboring usage requiring hot air).
    - **Direct expansion (DX) cooling**: The heat from the data center is removed by

using the refrigerant vapor expansion and compressions cycles to cool air.

Figure 6 – Exemplary modular (skid-based) heat recovery station (Credit: NZIH)

Data centers are critical facilities that operate continuously. With this in mind, almost all data center designs will include heat rejection devices downstream of heat reuse to guarantee facility supply temperatures are met. It helps to think of a Hierarchy of Heat Rejection Options. In a typical data center application, the first heat rejection method utilized could be heat reuse. If there is no demand from the heat host, the next option for heat rejection could be dry coolers, utilizing cooler ambient air to remove the heat from the facility loop. If ambient conditions are not favorable to a closed-loop cooling system, this could be accomplished by an open-loop cooling tower. In a system that employs open-loop cooling towers, it is important to note that the deployment of a heat reuse rejection option upstream will result in a reduction of on-site water usage, providing additional capital and environmental benefits.

## Components and connections of the heat recovery station

The following table (Table 3) lists the types of components required in the most basic heat reuse scenario. A liquid-to-liquid heat exchanger is the most critical component to achieve any type of heat reuse, and will be present in all scenarios regardless of the temperatures on either the data center side or the heat host side. Gauges, sensors, and meters are required in the system to facilitate monitoring of how the system is operating and to track how much heat is being supplied by the data center to the heat host. Other components, such as valves and strainers, are to be utilized following mechanical design guidelines of hydronic systems to facilitate maintenance of the system and its components. A flow control actuator on the data center side would be utilized to control the flow to the heat exchanger depending on the heating demand from the heat host. The flow control actuator is controlled based on inputs from the transducers, sensors, and flow meter on the heat host side, which will determine the flow rate required to supply the heat demand from the heat host. The line diagram (Figure 7) is an example of where this equipment is located in the system.

Depending on the overall design of the facility loop, and requirements of both the data center and heat host, the bottom portion of the table lists other equipment that may be necessary. When looking at the data center side, consideration of the pressure differential of the supply and return facility water loop, in conjunction with the pressure drop of the heat reuse loop and components, is required to determine if dedicated pumps for the heat reuse loop are required. Other hydronic components, such as air separators and expansion tanks may also be required or utilized depending on overall system design.

Depending on the contract and agreement between the data center and the heat host, or application of the heat host, additional equipment is required on the heat host side of the system. Where this equipment is located and the controlling party is dictated by the previously mentioned criteria. Ideally, these hydronics components are located at the heat host facility, with ownership and operational responsibilities residing with the heat host.

Table 3 - List of essential hardware (top portion) to enable heat reuse with additional hardware (bottom portion) to consider

| Heat Reuse Room Components | |
|---|---|
| | |
| Data Center Side | Heat Host Side |
| Liquid-to-Liquid Heat Exchanger | |
| Pressure transducers (2) | Pressure transducers (2) |
| Temperature sensors (2) | Temperature sensors (2) |
| Pressure gauges (2) | Pressure gauges (2) |
| Temperature gauges (2) | Temperature gauges (2) |
| Flow meter | Flow meter |
| HX inlet strainer | HX inlet strainer |
| Shut-off valves (2) | Shut-off valves (2) |
| Flow control actuator | |
| | |
| | Flow control actuator |
| Pump(s) | Pump(s) |
| Air separator | Air separator |
| Expansion tank | Expansion tank |
| | Heat pumps (if required) |

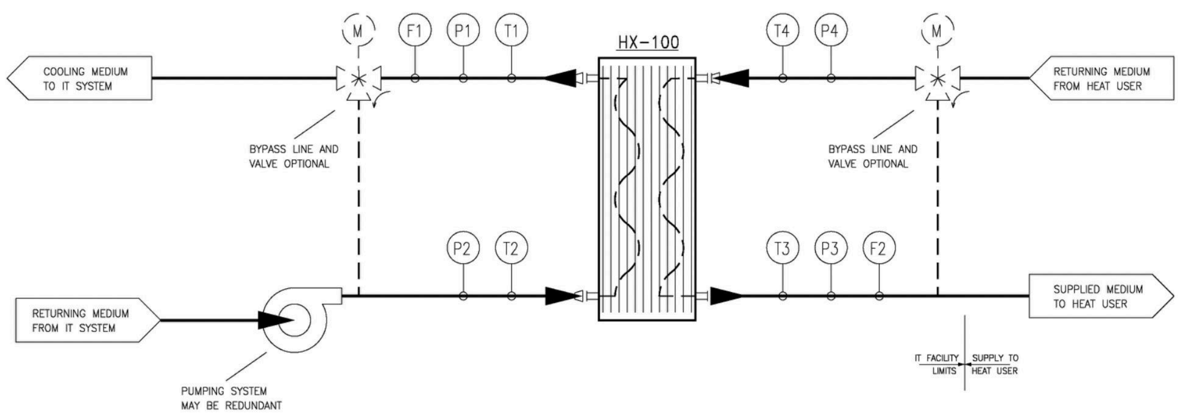


Figure 7 – Example HVAC line diagram of essential hardware

As this system will be connecting two separate entities, or companies, there must be a demarcation point. Depending on the maturity level of the data center (Data Center Heat Reuse Maturity Model section, Table 1), this point of ownership transfer can vary. Specifically looking at maturity levels 0 & 1, the demarcation point is the physical wall of the heat reuse room, with all essential equipment (Table 3) being owned and operated by the data center. This scenario allows full control over this ancillary heat rejection loop, and removes any access requirements of the heat host to the data center facility. If the heat host requires a greater temperature than the data center will provide, it would be their responsibility to procure and operate the equipment required to achieve this.

Table 4 details the space requirements to implement a heat reuse application for a variety of scenarios and capacities. The different IT supply temperatures are considered for both high and low delta applications, in a range of total data center IT capacity, to determine the dedicated space required.

General heat exchanger sizing best practices were considered, regardless of application, since the criteria can vary widely depending on many factors (geography, user, heat host, proximity, etc.). Assumptions, notes, and limits to this table include the following bullet points:

- Selection and sizing based on plate and frame heat exchanger, sized for the full capacity listed
- Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Certified unit
- HX and required clearances are the only consideration for footprint
- 10 PSI pressure drop limit through HX
- Fluid on both sides (FWS and offtaker side) is PG25%[1]
- Maximum fluid velocity in piping is limited to 2.13 m/sec
- Low delta refers to 4.4°C, high delta refers to 16.7°C

[1] Both FWS and offtaker side may be using other fluids such as treated water.

Table 4 – Sizing chart tool for allocating minimum footprint in facility to support heat reuse

| | | HOT SIDE | | | COLD SIDE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DC Load | Delta | Supply Temp to IT | Return Temp from IT | IT Flow Rate | Supply Temp to HH | Return Temp from HH | HH Flow Rate | Footprint | m² / MW | Minimum Pipe Size | HX Connections |
| (MW) | (high/low) | (°C) | (°C) | (L/s) | (°C) | (°C) | (L/s) | (m²) | (m²) | (in) | (in) |
| 1 | Low | 27.0 | 31.4 | 56.3 | 30.0 | 24.4 | 44.9 | 5.20 | 5.20 | 8 | 6 |
| 1 | Low | 40.0 | 44.4 | 56.2 | 43.3 | 37.8 | 44.8 | 5.20 | 5.20 | 8 | 6 |
| 1 | Low | 45.0 | 49.4 | 56.2 | 48.3 | 42.8 | 44.8 | 5.20 | 5.20 | 8 | 6 |
| 1 | High | 27.0 | 43.7 | 15.0 | 31.1 | 25.6 | 44.9 | 5.20 | 5.20 | 8 | 6 |
| 1 | High | 40.0 | 56.7 | 15.0 | 44.4 | 38.9 | 44.8 | 5.20 | 5.20 | 8 | 6 |
| 1 | High | 45.0 | 61.7 | 15.0 | 49.4 | 43.9 | 44.8 | 5.20 | 5.20 | 8 | 6 |
| 2 | Low | 27.0 | 31.4 | 112.5 | 30.0 | 24.4 | 89.9 | 5.85 | 2.93 | 10 | 8 |
| 2 | Low | 40.0 | 44.4 | 112.4 | 43.3 | 37.8 | 89.7 | 5.85 | 2.93 | 10 | 8 |
| 2 | Low | 45.0 | 49.4 | 112.4 | 48.3 | 42.8 | 89.7 | 5.85 | 2.93 | 10 | 8 |
| 2 | High | 27.0 | 43.7 | 30.1 | 31.1 | 25.6 | 89.8 | 5.02 | 2.51 | 10 | 8 |
| 2 | High | 40.0 | 56.7 | 30.1 | 44.4 | 38.9 | 89.7 | 5.02 | 2.51 | 10 | 8 |
| 2 | High | 45.0 | 61.7 | 30.1 | 49.4 | 43.9 | 89.7 | 5.02 | 2.51 | 10 | 8 |
| 3 | Low | 27.0 | 31.4 | 168.8 | 30.0 | 24.4 | 134.8 | 9.20 | 3.07 | 14 | 10 |
| 3 | Low | 40.0 | 44.4 | 168.6 | 43.3 | 37.8 | 134.5 | 9.20 | 3.07 | 14 | 10 |
| 3 | Low | 45.0 | 49.4 | 168.6 | 48.3 | 42.8 | 134.5 | 9.20 | 3.07 | 14 | 10 |
| 3 | High | 27.0 | 43.7 | 45.1 | 31.1 | 25.6 | 134.8 | 6.69 | 2.23 | 12 | 10 |
| 3 | High | 40.0 | 56.7 | 45.1 | 44.4 | 38.9 | 134.5 | 6.69 | 2.23 | 12 | 10 |
| 3 | High | 45.0 | 61.7 | 45.1 | 49.4 | 43.9 | 134.5 | 6.69 | 2.23 | 12 | 10 |
| 5 | Low | 27.0 | 31.4 | 281.3 | 30.0 | 24.4 | 224.6 | 17.37 | 3.47 | 16 | 14 |
| 5 | Low | 40.0 | 44.4 | 281.0 | 43.3 | 37.8 | 224.2 | 17.37 | 3.47 | 16 | 14 |
| 5 | Low | 45.0 | 49.4 | 280.9 | 48.3 | 42.8 | 224.1 | 17.37 | 3.47 | 16 | 14 |
| 5 | High | 27.0 | 43.7 | 75.2 | 31.1 | 25.6 | 224.6 | 8.36 | 1.67 | 16 | 10 |
| 5 | High | 40.0 | 56.7 | 75.2 | 44.4 | 38.9 | 224.2 | 8.36 | 1.67 | 16 | 10 |
| 5 | High | 45.0 | 61.7 | 75.2 | 49.4 | 43.9 | 224.1 | 8.36 | 1.67 | 16 | 10 |

Ultimately, there are many factors that will determine the size of the heat reuse system and its components, including availability of heat hosts, local codes or law, total capacity, and required redundancies. While the above table is based on sizing the heat reuse system to recover the entire IT load, a heat reuse system can be sized to recover any percentage of the total data center waste heat. It is important to view the heat reuse loop as a “secondary” or ancillary heat rejection method, with dry coolers or other downstream heat rejection devices still required to be sized for the full data center IT load. This will ensure normal data center operation regardless of heat host demand or availability. If physical space permits, consideration should be given to “future-proof” the heat reuse room to allow for expansion of heat reuse capacities up to the full load IT build out capacity by incorporating piping taps and space for additional equipment.

## Fluid monitoring with heat host

As with any hydronic system or loop, considerations need to be made to ensure the quality of the water to avoid degradation of the heat transfer equipment. Treatment of the loop fluids to suppress growth of biologics and fouling must be considered and deployed, by both the data center and the heat host. Given that the heat host can affect the fluid on their side of the system, and the quality of this fluid will impact equipment owned by the data center, industry standard fluid quality standards and metrics should be employed and included in contractual agreements between the data center and heat host.

## Location of the heat recovery station

The equipment dedicated to do the heat reuse process can be located in different spaces:

It can share the same space as the rest of the facility cooling equipment:

- **Pros**: savings due to less structural elements, less piping, less cabling, etc.
- **Cons**: if the heat exchanger is the demarcation point, this is located very close to other DC equipment and the piping from there to the outside (to the heat offtaker) becomes too large

It can be placed then into a separate room, being:

- **Integrated into the data center building**: separation from the rest of the equipment, easier to put it into a different security perimeter from the one for the cooling equipment, easier to establish a lower resiliency level (only one power connection, non-redundant, no uninterruptible power supply (UPS), not connected to the genset…), can still share the same fluid with the Facility Water System (FWS).
- **Outside the data center building but within data center boundaries (inside the fence)**: on top of the previous mentioned features that are even easier for this case, possibility of making it a modular space (containerized), reduction of the distance of the section that is not controlled by the data center (after the demarcation point) and otherwise goes through the data center plot, possibility of reducing the distance to other external items such as heat storage tanks or heat pumps.

- **Outside data center boundaries**: enlarges the distance to the demarcation point, which is now outside the data center, unless boundary close to the building, maybe requiring a secondary heat exchanger within the building; increases the possibility of incurring in technical issues outside the data center boundaries since data center-belonging equipment/installation is now outside of them; facilitates the work to external stakeholders related to the heat reuse and connection with other items such as heat storage tanks and heat pumps, external to the plot.

The location of the room can be also determined by the internal excess heat usages. If the excess heat is used for data center administrative areas space heating, it might be interesting to locate the room adjacent to the boiler room of the administrative area.

## Expected power, network, cooling connections, security level in the heat reuse station

While the concept of heat reuse as a means of data center heat rejection may be new to data center owners, operators, and designers, the design, construction requirements, and standards applied to the data center and other cooling systems will also be applicable to the heat reuse room.

An example of this is security. Taking a look at the security protocols required, they will be very similar to the data center's existing requirements. Treating the heat reuse as an additional heat rejection method for the data center can be very helpful while determining the levels of security, since the heat reuse and associated equipment has a direct impact on the cooling of the data center. For example, wherever the equipment required for heat reuse is located should be secured in the same manner that the main mechanical cooling system for the data center is. If access will be required to the heat reuse equipment by the heat host, it may be beneficial to isolate this equipment from the main mechanical cooling system to limit risk and increase security.

The following table (Table 5) is an example of some considerations that should be made in regard to the power, control, and connectivity of some of the heat reuse room components previously discussed. While the heat reuse system can be isolated from the main data center facility loop, it is still a connected system that has the potential to impact the overall data center heat rejection process. Due to this, all requirements around expected power, networking, and security levels applied to the downstream heat rejection devices and mechanical room must be applied to the heat reuse equipment and heat reuse room.

When designing the hydronic loops for new data centers, every effort should be given to consider and include taps or other future connection methods in the initial design, regardless if heat reuse is being considered at the time. This is a cost-effective way to "future-proof" the design and will allow for seamless addition, or expansion, of a heat reuse system with minimal impact to data center operations. The additional up-front cost would be minimal when compared to the costs associated with retrofitting the hydronic system while in operation.

Table 5 – Power and Controls for 1MW Example Case (Credit: David Kandel - Belimo Valves)

| Component | Power (W) | Instruments | Controls |
|---|---|---|---|
| Pressure transducers (2) | 03. VA (0.15 W) | Active Sensor | 0-10v to local area controller |
| Temperature sensors (2) | nil | Passive Sensor | resistive measurement to local area controller |
| Pressure gauges (2) | na | na | na |
| Temperature gauges (2) | na | na | na |
| Flow meter | 10 VA @ 24V | Analog output | 4 to 20 mA to local area controller |
| HX inlet strainer | na | na | na |
| Shut-off valves (2) 1MW | 52 W | on/off | on/off to local area controller |
| Shut-off valves (2) 5MW | 504 VA @ 120V | on/off | on/off to local area controller |
| Flow control actuator 1MW | 52 W | Analog output | 2-10 vdc to local area controller |
| Flow control actuator 5MW | 250 VA @ 120V | Analog output | 2-10 vdc to local area controller |
| Pump(s) 1MW | 10 -15 HP | Analog output | 2-10 vdc or 4 to 20 mA to local area controller |
| Pump(s) 5MW | 2 pumps @ 20 HP or 3 pumps @ 15 HP | Analog output | 2-10 vdc or 4 to 20 mA to local area controller |

## Measurement and reporting of excess heat

The granularity of metrics used for measuring heat transferred for reuse and other parameters will depend on application, location, local regulations, and stakeholder requirements. At a minimum, it would be sound practice for the data center to obtain and record parameters in the heat reuse loop that are being measured in their alternative heat rejection loops, such as temperatures to and from the heat reuse system, the delta of these temperatures, and flow rates. Measuring and recording system pressure drops will allow baseline values to be determined, and allow for trends deviating from this baseline to be used to monitor system health and alert the operators of arising problems that can be addressed with scheduled maintenance prior to failures that could result in system downtime.

There may exist requirements for formal reporting of all or certain parameters depending again on application, location, local regulations, and stakeholder requirements. Any requirements should be examined in detail to ensure that the correct data is being recorded, in the correct format and at the correct frequency.

The European Union is working on establishing a common rating scheme for data centers surrounding the measurement of waste heat reuse. This resource can be found at the following link:

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401364

## Expected redundancy/resiliency in the devices of the heat reuse room

Data center heat reuse projects add level(s) of redundancy to the data center by providing an additional free-cooling method, which is intended to reduce the usage of mechanical cooling systems. In the event of heat reuse system failure, the default would be a return to standard heat rejection system designed for the total capacity of the data center.

However, additional redundancy within the data center heat reuse installations, are driven by the expectations and necessities of the heat off takers, depending on their needs for consistent and reliable heat delivery. The maintainability of heat reuse systems will define the desired level of redundancy, which determines its ability to handle failures and continue operating and delivering heat to the offtakers. Among all components, the heat exchanger is probably the most critical, given that it is integral to the entire heat transfer process and could be the only engineered-to-order component in the most basic heat reuse application. Ensuring the heat exchanger is easily maintainable and quickly replaceable, is essential to meeting the above mentioned requirements. The chosen granularity for, for example, the heat exchanger, can be a wise choice. Deploying more than one heat exchanger instead of a single one totaling the same heat quantity is a way of doing it. In this scenario, at least a portion of the heat can still be delivered, while maintenance or replacement happens at a heat exchanger.

One of the main concerns around reliability stem from the quality and maintenance of the fluid in the heat host's loop. As mentioned in the fluid monitoring with heat host section, the data center should ensure protection of this method of heat rejection, and their impacted equipment, by including industry standard requirements utilized on their fluid loops in contractual agreements with the heat host.

Deployment considerations:

- Depending on heat host application(s), note that it may be beneficial to install more than one heat exchanger between the data center side and heat host side. This would allow preventative maintenance (PM) or repairs on one while the other heat exchanger(s) remain operational.
- For data centers with a mechanical room located directly below the data center floor, consider locating the heat exchanger(s) in a room where these components are located, suggest to the side of data center floor vs in mechanical room under data center floor as the additional heat exchanger(s) at might interfere with hydronic distribution system.
- Perspectives: data center (security, access to room with HXs), heat host (depending on criticality may also need backup heat source or while data center is built out to full capacity), single or multiple parties.

## Loops design, cascading

Consider two (or more) facility closed-loop systems that provide different supply temperatures for the cooling of IT equipment. This type of design introduces flexibility as well as resilience in operations as it supports a variety of IT system combinations over time to:

- Optimize temperature for system type
- Maintain an operational data center, allowing for system installations and repairs without creating data center outages.

A multiple cooling loop design offers an added benefit of system resiliency, as being tied into a district chilled water system can enable planned maintenance on the various cooling systems. The different hydronic loops include larger pipes and isolation valves that enable HPC systems to be added or removed without interruption to data center facility operations.

Similar to Figure 8, differentiating factor is multiple loops and what offers, idealized

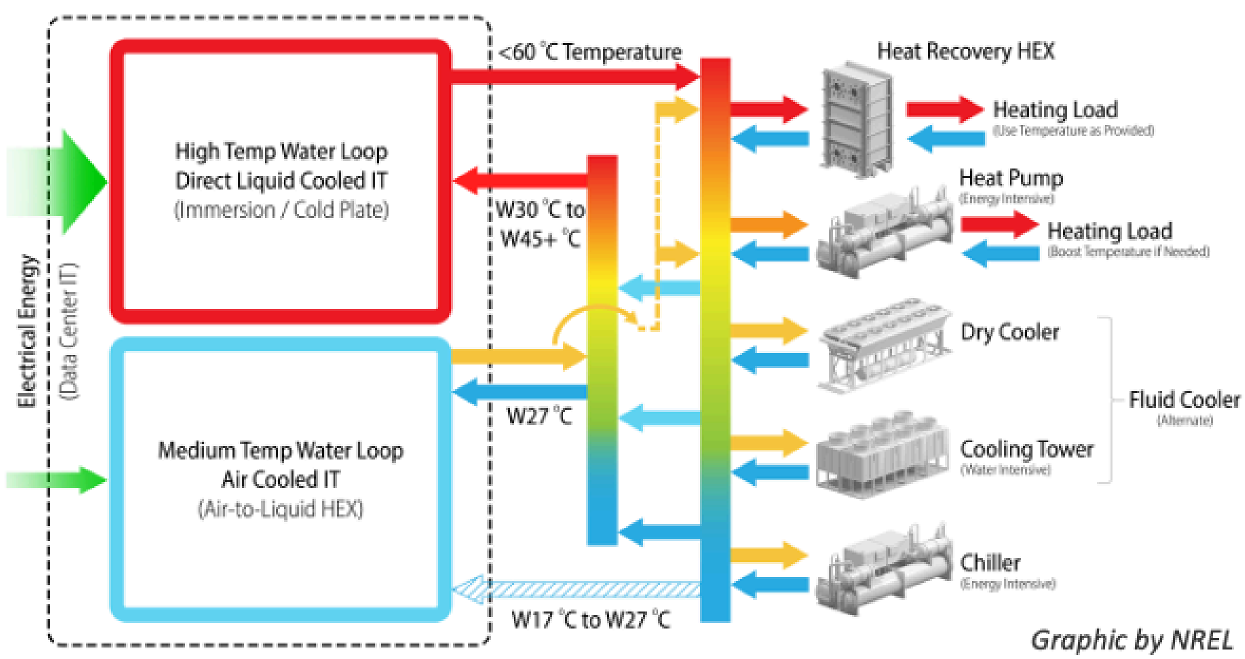


Figure 8 – Data center cooling and heat reuse, combinations (Credit: NREL)

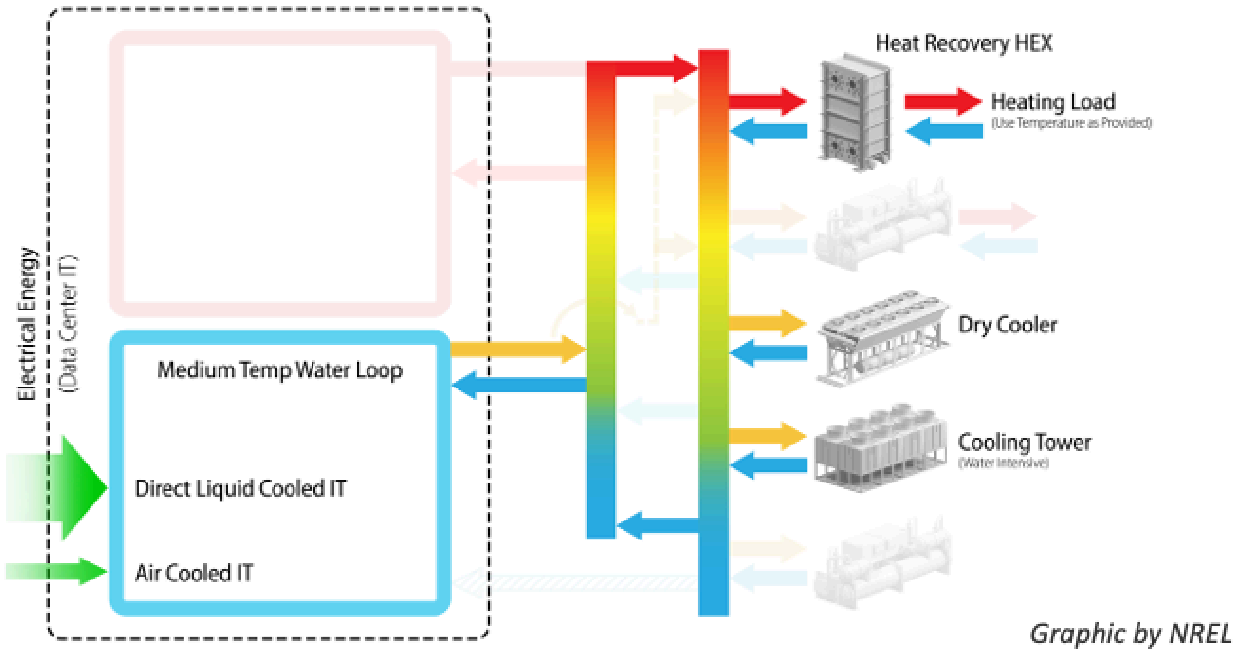


Figure 9 – Case for NREL HPC Data Center (Credit: NREL)

Above, most data centers have a single facility loop like shown in Figure 9 representing the case for NREL's HPC data center. Reference Appendix III with Cloud&Heat Block diagrams.

## Data centers retrofits for heat reuse

We can explore two possible scenarios for retrofitting data centers for heat reuse:

A. At some point in the cooling system, the data center heat is transferred to a liquid
B. The data center heat is not transferred to a liquid

Examining scenario A, the technical solution implemented will be based on a possible diversion of the heat transfer to a different path. The heat that is normally rejected to the environment will be diverted to the heat reuse system. Depending on how prepared the cooling system is to admit new components, this implementation will have varying degrees of invasiveness to the overall system, as well as varying degrees of impact to the operation of the data center. Different options can be considered to integrate heat reuse in this scenario:

- Tapping into the free-cooling loop, before the heat rejection happens: this implementation process will likely demand down-time and affect the operation of the data center, unless the free-cooling loop is not essential for the operation of the data center (e.g. chillers have their own outdoor condensing units, or the taps and valves have already been implemented in initial planning.
- Replacing a dry cooler with a heat reuse station: This may affect redundancy if the number of dry coolers is N+1 or fewer, and they are used as condensing units for the chillers. If redundancy isn't an issue, it could be a quick solution to reuse some of the excess heat, especially when there is not sufficient room to keep both the dry cooler and a heat reuse station.
- Tapping into the condensing units of the chillers: This can be more complex and depends on the piping configuration of each chiller manufacturer. Ideally, the condensing units should have pre-existing tapping points designed for this purpose.

In general, a retrofit is easier to implement with external modular heat reuse stations (e.g., within an outdoor container) because:

- There is likely no available space inside the data center.
- The site's build capacity has been maxed out, and no additional structures can be built.
- Tappings before dry coolers or condensing units can be done outdoors.

For scenario B, implementation will be more complex, as it typically requires an additional loop to transfer heat from the air to a liquid. An air-to-liquid heat exchanger would need to be installed before heat rejection, which would necessitate modifications to the fan system to handle a significantly higher pressure drop. Additionally, the new liquid-based loop would require valves, pumps, and sensors, as outlined in the components section above.

Alternatively, the heat in the air could be directly blown toward the heat receiver or passed through an air-to-air heat exchanger. However, these solutions are limited by the low transportability of air over long distances and the challenges of using air-based heat on the offtaker's side, such as more space requirements, poor storage capabilities, higher heat losses, more complex control systems, and lower heat capacity.

An air-based heat reuse system in such data centers could be advantageous for meeting the facility's own heating needs (e.g., for the administrative areas) or for heating nearby spaces. Implementing a liquid-based heat transfer solution would depend on regulatory requirements or supporting business cases.

# 6. Matching of the heating demand

## Seasonality and intraday variations

Data center excess heat production can vary along the day and the seasons of the year, due to mainly two reasons.

The first reason is inherent to the usage of the ITE that, depending on the data center type and application run, will be more or less constant. It seems obvious that a data center solely populated with ITE delivering digital services to a certain geographical region will have higher peaks during daytime. On the other hand, some applications realizing back-ups could prefer nighttime. In essence, the excess heat load curve arising from a data center will be unique to that data center, its ITE and in fact the working schedule of the applications within.

The second reason is subject to the climatic variations on the location. Colder ambient temperatures require lower or no usage of chillers and hence the heat rejection temperatures will be lower. Free-cooling happens due to the fact that the deltaT required to cool down the ITE is reached with those external temperatures. The temperature will be in turn higher when the ambient temperatures are higher and hence chillers will run to offer to the ITE the required lower temperatures and reject the heat using higher temperatures than the ambient one. This variation happens within a day but specially within seasons. External humidity values will also have an influence on the ambient temperatures needed for cooling down the rejected excess heat.

On the other hand, heat offtakers' needs for heating can also vary along the day and the seasons of the year, due to equivalent reasons.

The first one is inherent to the needs for heating, which depends on the type of activity and its influence from the surrounding climate. Industrial heating might be constant for processes that never stop or on the contrary, these might only run during daytime. Some industrial processes (in particular from the food industry) can be subject to seasonal variations and be only active during certain periods (e.g. after the harvesting season).

The second one is subject to the climatic variations, similarly as mentioned above for the data centers: households lower their heating demand in summer, so do greenhouses. On the other hand, water treatment might be more needed during summer than winter.

These intraday and seasonal variations need to be considered when coupling to an external heating demand or when planning for future potential demands. Some technical features could be considered to cope with these variations and enlarge the symbiosis between data center and heat hosts as much as possible: storage, boosting mechanisms, transformation machinery.

## Heat storage

Heat storage is essential for balancing the generation and consumption of heat energy, allowing the two processes to be decoupled over time. A key challenge in heat storage is mitigating continuous heat loss, which arises due to the temperature difference between the stored medium and the environment. To minimize these losses, thermal insulation is critical, particularly by avoiding thermal bridges.

Heat storage systems are generally categorized by storage duration (short-term vs. seasonal) and by the storage mechanism. The most common mechanisms are:

1. **Sensible heat storage**:
    - This type involves a change in the temperature of the storage medium during charging or discharging, without any phase change. The key parameter here is the material's heat capacity. Sensible Heat storage is versatile and can operate across a wide temperature range, especially at high temperatures. Examples include water or other fluids stored in buffer tanks.
2. **Latent heat storage**:
    - Unlike sensible heat storage, latent heat storage involves a phase change of the medium (typically from solid to liquid and vice versa) without a change in perceptible temperature during the process. The material absorbs or releases heat during this phase change. This allows for compact energy storage, particularly over a narrow temperature range.
3. **Thermochemical heat storage (sorption storage)**:
    - This method uses chemical reactions to store and release heat. Endothermic reactions (heat absorption) and exothermic reactions (heat release) provide a robust and compact way of storing energy. Examples include materials like silica gel and zeolites, which store energy through reversible chemical reactions.

**Short-term storage** is often achieved using freestanding water storage containers, while **long-term storage** options include:

- **Hot water heat storage**: Insulated tanks filled with water that can store large amounts of heat.
- **Gravel/water heat storage**: Similar to hot water storage but using a gravel and water mixture, which increases the storage capacity.
- **Geothermal heat storage**: Heat is stored in the ground, usually up to a depth of 100 meters, allowing for seasonal storage.
- **Aquifer heat storage**: Groundwater and surrounding earth are heated and stored in aquifers, which is effective in areas with standing groundwater.
- **Thermochemical and latent heat storage**: These are also viable options for long-term storage, providing greater energy density and stability.

Each method has specific advantages depending on the temperature range, duration, and the space or resources available for storage.

In data centers, both short-term and long-term thermal storage can be viable options, depending on the heat sink's load profile. The feasibility of geothermal or aquifer heat storage requires a careful evaluation, including a geographic survey and an understanding of local regulations. These solutions can offer significant long-term heat storage but are highly dependent on local geological conditions.

Sensible heat storage, typically in the form of hot water tanks, is a widely used and commercially developed method. Its primary advantage lies in its simplicity and scalability. However, the key disadvantage is the space requirement, as these systems need large volumes of water to store significant amounts of energy.

To calculate the necessary water tank size, the following parameters are crucial:

- Volume: flow for withdrawal, which defines how much water is needed to meet heating demands.
- Permissible temperature difference between the loading and withdrawal stages, which directly influences the energy stored.

For example, to store 1 MW of thermal energy in a water tank for a 30-minute bridging period, with a permissible 10 K cooling (i.e., the difference between the loading and withdrawal temperatures), the required storage volume is approximately 43 $m^3$. Analogously, 1MWh of heat storage requires ca. 80 $m^3$. This illustrates how space-intensive water storage can be for large heat loads.

## Boosting or transformation mechanisms

There are a few options for the equipment which goes between the data center cooling system and heat reuse to adapt or transform the energy type and temperature to the heat offtaking needs. The primary equipment driver is the cooling source temperature to heat recovery reuse application temperature differential.

Heat pumps

If the data center is close to a heat user that requires a higher temperature than the data center can deliver then a heat pump can be used to process the heat. It can take energy from the warm air/liquid emitted by the data center so cooling it. The heat pump will concentrate this energy up to the needed temperature. Heat pumps are a mature technology having been in use for over a century.

A heat pump can be used to transfer heat energy from a cooler reservoir, at temperature Tc, to a warmer reservoir, at temperature Th. The heat pump will require additional energy to perform this task, but the energy delivered, to the heat user, is normally much more than the additional energy needed to run the pump. The ratio of useful heating provided to work (energy) put into the heat pump is the Coefficient of Performance (COP). The higher the COP the better.

The COP is dependent on the difference between Tc and Th, in absolute terms. There is a theoretical maximum COP and this is defined by: $COP = \frac{Th}{Th-Tc}$, where Th and Tc are in degrees Kelvin.

This is the reciprocal of the thermal efficiency of an ideal heat engine, see Carnot's theorem. The efficiency will rise exponentially as Tc gets closer to Th.

This means that if your data center delivers 30°C and the heat user needs 80°C then the maximum COP will be: $COP(max\ for\ 30ºC to\ 80ºC) = \frac{273.15+80}{50} = 7.06$

For every joule of energy running the pump a theoretical maximum of 7.06 joules of heat energy at 80C can be delivered to the heat user. That is the 1 joule of work is added to 6.06 joules of heat from the cool reservoir to deliver 7.06 joules into the warm reservoir. The data center can raise the COP by delivering higher temperatures, 40°C gives a theoretical COP of 8.8 and 50°C gives 11.8 when the target is 80°C.

A heat pump works by using a fluid that will boil at a temperature under that of the cool reservoir and can be compressed into a liquid at over the temperature of the warm reservoir. This fluid is held in a closed loop. It is allowed to evaporate or boil in the cool reservoir, taking up latent energy while losing some heat energy to the cool reservoir, the gas is taken into the warm reservoir and compressed by a pump. The fluid is heated by being compressed, and taking up energy from the pump, to higher temperature than the warm reservoir. The fluid is kept at the high pressure and is allowed to emit energy to the warm reservoir so that it cools enough to condense. The liquid fluid is slowly released into the cool reservoir to start over again, through an expansion valve, that will reduce the pressure on the fluid enough so that it can boil at the temperature of the cool reservoir.

If the heat user is remote from the data center then it is more viable to locate any needed heat pump close to the user as the efficiency (and cost) of transporting the heat is better at a temperature closer to the ambient temperatures. An additional advantage of this is that the data center's intermittent heat can be stored and delivered at times of greater need. If the data center uses air cooling then the heat will need to be transferred to a low cost liquid to be transported. An additional issue may be that a heat pump within a data center may be counted in the PUE calculations, as it may be seen as part of the cooling infrastructure.

There are many suppliers of industrial heat pumps. If required, heat pumps can deliver 300°C, or more.

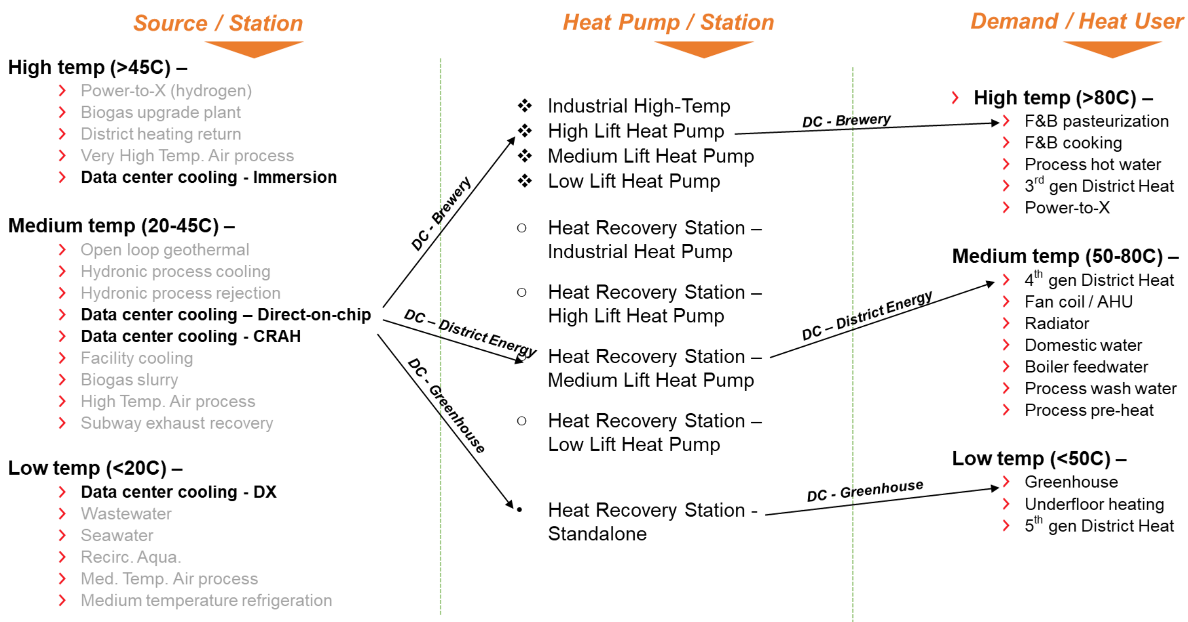


Figure 10 – Choices and variations in reference design architecture (Credit: NZIH)

The space required for a heat pump installation that could be employed for boosting the low-grade temperature of a data center to match a demand is highly variable, and depends on system differential, efficiency and technology utilized. To reserve at least 10m$^2$ per MW design capacity heat provided is a good conservative number to use.

Boilers

In some occasions the temperature boosting for the final usage can be done with boilers (gas or electric boilers). This method is of course less efficient than heat pumps but it can support a short-term peak demand without installing (and investing) additional heat pumps capacity, dimensioned to face the peak demand during a small amount of time. This solution avoids low energy efficiencies associated with heat pump partial load operation during the rest of the year and also stranded CAPEX (superfluous extra heat pump capacity only employed during peak hours).

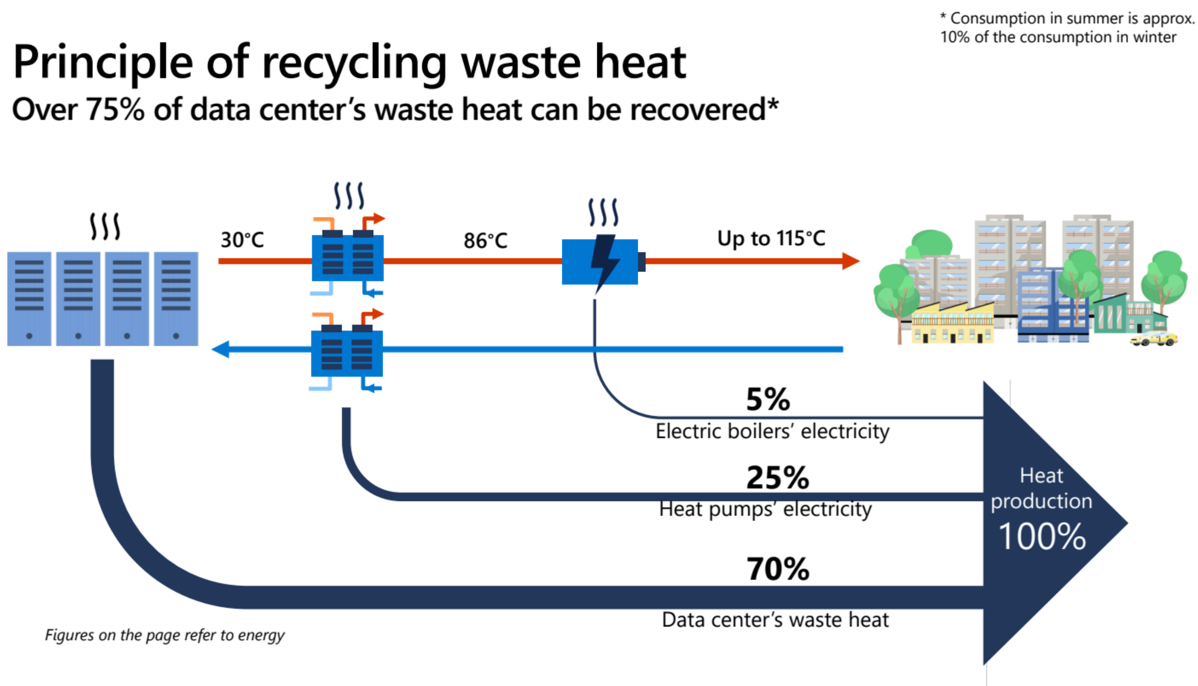


Figure 11 – Case for Microsoft Data Center in Finland (Credit: Microsoft)

## Heat to cooling

There are various mechanisms available to generate cooling effects driven by thermal energy. A universal schematic diagram is shown in Figure 12. The three most popular options are adsorption refrigeration, absorption refrigeration, and dehumidification cooling. Regarding heat reuse, the temperature of the heat source determines the performance of the chiller system.

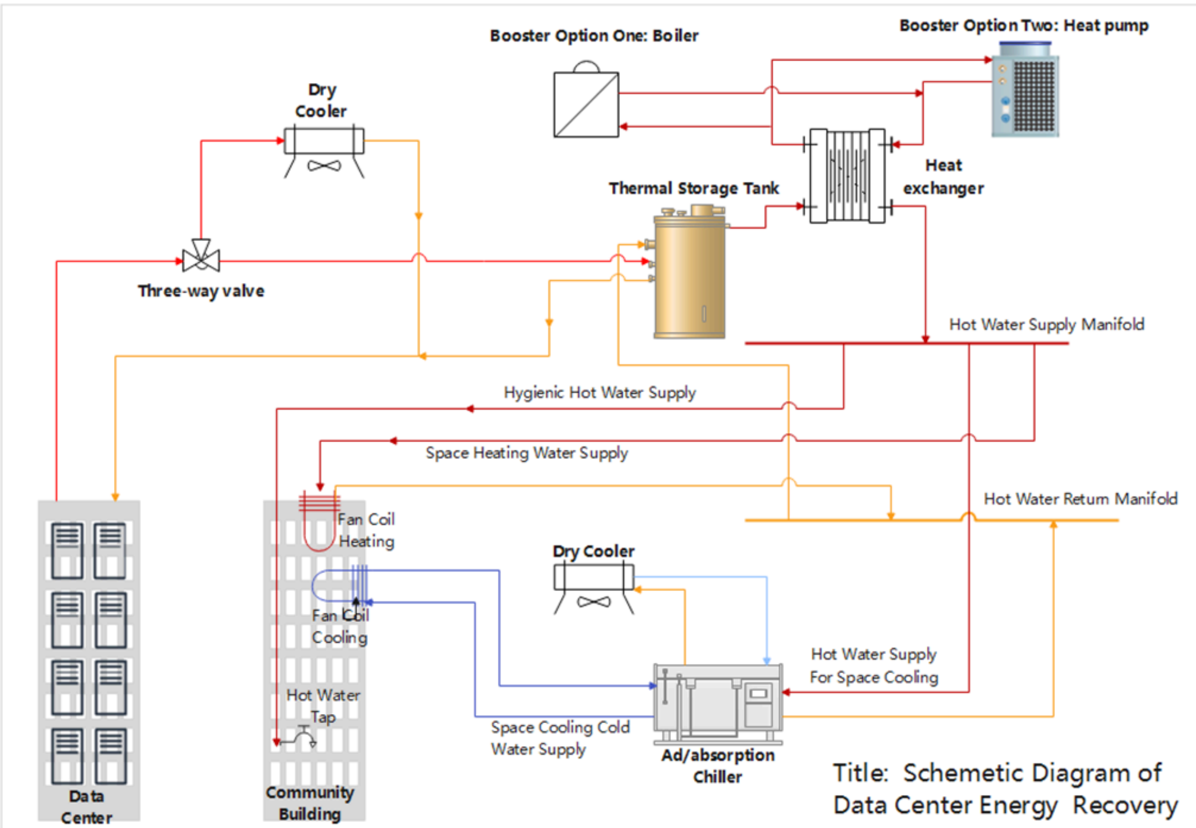


Figure 12 – Schematic diagram of data center excess heat recovery for adsorption cooling (Credit: ALCT)

To reuse the heat from DC for cooling purposes, the first step is to determine the minimum starting temperature for different thermal-driven chillers, specifically the minimal hot water threshold for adsorption and absorption chillers. The minimal starting temperature for an adsorption chiller is 45°C. When the inlet hot water temperature exceeds 55°C, its COP (Coefficient of Performance) will be higher than 0.4. For a single-effect absorption chiller, the minimal starting hot water temperature is 65°C. When the inlet hot water temperature exceeds 80°C, its COP can be higher than 0.75.

A two-effect absorption chiller has a higher COP at higher hot water temperatures, making it more suitable to be driven by steam. The half-effect absorption chiller[2], essentially two coupled single-effect absorption cycles, can operate with a thermal-driven temperature as low as 45°C. However, the COP of a half-effect absorption chiller is typically lower than 0.5 when the thermal-driven temperature varies from 45°C to 80°C due to the complex thermodynamic cycle.

Generally, the most suitable temperature range of hot water to drive chillers is between 55°C and 85°C. Specifically, 55°C to 75°C is more suitable for adsorption chillers, while 80°C to 120°C (pressurized hot water) is more suitable for absorption chillers.

Heat to power

Organic Rankine Cycle (ORC) has been considered for data center heat to power[2]. Unfortunately, with relatively low temperatures, the fraction of heat converted to electricity is less than 4%. Even so, ORC could still be interesting to add incremental capacity for sites that are limited in external power availability.

Isothermal heat engine, operates on similar principles of bubbly media as the heat pump and offers double the efficiency under a similar scenario[3]. Figure 13 shows the expected efficiency for inlet hot water at 65ºC and outlet hot water at 45ºC at various ambient temperatures. This additional clean power generation (up to 10% in cold winter ) is in addition to saving the cooling power consumption. The cooling plus the additional power generation may save up to 20% of the entire data center consumption.

[2] See work done by Villanova U., among others https://scholar.google.com/citations?user=UPf0gQwAAAAJ
S. Araya, G. F. Jones and A. S. Fleischer, "Organic Rankine Cycle as a Waste Heat Recovery System for Data Centers: Design and Construction of a Prototype," *2018 17th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, San Diego, CA, USA, 2018, pp. 850-858, doi: 10.1109/ITHERM.2018.8419530.

[3] See https://luminescentpower.com/ and OCP Heat Reuse general call 16/07/2024
2024-07-16_Luminescent_OCP_HeatReuse.pdf

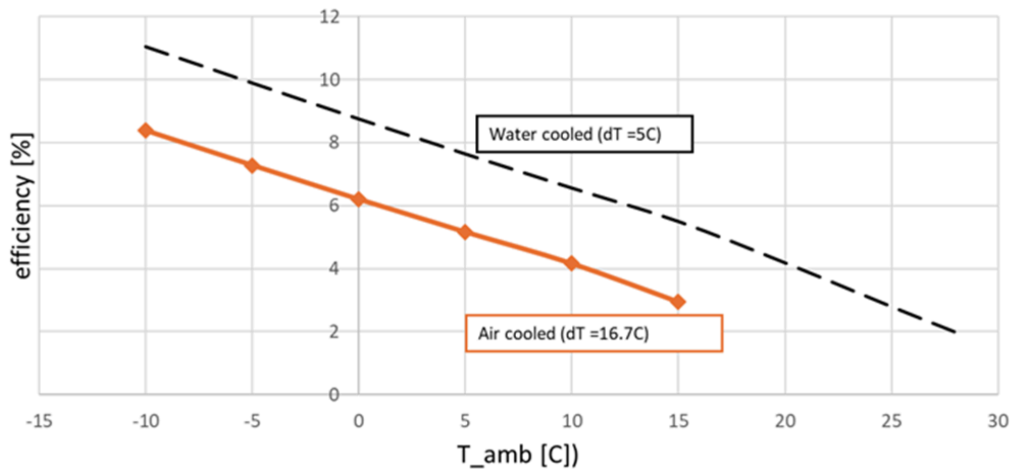


Figure 13 – Expected efficiencies for isothermal heat engine (Credit: Lava Power - formerly Luminescent)

## 7. Metrics

Previous OCP work, from this Subproject, introduces the topic of energy, water and carbon impacts of heat reuse[4]. The OCP Data center facility Sustainability Subproject, under the Energy/Heat/Water - Workstream[5] has been working on a whitepaper on the interrelation between energy and water consumption, carbon emissions and heat reuse.

The main findings of that work are the following:

Table 6 – Impacts of heat reuse on data center's energy and water consumption and carbon emissions (Credit: OCP DCF Sustainability Subproject - Energy/Water/Heat workstream

| Scenario | Effect | Energy Implications | Water Implications | Carbon Footprint Implications |
|---|---|---|---|---|
| No Physical Modification of Waste Heat | Reduced Mechanical Cooling in Data Center | Direct lower energy usage at compressors and fans | Indirectly lowers water usage (energy supply) | Indirectly lowers carbon footprint (reduced energy supply carbon) |
| | Reduced Evaporative Cooling in Data Center | Direct lower energy usage for evaporative systems (pumps, sprays) | Direct lower water usage (less evaporation) | Indirectly lowers carbon footprint (reduced energy supply carbon) |
| | Reduced Thermal Energy at Heat Offtaker | Lower energy usage for heating system (boilers, heat pumps, solar installations) | Lower water usage (less evaporation); potential water gain if used for dirty/salty water treatment; potential higher water use in case of leaks | Lower carbon footprint due to reduced fuel burning; potential carbon removal if used for carbon capture |
| Physical Modification of Waste Heat | Less Energy Required Subscenario | Direct energy saving from global perspective even if additional machinery is used | Lower water footprint | Lower overall carbon footprint |
| | Equal/More Energy Required Subscenario | No direct energy saving; possibly equal or more energy consumption | Equal or more water footprint due to higher energy and machine usage | Equal or more carbon footprint if additional energy is required |
| | Responsibility for Heat Transformation | Offtaker generally responsible for waste heat modification, but data center may handle it if legally | | |

[4] https://www.opencompute.org/documents/20230623-data-centers-heatreuse-101-3-2-docx-pdf
[5] https://www.opencompute.org/projects/dcf-sustainability

| | | | | |
|---|---|---|---|---|
| | | required or economically beneficial | | |

From the previous table, we can generally state that there are:

Table 7 – General impacts on data center's PUE, WUE and CUE of the introduction of heat reuse

| **Heat reuse scenario where:** | **PUE**[6] | **WUE**[7] | **CUE**[8] |
|---|---|---|---|
| the excess heat suffered no physical change | ↘↘ | ↘↘ | ↘↘ |
| the excess heat suffered a modification/transformation requiring low extra energy | ↘ | ↘ | ↘ |
| the excess heat suffered a modification/transformation requiring high extra energy | ↗ | ↗ | ↗ |

In general, employing heat reuse can lead to larger free-cooling periods, hence requiring less mechanical energy. In general, heat reuse will be a more energy efficient free-cooling method as the standard free-cooling method, since, in general, instead of a liquid-to-air heat exchanger and fans used for heat rejection to the outdoor environment, only a liquid-to-liquid heat exchanger will be used. A pump is required to move the liquid to the heat rejection device or the heat exchanger for heat reuse and its characteristics can slightly vary according to the distance and pressure losses but, in general, if properly dimensioned, the energy consumption of such, should remain similar. Employing a heat pump within the data center boundaries to boost the temperature of the excess heat will generally incur in unnecessary higher energy consumption from the perspective of the data center, especially during cold ambient hours. This is the case of some data centers running a heat reuse maturity model of 3 or above (Table 1), who have chosen to be a more active part of the decarbonized heat generation system and are most probably compensating the higher energy consumption and costs by earnings from their heat, from carbon emissions avoidance or even tax exemptions.

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[6] As defined by the Green Grid and the ISO 30134
[7] As defined by the Green Grid and the ISO 30134
[8] As defined by the Green Grid and the ISO 30134. The CUE strongly depends on the carbon footprint intensity of the local power grid. https://www.carbonfootprint.com/international_electricity_factors.html

These are general "rules of thumb" that will vary depending on the particular scenarios to be considered. Future work will evaluate the impacts on the PUE, WUE, CUE metrics depending on different data center cooling scenarios and different climate regions. Measurements and estimations are needed for determining the impact on the cooling system energy consumption, on its different essential parts: air/coolant handling, cooling production, and heat rejection. Following the ASHRAE 90.4. annualized MLC calculation methods can be helpful.

We have focused on the impacts of heat reuse on the data center emissions and water and energy consumptions and noted that in some cases where a transformation of the heat is involved, there could be negative impacts on the above-mentioned metrics. These impacts can be largely countered if we start considering the positive impacts on the heat user and evaluating the global impact. The analysis of the impacts the heat reuse project can generate on the heat receiver side, will strongly depend on the use case and the alternative the heat receiver will otherwise employ to generate the heat. It seems evident that a heat receiver using a gas boiler for heating will avoid the emissions associated with burning gas and this avoidance belongs to the heat user and not the data center. Similarly, heat users employing the excess heat for water sanitation would generate a positive impact on water but it will be associated with their activity and not the data centers. The usage of a heat pump will imply higher energy consumption but will generate a higher energy output for the heat end user and generally will result in energy savings compared to an electrical heater, a gas boiler or a heat pump condensing against a cold outdoor environment.

A metric that needs to be mentioned is the ERF (Energy Reuse Factor) which was created by the Green Grid and then defined in the ISO 30134 as "the ratio of energy being reused divided by the sum of all energy consumed in a data center". A derived metric of this one combined with the essences of he PUE would be the ERE, defined as well by the Green Grid[9] as ratio of energies:

$$ERE = \frac{Cooling + Power + ITE - Heat\ Reused}{ITE} = (1 - ERF) \times PUE$$

While the ERF lies between 0 and 1, the ERE, that can be interpreted as an "enhanced" PUE, can fall even under 1, in case the amount of heat reused is higher than the energy consumed by the MEP facility.

[9] https://datacenters.lbl.gov/sites/default/files/EREmetric_GreenGrid.pdf

A relevant question is if the own usage of the excess heat can be considered in these metrics. The ISO30134 considers that heat reuse has to be taken into account if it leaves the data center but not if it is used somehow in an internal process to increase the energy savings internally. Interestingly, the latest reporting scheme for data centers from the delegated act of the EU EED directive[10], the heat reuse of data center is defined as:

> “Waste heat reused (‘EREUSE’, in kWh) shall be measured as defined by, and by using the methodology set out in, the CEN/CENELEC EN 50600-4-6 standard or equivalent. Data centers shall measure the heat that is used or reused outside of the data center boundary, and which substitutes partly or totally energy needed outside the data center boundary.
>
> (...) Reused energy shall be measured at the boundary of the data center at the point where the energy provided is handed off to be used by the other party.
>
> If part of the waste heat is reused for cooling the data center, that part must be subtracted from the reused waste heat, that is to say, subtracting the share of flow rate of cooling fluid used in the data center”

For the EU Commission, heat reuse to be reported needs to involve a third party usage.

Interestingly, in the ASHRAE 90.4 Standard, the heat reused is introduced in the calculation of the MLC, to avoid that, by promoting the use of otherwise wasted heat for third-party purposes, the design is not negatively impacted in the MLC calculation, even if there are net energy increases from installing heat transfer equipment or running data center cooling systems at reduced efficiency to support heat recovery.

[10] https://eur-lex.europa.eu/eli/reg_del/2024/1364/oj

## 8. Conclusion

This paper has explored some critical considerations, design elements, and technological options surrounding data center heat reuse. As global energy demands and environmental concerns rise, the reuse of excess heat from data centers has emerged as a promising solution to improve energy efficiency and sustainability. The paper delved into both business and technical aspects, beginning with the identification of key stakeholders and the introduction of a heat reuse maturity model to guide organizations through various stages of implementation.

From a design perspective, we outlined the architecture of heat recovery stations, covering essential components, connections, and location considerations, while also addressing the critical importance of power, network, and cooling infrastructures in the overall system. The focus on redundancy and resiliency emphasized the need for reliable and secure systems that can handle the unique challenges posed by heat reuse initiatives. Additionally, retrofitting existing data centers to accommodate heat reuse was discussed, with attention given to how design modifications can maximize the effectiveness of heat recovery.

The matching of heating demand, including seasonality and intraday variations, was another focal point, highlighting the importance of effective heat storage and transformation mechanisms. The integration of heat pumps, boilers, and heat-to-cooling or heat-to-power conversion systems demonstrated the versatility of heat reuse technologies in various applications. The paper also introduced key metrics to measure the performance and efficiency of heat reuse systems, discussing the impact on PUE, WUE and CUE of heat reuse.

Overall, data center heat reuse represents a significant opportunity for businesses to reduce energy waste and contribute to broader sustainability goals, incorporating intersectoral collaboration. However, successful implementation requires a careful balance of technical innovation, stakeholder collaboration, and a deep understanding of heating demand and system design. This paper serves as a guide for planning the space and shape of a present or future heat reuse project and introduces the technical and management staff in charge of a data center development to the technical challenges and opportunities of it.

## Abbreviations

| | |
|---|---|
| ACF | Advanced Cooling Facilities |
| AHRI | Air-Conditioning, Heating, and Refrigeration Institute |
| BIM | building information modeling |
| CAPEX | capital expenditure |
| COP | coefficient of performance |
| CRAH | computer room air handler |
| D2chip | direct-to-chip |
| DCF | Data Center Facilities |
| DX cooling | direct expansion cooling |
| FWS | facility water system |
| HVAC | heating, ventilation, and air conditioning |
| HX | heat exchanger |
| NZIH | Net Zero Innovation Hub for Data Centers |
| ORC | organic Rankine cycle |
| PM | preventative maintenance |
| RDHx | rear door heat exchanger |
| SLA | service level agreement |
| TCS | technology cooling system |

Used interchangeably: heat consumer, heat end user, heat offtaker, heat receiver

heat recovery station, heat reuse station, heat reuse room

# References


**OCP Heat Reuse subproject**

1. OCP Heat Reuse subproject, OCP site: https://www.opencompute.org/projects/heat-reuse and wiki page: https://www.opencompute.org/wiki/Cooling_Environments/Heat_Reuse

2. OCP Heat Reuse Map: https://www.google.com/maps/d/edit?hl=en&hl=en&mid=1bTp4Ugy7FGwfPadNlmfZpYwGY5Z5B7o&ll=28.87172622901383%2C-40.21607810348212&z=3

3. Data Centers Heat Reuse 101, by OCP Heat Reuse: https://www.opencompute.org/documents/20230623-data-centers-heatreuse-101-3-2-docx-pdf

4. Policies to Accelerate Data Center Heat Reuse: Achieving Economic and Climate Change Goals (Revision 1.0 or higher), by OCP Heat Reuse: https://www.opencompute.org/documents/2024-02-22-ocp-heatreuse-wp-policies-vfinal-docx-2-pdf

5. Heat Reuse Economics, by OCP Heat Reuse: *refer to wiki page for latest status*

**Other OCP resources**

6. Data Center Liquid Distribution Guidance & Reference Designs (Revision 1.0 or higher), by OCP Advanced Cooling Facilities (ACF): https://docs.google.com/document/d/1h7dv_bP3Yc7ASUARkNXxz6P557mS3s6Ame8GH3vhfFw/edit

# Appendix I – Reference designs, block diagrams

There are different possible ways of reusing the excess but all depend essentially on the temperature it is generated and the temperature it is needed. In this appendix, the block diagrams for six different scenarios are presented:

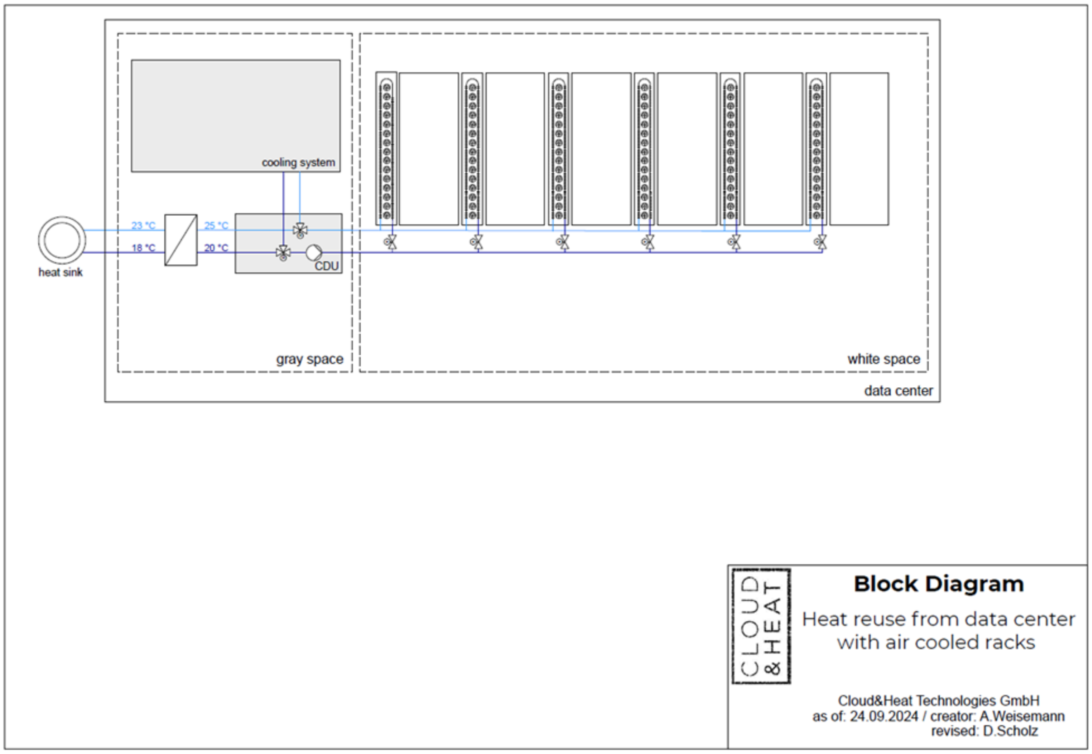


Figure 14 – Heat reuse from data center with air cooled racks (Credit: Cloud&Heat Technologies)

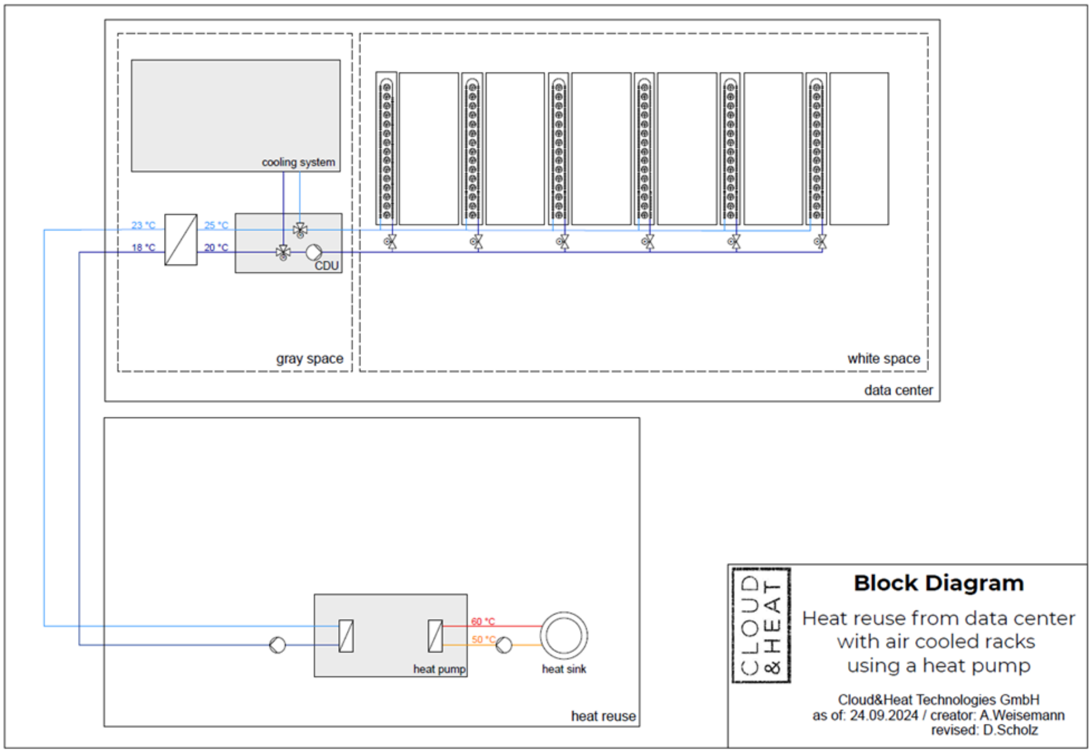


Figure 15 – Heat reuse from data center with air cooled racks using a heat pump (Credit: Cloud&Heat Technologies)

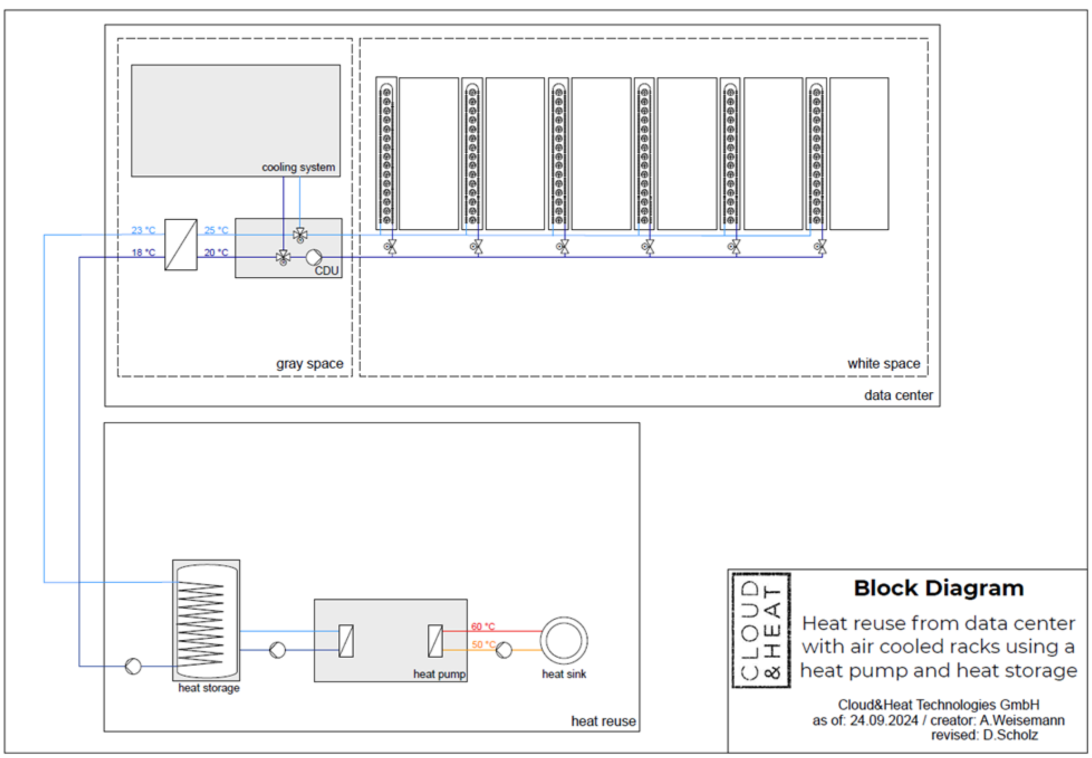

Figure 16 – Heat reuse from data center with air cooled racks using a heat pump and heat storage (Credit: Cloud&Heat Technologies)

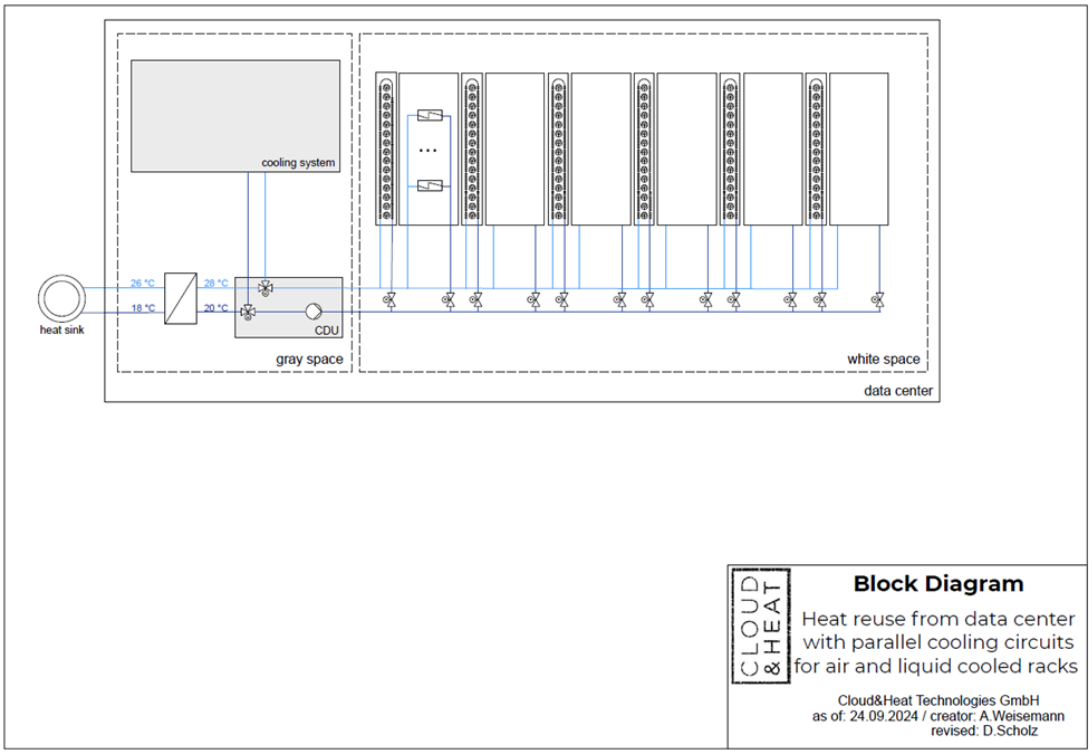


Figure 17 – Heat reuse from data center with parallel cooling circuits for air and liquid cooled racks (Credit: Cloud&Heat Technologies)

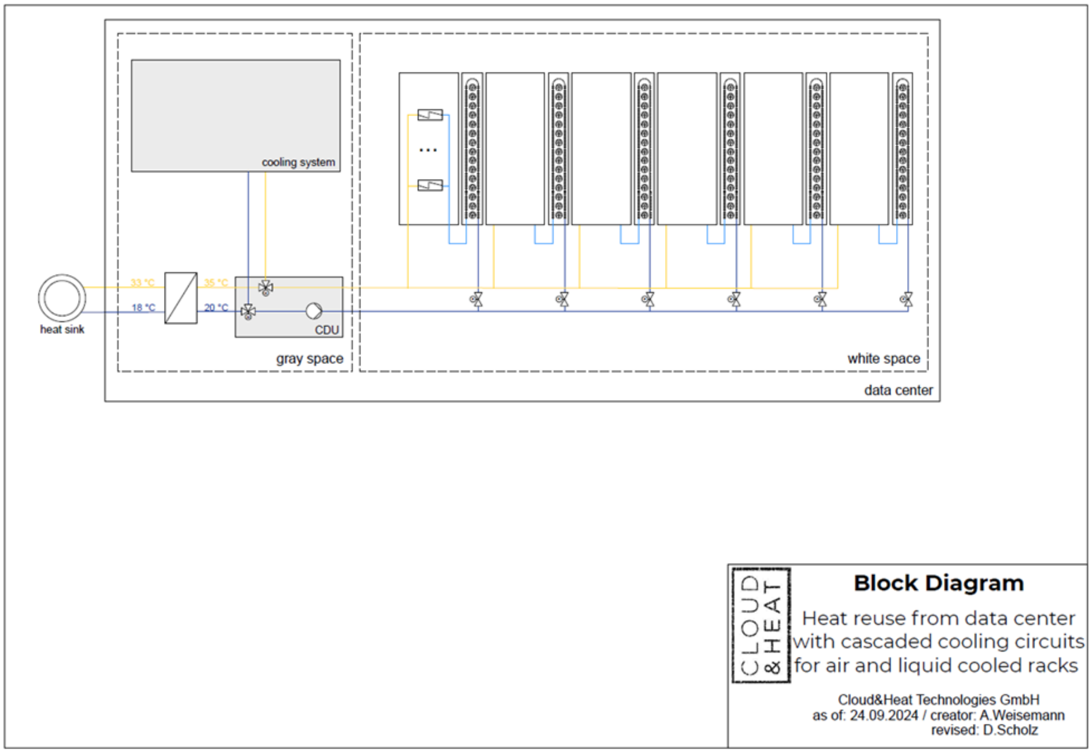


Figure 18 – Heat reuse from data center with cascaded cooling circuits for air and liquid cooled racks (Credit: Cloud&Heat Technologies)

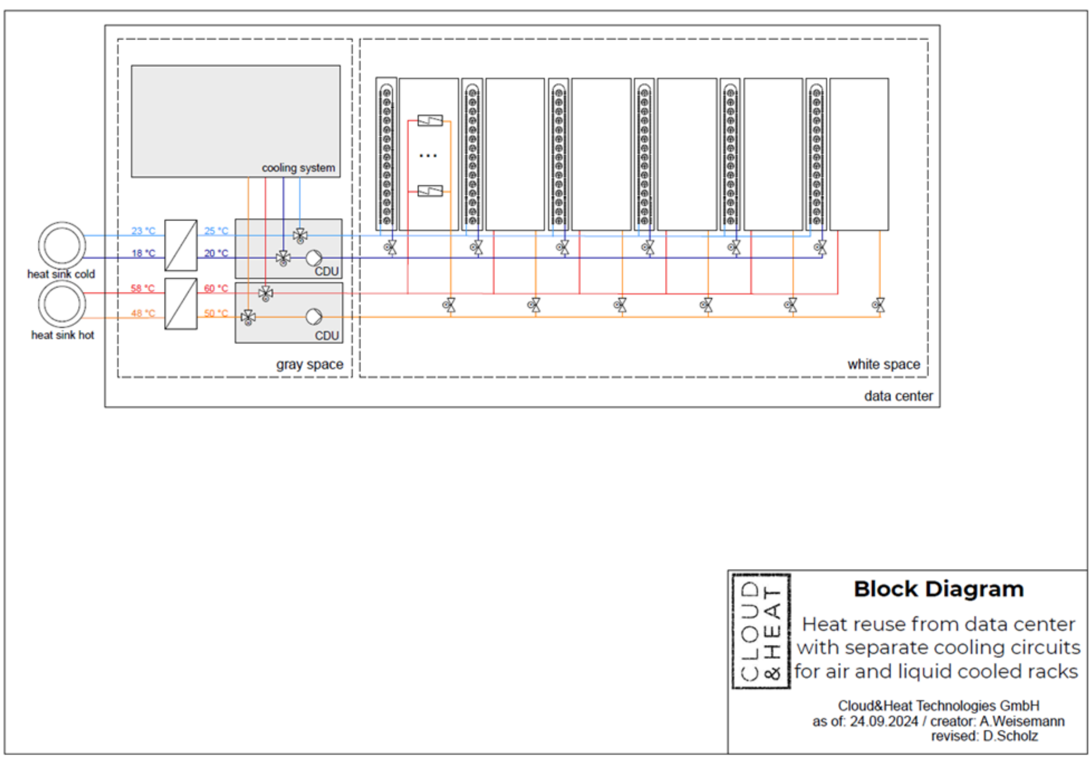

Figure 19 – Heat reuse from data center with separate cooling circuits for air and liquid cooled racks (Credit: Cloud&Heat Technologies)

# Appendix II - Two-phase DLC heat reuse

For 2-phase cooling, the ITE is cooled by an evaporating dielectric working fluid, which is partially vaporized. The vapor is condensed to reject the heat. This can be done any of several ways: indirect heat transfer from air-cooled ITE to 2-phase (e.g., via a CRAH or rear-door heat exchanger), direct to chip, or immersion. Coolant circulation can be active (pump via a CDU) or passive (via thermosyphon operation).

There are 2 variants of heat reuse with 2-phase cooling that can be implemented with any 2-phase cooling configuration:

- Direct heat recovery by condensing in the heat exchanger (HX) sending heat to the end user . This is the 2-phase analog of Scenarios 2a / 3a in Table 2.

- Add a vapor recompressor before condensing hotter vapor in the HX. (This essentially integrates the heat pump with the ITE cooling loop). This is the 2-phase analog of Scenarios 2c / 3c in Table 2, but avoids a secondary refrigerant loop and intermediate exchanger between ITE cooling and heat pump, so the COP is inherently higher than indirect heat pump. A generic sketch showing the 2-phase operating and heat recovery modes is shown in Figure 20.

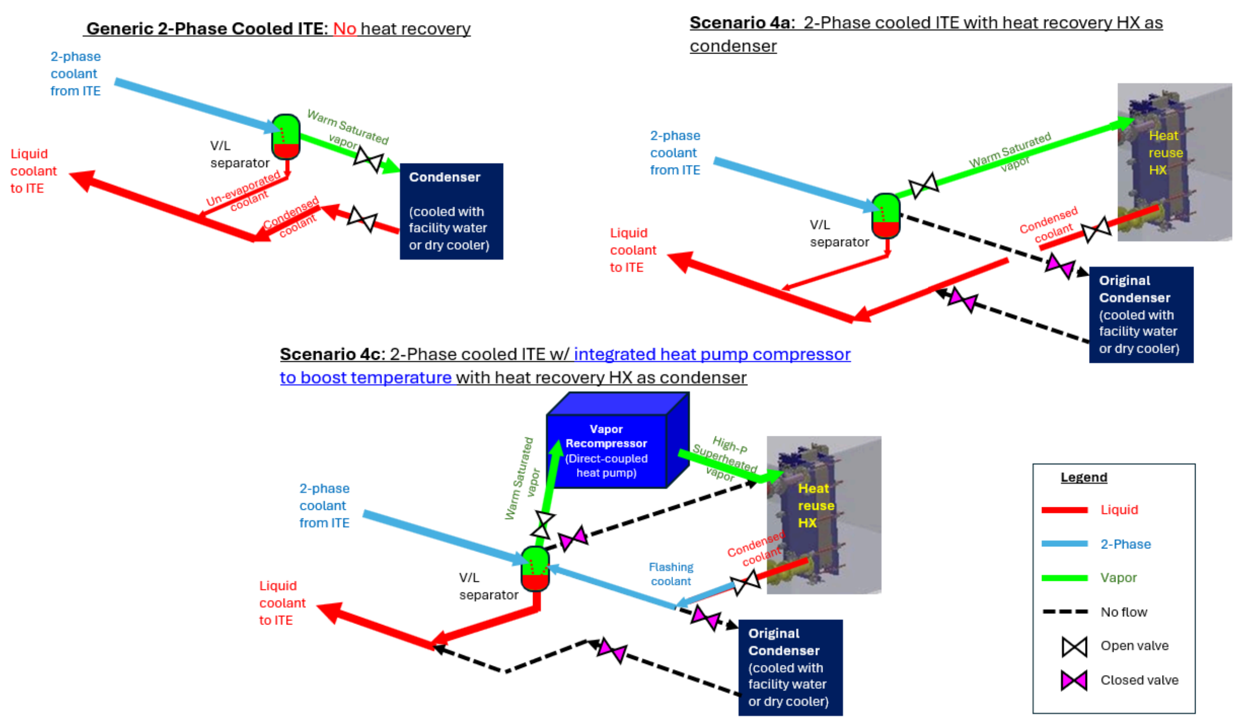


Figure 20 – Generic 2-phase cooling operating modes without and with heat reuse (Credit: QuantaCool)

Table 8 - Scenario combinations for 2-phase liquid cooling

| Scenario | ITE cooling | Facility supply-return temperatures | Heat Storage | Boosting mechanisms |
|---|---|---|---|---|
| 4a | Liquid cooling 2-phase (D2Chip / Immersion + cooling towers / dry-coolers) | supply: 30-40<br>return: 40-55 | No | No |
| 4b | | | Yes | No |
| 4c | | | No | Heat pump |
| 4d | | | Yes | Heat pump |

# Appendix III - Heat pump heat reuse additional considerations

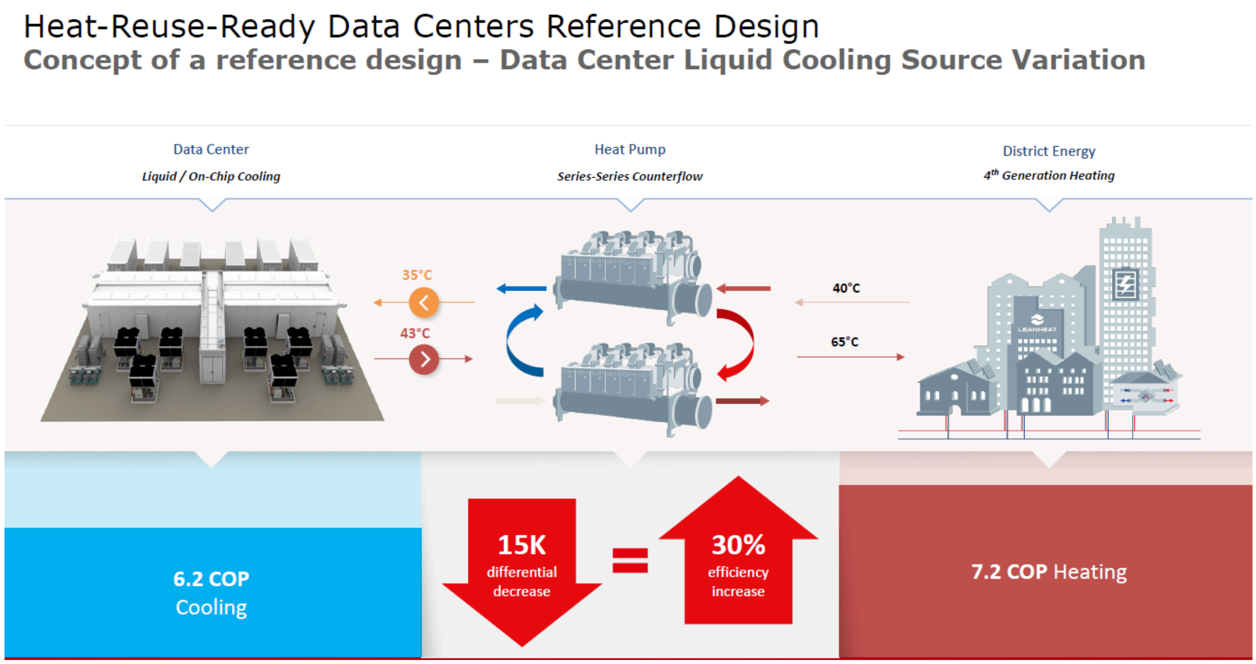


Figure 21 – Impact of a series-series counterflow heat pump on COP (Credit: NZIH)

Frequently missed in discussions on the potential for heat reuse is the business case improvement implication of moving from traditional CRAH-based systems to liquid cooling. Shown here is the conservative 15K increase in cooling temperature which corresponds with that change to direct-on-chip cooling. Heat pump efficiency increases roughly 2% for each 1K decrease in the differential work the heat pump has to accomplish. This directly correlates with heat reuse operating cost, meaning that a 15K increase in cooling temperature increases the heat reuse business case return by ~30%.

# About Open Compute Project

The Open Compute Project Foundation is a 501(c)(6) organization which was founded in 2011 by Facebook, Intel, and Rackspace. Our mission is to apply the benefits of open source to hardware and rapidly increase the pace of innovation in, near and around the data center and beyond. The Open Compute Project (OCP) is a collaborative community focused on redesigning hardware technology to efficiently support the growing demands on compute infrastructure. For more information about OCP, please visit us at http://www.opencompute.org