HOLISTIC ENERGY MANAGEMENT AND THERMAL WASTE INTEGRATED SYSTEM FOR ENERGY OPTIMIZATION

HEATWISE

# KPIs for energy performance and waste heat recovery efficiency from IT infrastructure in buildings

Project ID: 101138491

Prepared by: Aalborg University

September 2024

Funded by
the European Union

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
**State Secretariat for Education,**
**Research and Innovation SERI**
EU Framework Programmes

# KPIs for energy performance and waste heat recovery efficiency from IT infrastructure in buildings

| | |
|---|---|
| Project acronym | **HEATWISE** |
| Project title | Holistic Energy Management and Thermal Waste Integrated System for Energy Optimization |
| GA Number | 101138491 |
| Call identifier | HORIZON-CL5-2023-D4-01 |
| Topic identifier | HORIZON-CL5-2023-D4-01-04 |
| Project duration | 36 months |
| Related work package | WP3 |
| Deliverable no. | D 3.3 |
| Dissemination Level | PU |
| Deliverable type | Report |
| Due Date of deliverable | September 2024 |
| Completion date of deliverable | 26 September 2024 |
| Coordinator | H1 Systems |
| Website | www.heatwise.eu |
| Lead beneficiary of deliverable | AAU |
| Author(s) | Melgaard, Simon Pommerencke<br>Jensen, Rasmus Lund<br>Humbert, Gabriele<br>Yilmaz, Cagatay |
| Contributor(s) | Tell, Alessandro |
| Reviewer(s) | Barestrand, Henrik |
| Keywords | Data Centre, Energy management, Waste heat, Building, HVAC, Systems, KPI, Energy savings, COP |

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

**Document history:**

| Revision | Date | Status |
|---|---|---|
| V0.1 | 16.08.2024 | Initial draft |
| V0.2 | 15.09.2024 | Version sent to review |
| V0.3 | 18.09.2024 | Version after internal review |
| V0.4 | 18.09.2024 | Version sent for internal approval |
| V1.0 | 26.09.2024 | Final report |

## Disclaimer

## Copyright Notice

## Acknowledgment

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

## Table of contents

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

# 1. Executive Summary

The aim of this report was to identify useful key performance indicators (KPIs) to be used in the HEATWISE project for assessing the utilization of waste heat recovery from the IT infrastructure in the building. The KPIs could, in practice, also be used for other waste heat sources.

To begin with, the generalized schematic of the hot water flows in buildings with integrated data centres and potential grid connections is presented in section 3.1. This schematic is on a high level, meaning that it can be adjusted to fit the different configurations of the pilots and other buildings.

Following the schematic, a literature study of existing KPIs for waste heat use in data centres (section 4.1) and buildings (section 4.2) was made to provide an overview of what is currently used. Some of the KPIs for the data centre are also incorporated in the HEATWISE project, but these are further covered and explained in Deliverable 6.1.

With the literature study performed and the currently used KPIs identified, seven KPIs suitable for assessing the buildings with integrated data centres were made, these can all be seen in section 4.3. These seven KPIs are the following:

- Waste heat utilization (WHU)
    - The purpose is to assess how much of the waste heat is actually utilized.
    - It is based on the energy reuse factor (ERF) and waste heat recovery efficiency.
- Degree of coverage for the building ($DOC_B$)
    - The purpose is to assess how much of the building's heating demand is covered by the data centre waste heat.
    - It was found in literature.
- Potential waste heat coverage for the building ($PWHC_B$)
    - The purpose is to assess how much of the building's heating demand can potentially be covered using the waste heat from the data centre.
    - It is a newly developed KPI.
- Primary energy savings for the building ($PES_B$)
    - The purpose is to assess how much primary energy is saved for the building by using the waste heat compared to if it was not used. It is slightly different from the definition used for the data centre, which can be seen in deliverable 6.1.
    - It was found in literature.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

- COP of waste heat utilization in building ($COP_{WHU,B}$)
    - The purpose is to analyze how much electricity is used to provide the waste heat to the building.
    - It is based on the classic coefficient of performance (COP), but modified to take into account the circulation pumps and other necessary electricity use.
- COP of waste heat utilization to grid ($COP_{WHU,G}$)
    - The purpose is to analyze how much electricity is used to provide the waste heat to the grid.
    - It is based on the classic COP but modified to take into account the circulation pumps and other necessary electricity use.
- Waste heat utilization restrictors (WHUR)
    - The purpose of the KPI is to provide feedback on which part of the waste heat supplied from the data centre restricts its use in the building.
    - It is a newly developed KPI.

After the KPIs were selected and developed, those KPIs where the pilots had the necessary data were tested in section 4.4 to see how they would work initially. In this case, it was the PSNC and EMPA pilots, as these have an air-cooled data centre connected. For overviews and details of the pilots, see HEATWISE deliverable 3.2.

It can be seen that the PSNC pilot has high optimization potential. This is because it is currently utilizing a system where the temperature from the data centre is very low and thus needs to be increased by heat pumps, causing the heat pumps to be the main heat provider instead of the waste heat.

For the EMPA pilot, several of the KPIs have the necessary measurement points, but as the liquid cooling system has not yet been deployed, the data centre is solely air-cooled. Therefore, it is not currently possible to use any waste heat due to the low temperatures at which it can be supplied.

The conclusion is, therefore, that though the usefulness of the waste heat is currently rather low, there appears to be a significant potential if the water temperature out of the data centres can be increased using the ZutaCore technology. This will, though, be further investigated in later deliverables such as D3.4.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

# 2. List of abbreviations

| Acronym | Meaning |
|---|---|
| **AHU** | Air handling unit |
| **COP** | Coefficient of performance |
| **DC** | Data Centre |
| **DHW** | Domestic hot water |
| **DOC** | Degree of coverage |
| **ERF** | Energy reuse factor |
| **EQC** | Energy quality coefficient |
| **HP** | Heat pump |
| **HVAC** | Heating, ventilation, and air-conditioning |
| **KPI** | Key performance indicator |
| **MHS** | Main heating energy supply |
| **PES** | Primary energy savings |
| **PWHC** | Potential waste heat coverage |
| **WHR** | Waste heat recovery |
| **WHU** | Waste heat utilization |
| **WHUR** | Waste heat utilization restrictors |

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

# 3. Introduction

This report focuses on specifying the key performance indicators (KPIs) for this project when assessing the performance of using the waste heat in the building or grid. It takes offset in classic KPIs for waste heat use in data centres and KPIs for waste heat use in buildings and tries to harmonize these to get KPIs for waste heat from data centres used in buildings or grid.

It is important to get suitable KPIs because using those for the data centres or buildings alone may create suboptimal conditions where only one performs well while the other performs poorly.

Some KPIs to be used are adapted from the classic KPIs, while others are newly developed with the integration of data centres in buildings in mind.

## 3.1. Measurement points used in the KPI methods

All upcoming KPIs will require different measurements at various locations in the building or the intersection between the data centre and the building. The measurement points have therefore been standardized to an idealized building and data centre schematic, as seen in Figure 3.1.

In total, there are twelve different measurement locations, which can all include a combination of water temperature (T), water flow rate (F), heating energy (H), and electric energy (E).

It should be noted that not all of the measurement locations will be available for all buildings. For example, point 1/2 should only be used if points 3/4 and 7/8 are not available, as they are in a better location to measure in due to the separate temperatures from the different systems, but having point 1/2 is better than not having the measurement.

If the data center is supplying the heat directly to the grid, the points 11/12 are used.

The HVAC systems marked in Figure 3.1 include all the individual heating, ventilation, and air-conditioning (HVAC) systems, along with the domestic hot water (DHW) systems. If measurements are needed directly at the individual HVAC or DHW systems, the variable

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

will be named $X_{HVAC}$. The individual components included in this category could be heating coil for air handling unit, heat exchanger for space heating, and a heat exchanger for DHW.

The building's main heating energy supply (MHS) defines the heating source of the building. It can, for example, be a boiler, district heating supply, heat pump, or something else that supplies the heat.

When defining the measurement points in the KPIs, they will start with either T, F, H, or E to specify the data type, followed by the point name from section 3.1.1 to section 3.1.12.

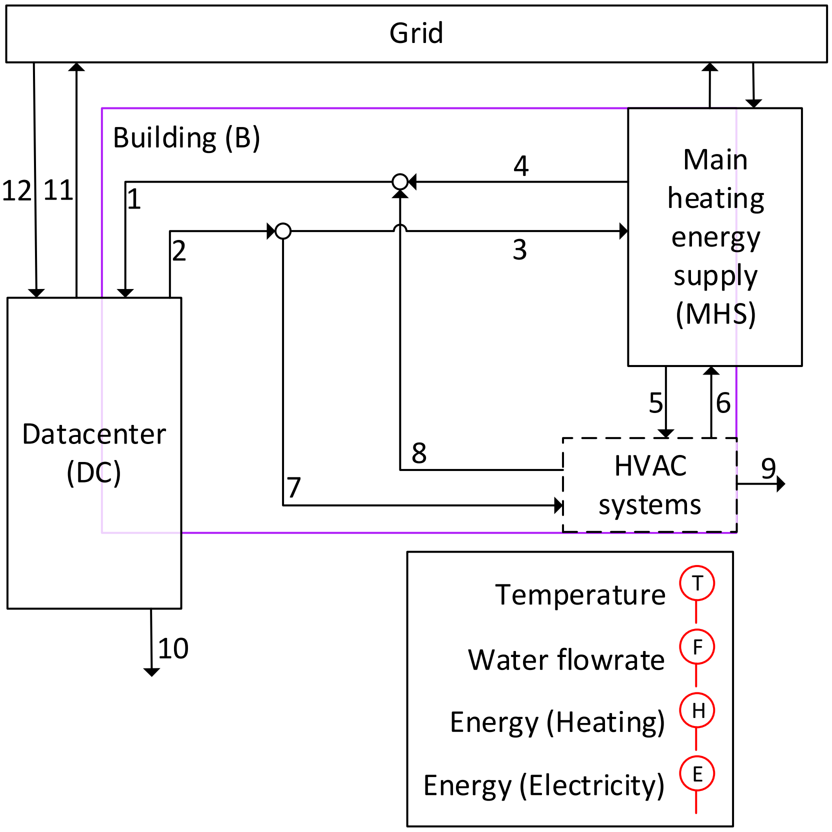

*Figure 3.1: Building and data centre schematic with location markings of the different measurement points. The legend indicates the four measurement types appearing in the different KPIs.*

## 3.1.1. Point 1 – B_to_DC

This point is located in the connection between the building and the data centre, where the water is circulated back to the data centre. This point cannot distinguish between the different building systems, as it can only measure the mixed water from all the systems.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

### 3.1.2.Point 2 – DC_to_B

This point is located in the connection between the data centre and the building, where the coolant is supplied to the building. It is measured before branching towards individual HVAC systems or the MHS.

### 3.1.3.Point 3 – DC_to_MHS

This point is located in the connection between the data centre and the main heating energy supply, where the water is supplied to the main heating energy supply. It is measured after all branching, meaning it will not branch anymore before reaching the main heating energy supply.

### 3.1.4.Point 4 – MHS_to_DC

This point is located in the connection between the main heating energy supply and the data centre, where the water is circulated back to the data centre. It is measured before merging with other branches, meaning it only measures what the main heating energy supply uses.

### 3.1.5. Point 5 – MHS_to_HVAC

This point is located in the connection between the main heating energy supply and the individual HVAC (and DHW) systems, where the water is supplied to the HVAC systems. It is preferably measured in the individual HVAC systems.

### 3.1.6. Point 6 – HVAC_to_MHS

This point is located in the connection between the individual HVAC (and DHW) systems and the main heating energy supply, where the water is circulated back to the main heating energy supply. It is preferably measured in the individual HVAC systems.

### 3.1.7. Point 7 – DC_to_HVAC

This point is located in the connection between the data centre and the HVAC (and DHW) systems, where the water is supplied to the HVAC. It is measured at the individual systems after all branching is done, meaning that it can consist of many separate measurement

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

points that must be kept individual for each system to get the precise distribution and use.

### 3.1.8. Point 8 – HVAC_to_DC

This point is located in the connection between the HVAC (and DWH) systems and the data centre, where the water is circulated back to the data centre. It is measured at the individual systems before any branching is done, meaning that it can consist of many separate measurement points that must be kept individual for each system to get the precise distribution and use.

### 3.1.9. Point 9 – HVAC_to_out

This point is located in the individual HVAC systems that have a possibility of dumping heat outside of the building. This could, for example, be dry coolers or a heat exchanger on the exhaust side of an air handling unit (AHU).

### 3.1.10. Point 10 – DC_to_out

This point is located in the data centre, where it dumps the excess heat. This could, for example, be through a dry cooler.

### 3.1.11. Point 11 – DC_to_GRID

This point is located in the connection between the data centre and the grid, where the hot water is supplied to the grid.

### 3.1.12. Point 12 – GRID_to_DC

This point is located in the connection between the grid and the data centre, where the water is circulated back to the data centre.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

# 4. KPI overview

This section includes an overview of existing KPIs for waste heat in data centres and existing KPIs for waste heat in buildings. Following these overviews, the KPIs for waste heat in data centres integrated into buildings are adopted or developed before being tested on the pilots where possible with the currently available data.

## 4.1. KPIs for waste heat in data centres

The Energy Reuse Factor (ERF) is a key performance indicator used in the context of data centre sustainability, specifically to measure the effectiveness of energy reuse. ERF quantifies the proportion of a data centre's total energy consumption that is reused, typically as waste heat, in other applications outside the data centre itself.

The ERF is calculated using the following formula:

$$ERF = {}^{E_{REUSE}}\!/_{E_{DC}}$$

- **$E_{REUSE}$** (Energy Reused): This is the amount of energy, measured in kilowatt-hours (kWh), that is reused or repurposed outside the data centre's boundary. For instance, waste heat can be used for heating nearby buildings or industrial processes.
- **$E_{DC}$** (Total Energy Consumption): This represents the total energy consumed by the data centre, including all electricity, fuels, and other energy sources used for cooling (European Commission, 2024), typically also measured in kilowatt-hours (kWh).

ERF is an essential metric for assessing the environmental impact of a data centre. A higher ERF indicates that a greater portion of the energy consumed by the data centre is being effectively reused, thereby reducing the overall waste and improving the sustainability of the facility. It aligns with broader energy efficiency and sustainability goals by promoting the recovery and reuse of energy that would otherwise be lost.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

## 4.2. KPIs for waste heat in buildings

In the context of building applications, indicators of waste heat recovery (WHR) is not considered within the system-level KPIs commonly adopted in the literature (Fowler, Wang, Deru, & Romero, 2010) (Li, Hong, Lee, & Sofos, 2020). Additionally, to the best of the author's knowledge, no standards, reports, or papers have been dedicated to reviewing KPIs for WHR in buildings. Nevertheless, an increasing amount of publications and reports have been dedicated to numerical and experimental case studies, although a higher share of publications targeted the industrial sector (Farhat, Faraj, Hachem, Castelain, & Khaled, 2022).

KPIs for waste heat recovery span across multiple domains. As discussed within the SoWhat project (Porta & Oliver, 2021), KPIs for WHR can be clustered in economic, energetic, environmental, and social domains. Regarding energetic KPIs, these need to evaluate not only how much thermal energy can be recovered from the heat source, but also how much thermal energy can be successfully transferred to the user. Three key technical aspects become, therefore, crucial:

(i) **Temporal aspect**: when is the heat recovered compared to when is the heat demanded;
(ii) **Qualitative aspect**: the temperature levels of the recovered heat compared to the demand;
(iii) **Quantitative aspect**: how much energy is recovered compared to the amount required.

Based on several case studies for waste heat recovery solutions in buildings, an overview of the most adopted KPIs can be found in Table 1. One popular KPI is the waste heat recovery efficiency (resembling the ERF from section 4.1), which measures the heat recovered over the total heat provided to the WHR technology. The WHR efficiency is typically calculated for short periods of operation (from minutes to days), although few works also reported an annual WHR efficiency (Korpela, et al., 2022) (Wallin, Madani, & Claesson, 2012). Differently from the waste heat recovery efficiency, the system efficiency also accounts for the auxiliaries and other components necessary to fulfill the demand requirements. The system boundaries considered for this metric are case study specific. Compared to the previous KPI, the focus is shifted more toward the entire energy system rather than WHR technology exclusively. Nonetheless, such a metric only considers the amount of heat supplied and disregards if such heat is rather used in the building or dispersed. That is, The traditional definitions of WHR and system efficiency focus more on the recovery process rather than the end-use of the recovered energy.
In contrast, the primary energy saving (PES) for the building calculates the energetic benefits of implementing a WHR system (for the PES definition of data centres, see

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

deliverable 6.1). These benefits are calculated by considering how energy demand is satisfied and requires a baseline to be estimated, e.g. the energy consumption prior to the WHR system implementation. The PES depends on the share of recovered heat that is used within the building, namely the degree of coverage.

Overall, there is consensus on the energetic KPIs adopted to assess the benefits of WHR systems. However, only a few KPIs measure the quality of a waste heat recovery stream. An attempt in this direction was made by Wu et al. (Wu, et al., 2024), where energy quality coefficient (EQC) was proposed, which depends on the temperature of the recovered heat as well as on the ambient temperature. However, no influence of the desired application temperature, e.g. required temperature level to provide domestic hot water, is accounted for in this metric.

Concerning economic and environmental KPIs, most of the reviewed studies reported on yearly saved costs from WHR solutions and on the calculation of the payback time to ensure a return on the investment. Furthermore, emission reductions, calculated as $kg_{CO2}/y$, are often reported in the analysed literature.

*Table 1 Overview of the most popular KPIs for waste heat recovery in buildings.*
*(*) up to 4 references per KPI are reported.*

| Category | Name | Description | Aspect(s) Considered | Ref. (*) |
|---|---|---|---|---|
| *Energetic* | *Waste Heat Recovery Efficiency* | The ratio between heat recovered (outlet of a WHR technology) and maximum amount of available heat (input to WHR technology). | *Quantitative.* | (Cuce, Cuce, & Riffat, 2016)<br>(Wehbi, et al., 2022)<br>(Mardiana-Idayu & Riffat, 2012)<br>(Farhat, Faraj, Hachem, Castelain, & Khaled, 2022) |
| | *System efficiency* <u>*or*</u> *System performance ratio* | Evaluates the overall performance of the waste heat recovery system (including auxiliaries). In most cases, the amount of energy successfully used in the building is not accounted for. | *Quantitative; Qualitative.* | (Reddy, Bonfochi Vinhaes, Naber, Robinett, & Shahbakhti, 2023)<br>(Farhat, Faraj, Hachem, Castelain, & Khaled, 2022)<br>(Wallin, Madani, & Claesson, 2012)<br>(Sunu, et al., 2020) |

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

| | | | | |
|---|---|---|---|---|
| | *Primary Energy Saving (PES)* | Evaluates the potential energy savings achieved through waste heat recovery. It requires a baseline. | *Quantitative; Qualitative; Temporal.* | (Mardiana-Idayu & Riffat, 2012)<br>(Reddy, Bonfochi Vinhaes, Naber, Robinett, & Shahbakhti, 2023)<br>(Pokhrel, Amiri, Poncet, Sasmito, & Ghoreishi-Madiseh, 2022)<br>(Korpela, et al., 2022) |
| | *Degree of Coverage* | Measures how much of the total heating demand is covered by the heat recovery system. | *Quantitative; Qualitative; Temporal.* | (Wallin, Madani, & Claesson, 2012) |
| | *RES contribution rate or RES share* | Share of RES energy over total primary energy required to satisfy the building demand. Adopted to quantify if RES integration is improved thanks to WHR solutions. | *Quantitative; Qualitative; Temporal.* | (Korpela, et al., 2022) |
| | *Energy Quality Coefficient (EQC)* | Indicator of energy quality, with 0 indicating no use and 1 indicating mechanical energy. For thermal systems, EQC is defined as $EQC_{th} = 1 - \frac{T_0}{T_h}$, with $T_0$ referring to ambient temperature and $T_h$ referring to the hot temperature. | *Qualitative.* | (Korpela, et al., 2022) |
| | *Coefficient of performance (COP)* | Ratio of useful heating over energy required. In few instances, calculated as seasonal COP (SCOP), for example (Korpela, et al., 2022) and (Farhat, Faraj, Hachem, Castelain, & Khaled, 2022). | *Quantitative;*<br>*Qualitative.* | (Cuce, Cuce, & Riffat, 2016)<br>(Sunu, et al., 2020)<br>(Pokhrel, Amiri, Poncet, Sasmito, & Ghoreishi-Madiseh, 2022)<br>(Perez, et al., 2016) |
| | *Share of heat supplied by* | is the proportion of total heat demand that is supplied by the heat pump. | *Quantitative.* | (Perez, et al., 2016) |

| | | | | |
|---|---|---|---|---|
| | *the heat pump* | | | |
| *Economic* | *Annual cost reduction* | Reduction in operational costs derived from waste heat recovery. It requires a baseline. | - | (Wu, et al., 2024)<br>(Burlacu, et al., 2018)<br>(Wehbi, et al., 2022)<br>(Korpela, et al., 2022) |
| | *Payback time* | Amount of time to recover the investment cost associated with the WHR system. | - | (Wu, et al., 2024)<br>(Wehbi, et al., 2022)<br>(Burlacu, et al., 2018)<br>(Korpela, et al., 2022) |
| *Environmental* | *Emissions reduction* | Evaluates the reduction in CO2 emissions achieved through the implementation of the waste heat recovery system. It requires a baseline. | - | (Wehbi, et al., 2022)<br>(Korpela, et al., 2022)<br>(Burlacu, et al., 2018)<br>(Zabihi Tari, Khosravi, Maleki Dastjerdi, Khoshnevisan, & Ahmadi, 2023) |

## 4.3. KPIs for waste heat in data centres integrated in buildings

This subsection presents and explains the details of the KPIs used further in this project.

In total, seven different KPIs have been selected to cover different aspects of using waste heat and understanding the potential for using waste heat. These are further explained individually in sections 4.3.1 to 4.3.7.

### 4.3.1. KPI1 – Waste heat utilization

The waste heat utilization (WHU) assesses how much of the waste heat generated by the data centre is utilized in either the building or the grid. It is similar in structure and purpose to the ERF from section 4.1 but differs in the fact that it does not consider how much energy is supplied to the data centre. It also resembles the waste heat recovery efficiency from section 4.2, though it takes into account how much of the waste heat is

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

actually utilized, not just recovered. It can, therefore, be seen as an extension of both taking into account the actual reuse of the waste heat.

The KPI has built-in limits, meaning that the worst value will be 0, and the best value will be 1. If the KPI becomes 0, it means that all the waste heat is dumped to the outside, while a value of 1 means that all waste heat is used in either the building or the grid.

It is found in two general formulations, depending on available data. The measurement points can be seen in Figure 4.1.

The first formulation requires fewer general data points and is shortened as $WHUE_S$ (equation (1)), with the S being for simple. The second formulation requires more data points and is therefore shortened as $WHUE_D$ (equation (2)), with the D being for detailed.

$$WHU_S = \frac{H_{DC\_to\_B} + H_{DC\_to\_GRID} - H_{HVAC\_to\_out}}{H_{DC\_to\_B} + H_{DC\_to\_GRID} + H_{DC\_to\_out}} \tag{1}$$

$$WHU_D = \frac{H_{DC\_to\_MHS} + H_{DC\_to\_HVAC} + H_{DC\_to\_GRID} - H_{HVAC\_to\_out}}{H_{DC\_to\_MHS} + H_{DC\_to\_HVAC} + H_{DC\_to\_GRID} + H_{DC\_to\_out}} \tag{2}$$

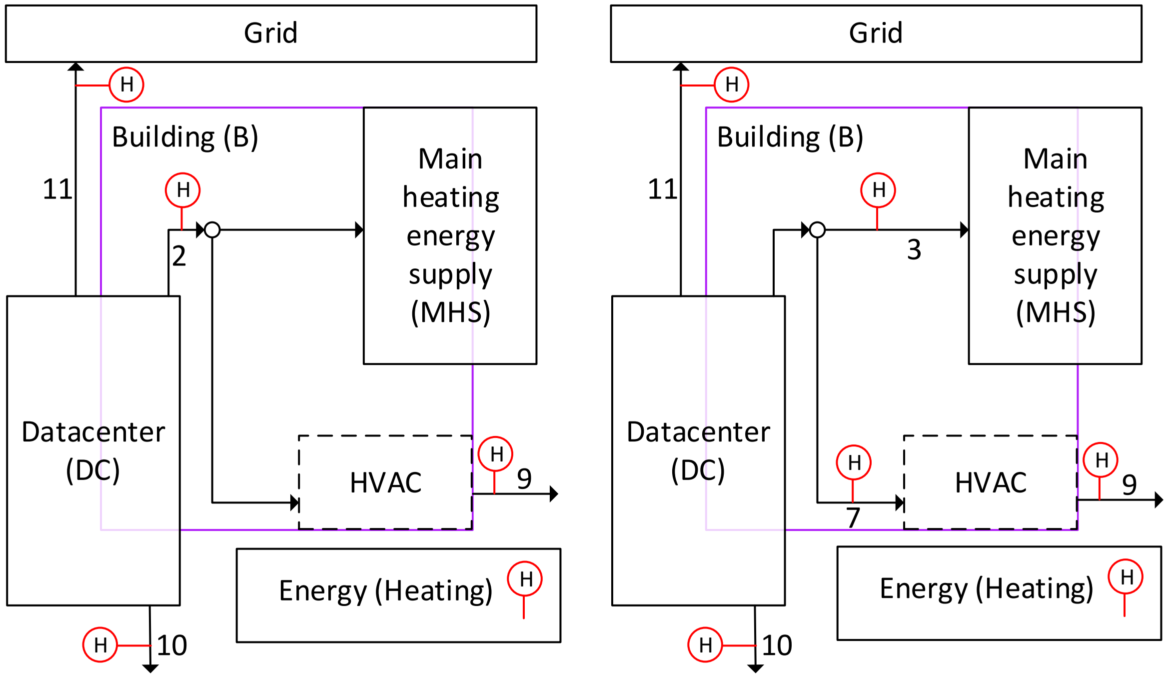

*Figure 4.1: Measurement locations for the $WHU_S$ (equation (1)) to the left and the $WHU_D$ (equation (2)) to the right.*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

### 4.3.2. KPI2 – Degree of coverage for the building

The degree of coverage for the building ($DOC_B$) assesses how much of the building's total heating energy use is covered by waste heat from the data centre. The KPI was found in the literature study in section 4.2.

The KPI has built-in limits, meaning that the worst value will be 0, and the best value will be 1. If the KPI becomes 0, the waste heat covers none of the building's heating need, while if it becomes 1, the entire heating need is covered.

It is found in two general formulations, depending on available data. The measurement points can be seen in Figure 4.2. The first formulation requires fewer general data points and is shortened as $DOC_{B,S}$ (equation (3)), with the S being for simple. The second formulation requires more data points and is therefore shortened as $DOC_{B,D}$ (equation (4)), with the D being for detailed.

$$DOC_{B,S} = \frac{H_{DC\_to\_B}}{H_{DC\_to\_B} + H_{MHS\_to\_HVAC}} \tag{3}$$

$$DOC_{B,D} = \frac{H_{DC\_to\_MHS} + H_{DC\_to\_HVAC}}{H_{DC\_to\_MHS} + H_{DC\_to\_HVAC} + H_{MHS\_to\_HVAC}} \tag{4}$$

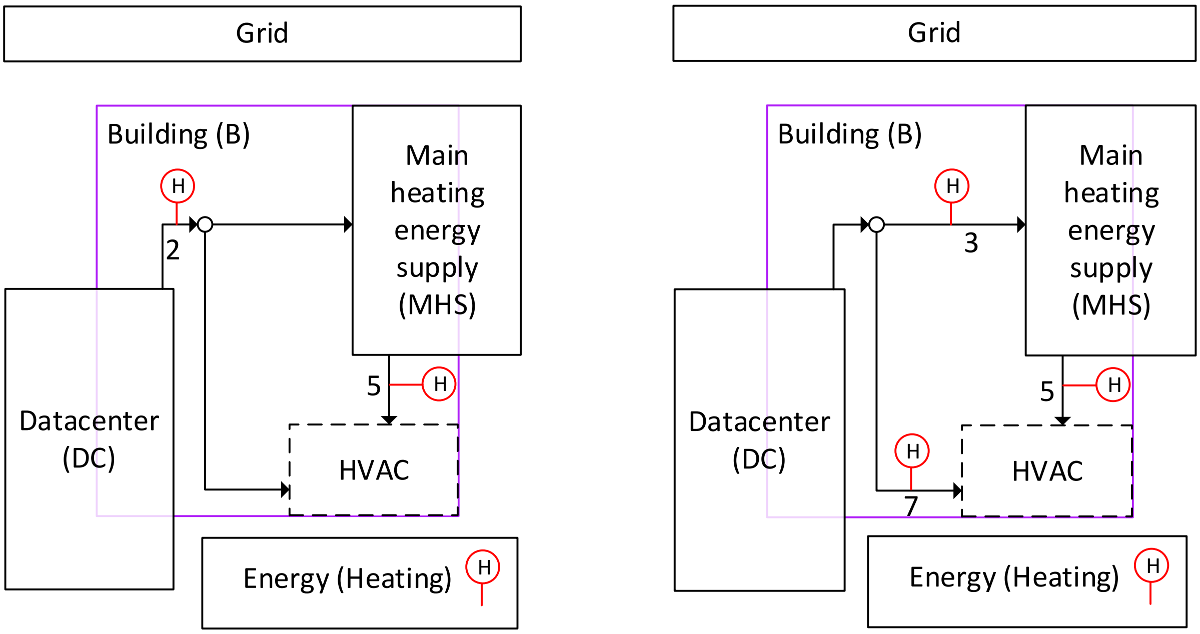

*Figure 4.2: Measurement locations for the $DOC_{B,S}$ (equation (3)) to the left and the $DOC_{B,D}$ (equation (4)) to the right.*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

### 4.3.3. KPI3 – Potential waste heat coverage for the building

The potential waste heat coverage for the building ($PWHC_B$) assesses how much of the building's total heating energy use could potentially be covered by waste heat from the data centre.

The KPI only has partial built-in limits, meaning that the worst value will be 0, but there is no upper limit. If the KPI becomes 0, the waste heat could not cover any of the building's heating need, while if it becomes 1, the entire heating need could theoretically be covered. If the value becomes larger than 1, the data centre produces more waste heat than what could be used in the building under the current operating conditions.

It is found in two general formulations, depending on available data. The measurement points can be seen in Figure 4.3.

The first formulation requires fewer general data points and is shortened as $PWHC_{B,S}$ (equation (5)), with the S being for simple. The second formulation requires more data points and is therefore shortened as $PWHC_{B,D}$ (equation (6)), with the D being for detailed.

| | | |
|---|---|---|
| | $PWHC_{B,S} = \frac{H_{DC\_to\_B} + H_{DC\_to\_out}}{H_{DC\_to\_B} + H_{MHS\_to\_HVAC}}$ | *(5)* |
| | $PWHC_{B,D} = \frac{H_{DC\_to\_MHS} + H_{DC\_to\_HVAC} + H_{DC\_to\_out}}{H_{DC\_to\_MHS} + H_{DC\_to\_HVAC} + H_{MHS\_to\_HVAC}}$ | *(6)* |

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

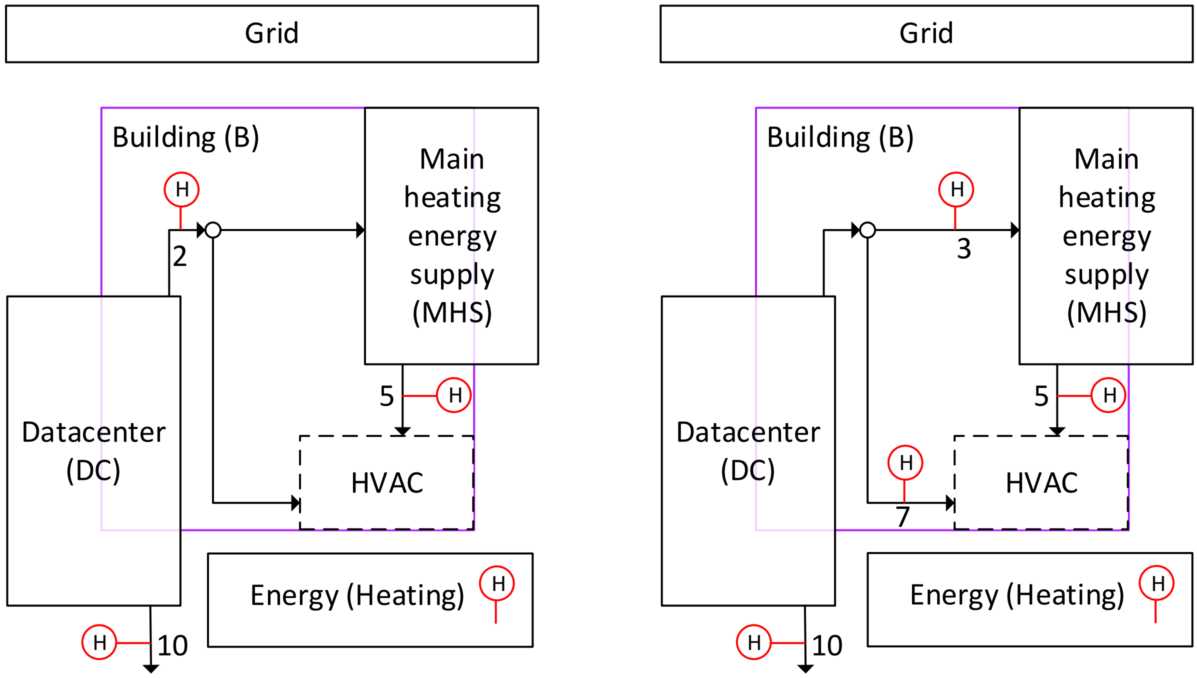

*Figure 4.3: Measurement locations for the PWHC$_{B,S}$ (equation (5)) to the left and the PWHC$_{B,D}$ (equation (6)) to the right.*

### 4.3.4. KPI4 – Primary energy savings for the building

The Primary Energy Savings (PES$_B$) for the building will only be calculated if the building is operating under normal conditions. In this case, normal conditions mean that it has not increased its heating energy use to better fit the data centre's waste heat production. However, if all the extra waste heat from the data centre is handled by dumping it out of the building (through position 9) it can also be calculated.

The reason the KPI cannot be calculated when the HVAC systems run in a mode that forces the building to accept more energy is that it is no longer representative of the buildings energy use without the data centre. This is because the baseline has been chosen to be the energy use at the same time instead of calculating a theoretical baseline based on historical data. It was done this way as it is the simplest version that can be generalized for many different buildings without the need for complex models, while also not making assumptions about a theoretical energy use that is expected under the circumstances.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

The included terms for the calculation are set in accordance with the European Unions energy performance of buildings directive (THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2024).

The result of the $PES_B$ will be a value between 0 and 1. A value of 1 indicates a 100% primary energy saving, a value of 0 means that there is no saving. In reality it will not normally be possible to reach a value of 1 as the electricity use will be added to the heating energy use, while only the heating energy use can be fully compensated by the data centre.

If it is in normal operation, then the $PES_B$ is calculated either as the $PES_{B,S}$ (equation (7)) or $PES_{B,D}$ (equation (8)) depending on the measurement point locations as seen in Figure 4.4.

$$\begin{gathered}
H_{gain,s} = \left(H_{DC\_to\_B} - H_{HVAC\_to\_out}\right) * F_H \\
H_{use,s} = \left(H_{MHS\_to\_HVAC} + H_{DC\_to\_B} - H_{HVAC\_to\_out}\right) * F_H \\
E_{use,s} = \left(E_{MHS\_to\_HVAC} + E_{HVAC} + E_{light}\right) * F_E \\
PES_{B,S} = \frac{H_{gain,s}}{H_{use,s} + E_{use,s}}
\end{gathered} \tag{7}$$

$$\begin{gathered}
H_{gain,d} = \left(H_{DC\_to\_MHS} + H_{DC\_to\_HVAC} - H_{HVAC\_to\_out}\right) * F_H \\
H_{use,d} = \left(H_{MHS\_to\_HVAC} + H_{DC\_to\_MHS} + H_{DC\_to\_HVAC} - H_{HVAC\_to\_out}\right) * F_H \\
E_{use,d} = \left(E_{MHS\_to\_HVAC} + E_{HVAC} + E_{light}\right) * F_E \\
PES_{B,D} = \frac{H_{gain,d}}{H_{use,d} + E_{use,d}}
\end{gathered} \tag{8}$$

FH is the primary energy factor for the heating energy, while FE is the primary energy factor for the electricity. Both will depend on the local conditions for generating the heating energy and the electricity. The KPI can also easily be converted to work for either cost savings or CO2e emission savings by substituting the primary energy factors for their price or CO2e equivalents.

$E_{light}$ is the electricity use for artificial light in the building.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

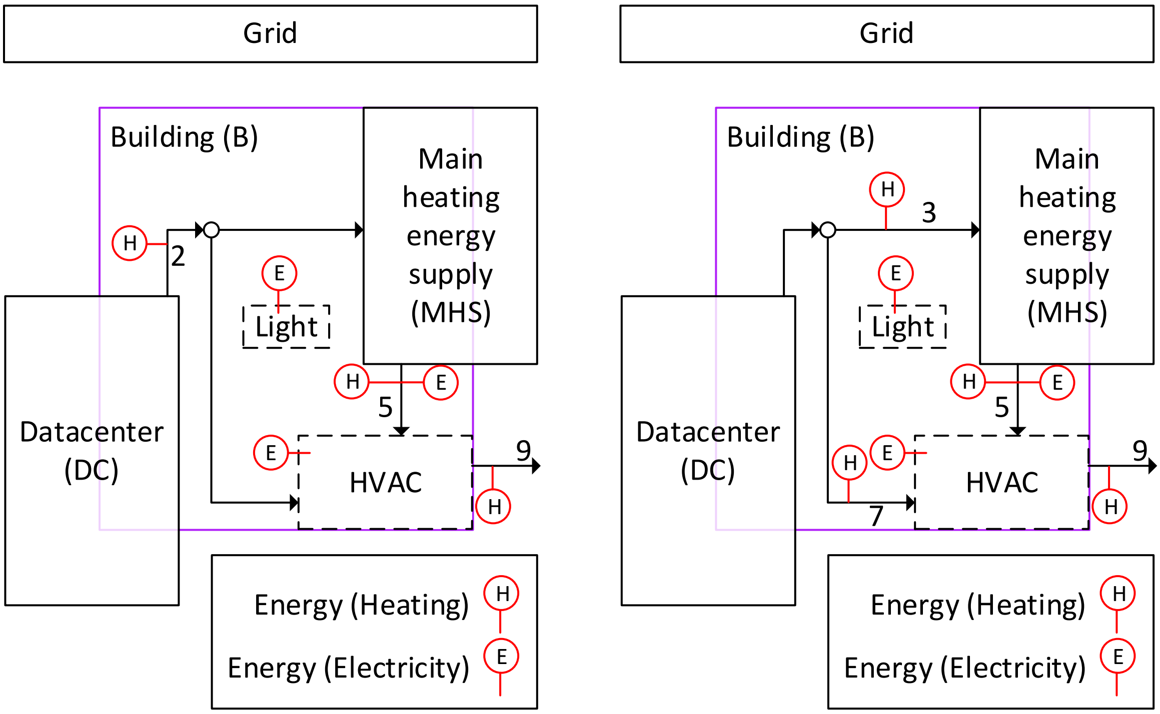

*Figure 4.4: Measurement locations for the $PES_{B,S}$ (equation (7)) to the left and the $PES_{B,D}$ (equation (8)) to the right.*

### 4.3.5. KPI5 – COP of waste heat utilization in building

The COP of waste heat utilization in building ($COP_{WHU,B}$) is used to assess how much electrical energy is used to transport and utilize the data centre waste heat in the building. It takes offset in the classic COP formulation from section 4.2.

It is only partially limited, with 0 being the lower limit indicating that there is an electricity use, but no waste heat is being utilized. In general the KPI should be as high as possible as that will indicate better performance, with lower electricity use compared to heating energy used.

The KPI is found in six different formulations. These formulations are designed to cover different conditions, depending on whether there is a heat pump in the system to increase the temperature supplied to the technical systems using hot water in the building.

The first two formulations cover the case where there is no heat pump (HP) to increase the temperature of the hot water from the data centre, as seen in Figure 4.5. These are

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

found in the simple version named $COP_{WHU,B,noHP,S}$ (equation (9)) and the detailed version named $COP_{WHU,B,noHP,D}$ (equation (10)).

The next two formulations cover the case where there is a heat pump between the data centre and the building, while it uses the measurement of the heat delivered to the building, as seen in Figure 4.6. These are also found in a simple version $COP_{WHU,B,HPB,S}$ (equation (11)) and a detailed version $COP_{WHU,B,HPB,D}$ (equation (12)).

The last two formulations also cover the case where there is a heat pump between the data centre and the building, while the waste heat removed from the data centre is used, as seen in Figure 4.7. As the others it is also found in a simple version $COP_{WHU,B,HPDC,S}$ (equation (13)) and a detailed version $COP_{WHU,B,HPDC,D}$ (equation (14)).

In all of the KPI formulations, there is a term called $E_{HVAC}$, which accounts for the increase in electricity use due to the heat waste reuse system being run. This term could include, for example, extended time in operation of the AHU fans, increased air flow rate from the AHU, and extended time in operation for the pumps in the heating system.

Electricity measurements are included for both the main branch from the data centre and the subbranches to the HVAC and MHS because there may be both global and local circulation pumps depending on the system configuration. These should all be taken into account.

For the cases with heat pumps, it is important to consider the circulation pumps on both sides of the HP, along with the electricity use for the HP itself. However, as the HP will increase the amount of heating energy being circulated on the building side, it is important to identify if the desired COP is the one on the building side or the data centre side and then use the appropriate formulation.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

| | |
|---|---|
| $COP_{WHU,B,noHP,S} = \frac{H_{DC\_to\_B}}{E_{HVAC} + E_{DC\_to\_B} + E_{DC\_to\_HVAC} + E_{DC\_to\_MHS}}$ | *(9)* |
| $COP_{WHU,B,noHP,D} = \frac{H_{DC\_to\_HVAC} + H_{DC\_to\_MHS}}{E_{HVAC} + E_{DC\_to\_B} + E_{DC\_to\_HVAC} + E_{DC\_to\_MHS}}$ | *(10)* |

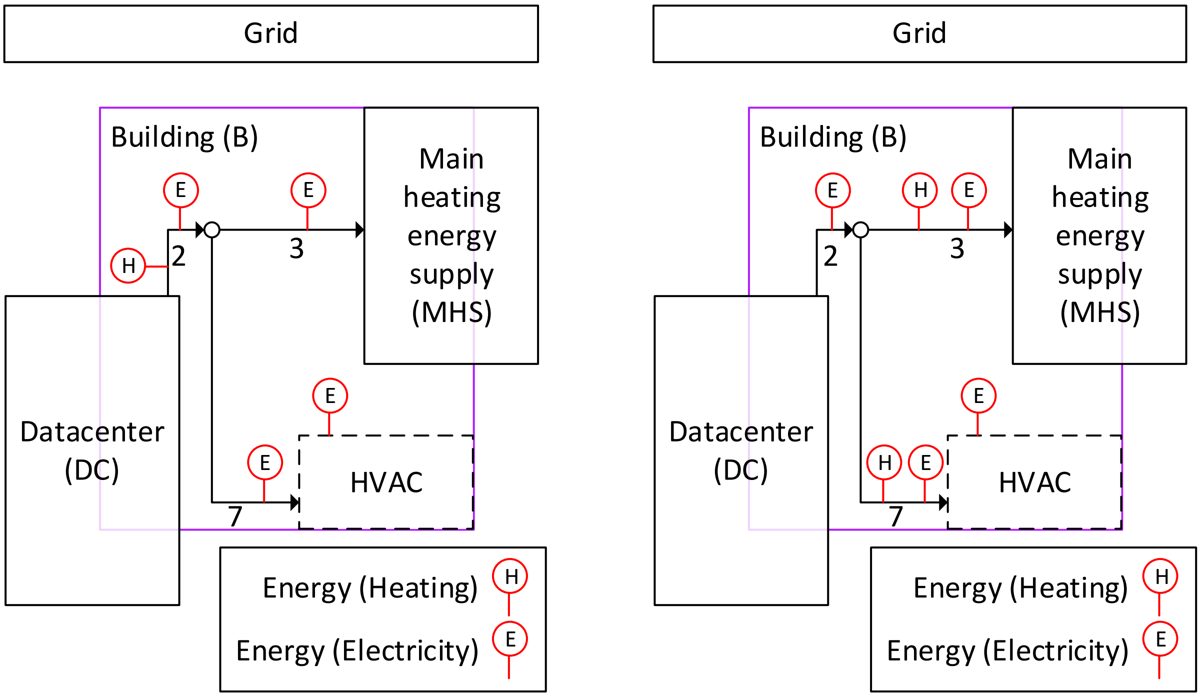

*Figure 4.5: Measurement locations for the $COP_{WHU,B,noHP,S}$ (equation (9)) to the left and the $COP_{WHU,B,noHP,D}$ (equation (10)) to the right.*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

$$COP_{WHU,B,HPB,S} = \frac{H_{HP\_to\_B}}{E_{HVAC} + E_{HP} + E_{DC\_to\_HP} + E_{HP\_to\_B} + E_{HP\_to\_MHS} + E_{HP\_to\_HVAC}} \tag{11}$$

$$COP_{WHU,B,HPB,D} = \frac{H_{HP1\_to\_HVAC} + H_{HP2\_to\_MS}}{E_{HVAC} + E_{HP1} + E_{HP2} + E_{DC\_to\_B} + E_{B\_to\_HP1} + E_{B\_to\_HP2} + E_{HP2\_to\_MHS} + E_{HP1\_to\_HVAC}} \tag{12}$$

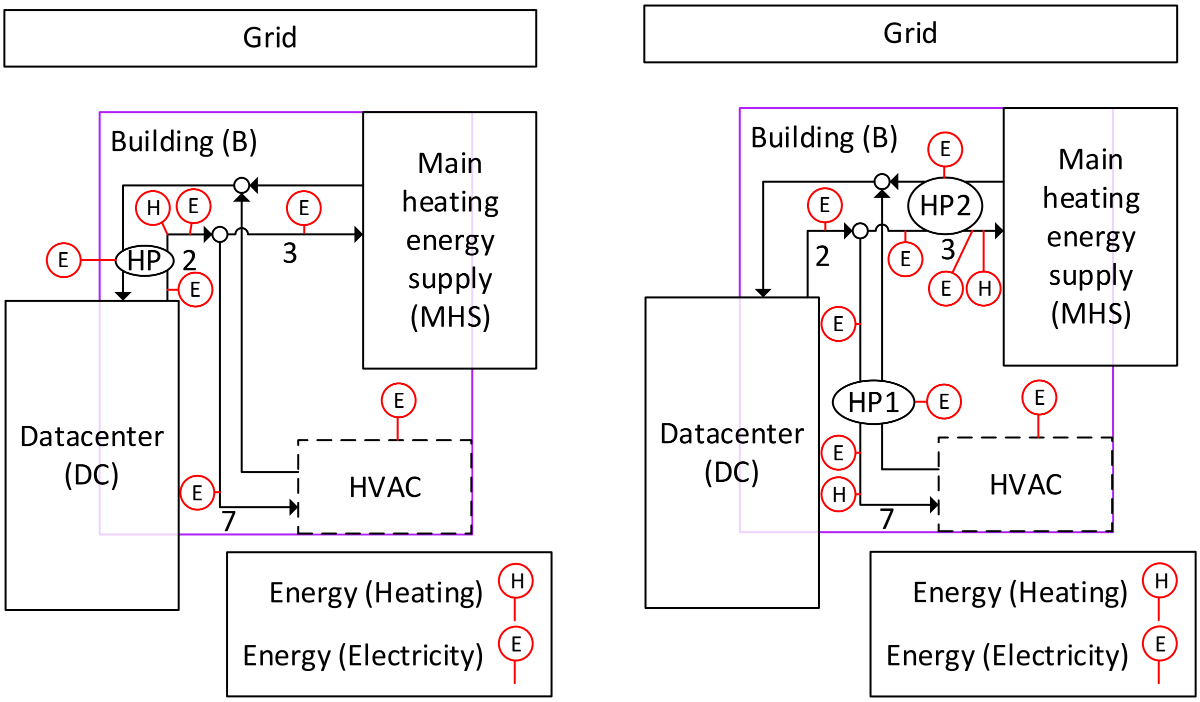

*Figure 4.6: Measurement locations for the $COP_{WHU,B,HPB,S}$ (equation (11)) to the left and the $COP_{WHU,B,HPB,D}$ (equation (12)) to the right.*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

$$COP_{WHU,B,HPDC,S} = \frac{H_{DC\_to\_HP}}{E_{HVAC} + E_{HP} + E_{DC\_to\_HP} + E_{HP\_to\_B} + E_{HP\_to\_MHS} + E_{HP\_to\_HVAC}} \tag{13}$$

$$COP_{WHU,B,HPDC,D} = \frac{H_{DC\_to\_HP1} + H_{DC\_to\_HP2}}{E_{HVAC} + E_{HP1} + E_{HP2} + E_{DC\_to\_B} + E_{B\_to\_HP1} + E_{B\_to\_HP2} + E_{HP2\_to\_MHS} + E_{HP1\_to\_HVAC}} \tag{14}$$

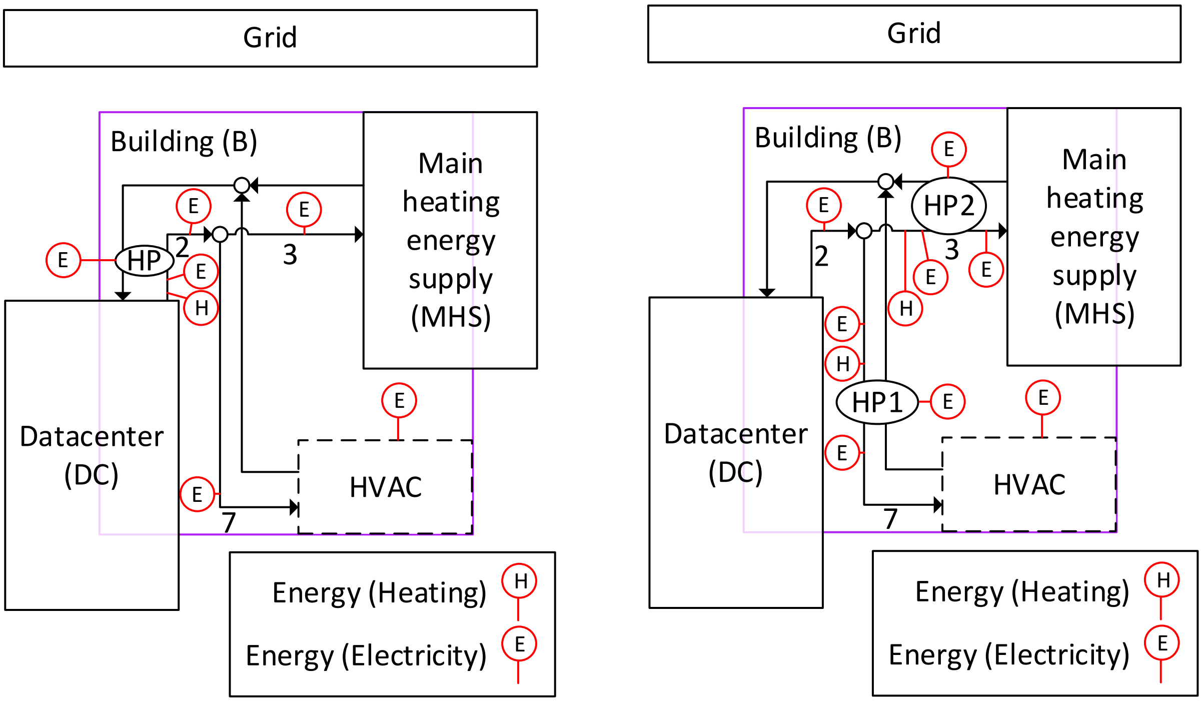

*Figure 4.7: Measurement locations for the $COP_{WHU,B,HPDC,S}$ (equation (13)) to the left and the $COP_{WHU,B,HPDC,D}$ (equation (14)) to the right.*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

### 4.3.6. KPI6 – COP of waste heat utilization to grid

The COP of waste heat utilization to grid ($COP_{WHU,G}$) is used to assess how much electricity is used to transfer the waste heat from the data centre to the grid. It takes offset in the classic COP formulation from section 4.2.

It is only partially limited, with 0 being the lower limit and signifying that no heat is being transported. As this KPI is a COP-type formulation, the higher the value, the better the performance.

As the grid can have rather high requirements for the supply temperature necessary to dump the waste heat into it, it may be necessary to have a heat pump between the data centre and the grid. There are, therefore, three different formulations of this KPI.

The first formulation covers the case without a heat pump and is named $COP_{WHU,G,noHP}$ (equation (15)). The measurement points for this formulation can be seen in Figure 4.8.

The second formulation covers the case where there is a heat pump and it is using the heating on the grid side. It is named $COP_{WHU,G,HPG}$ (equation (16)) and can be seen in Figure 4.9.

The last formulation covers the case where there is a heat pump and it is using the heating on the data centre side. It is named $COP_{WHU,G,HPDC}$ (equation (17)) and can be seen in Figure 4.9.

It is important to note that even though the electricity measurements are shown on the connection from the data centre to the grid, the actual circulation pump can be located on the other connection where it is from the grid to the data centre. No matter where the pump is located, the electricity use must be included.

|  |  |  |
|---|---|---|
|  | $COP_{WHU,G,noHP} = \frac{H_{DC\_to\_GRID}}{E_{DC\_to\_GRID}}$ | (15) |
|  | $COP_{WHU,G,HPG} = \frac{H_{HP\_to\_GRID}}{E_{DC\_to\_HP} + E_{HP} + E_{HP\_to\_GRID}}$ | (16) |
|  | $COP_{WHU,G,HPDC} = \frac{H_{DC\_to\_HP}}{E_{DC\_to\_HP} + E_{HP} + E_{HP\_to\_GRID}}$ | (17) |

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

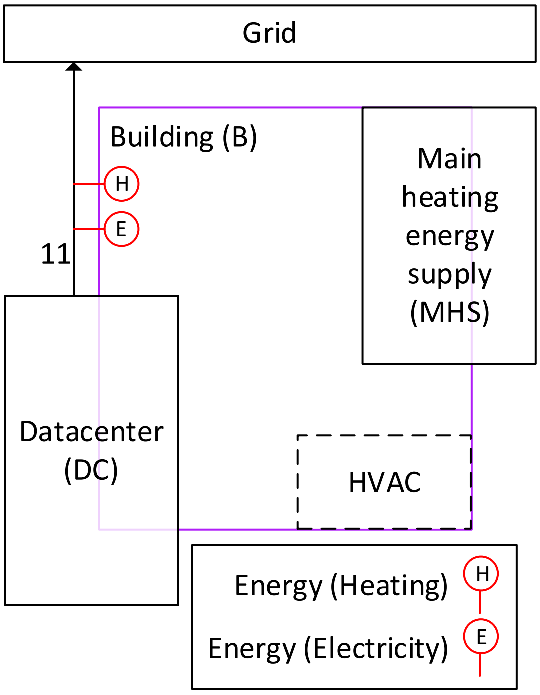

*Figure 4.8: Measurement locations for the $COP_{GWHU,noHP}$ (equation (15)).*

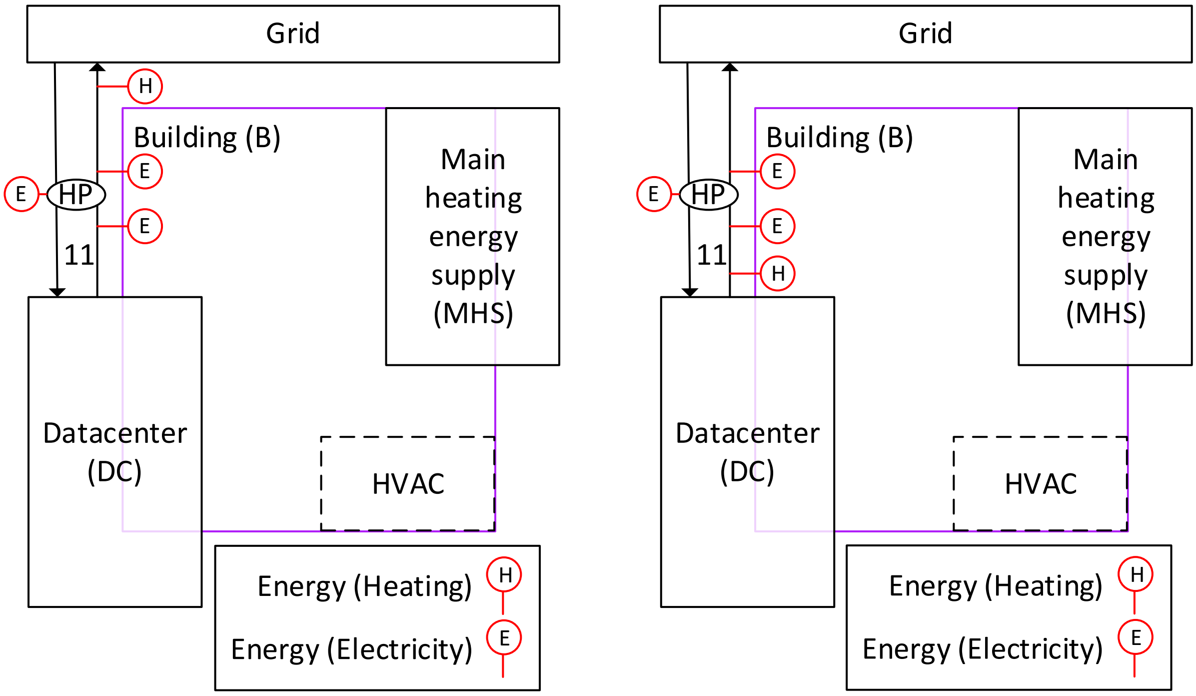

*Figure 4.9: Measurement locations for the $COP_{GWHU,HPG}$ (equation (16)) to the left and the $COP_{GWHU,HPDC}$ (equation (17)) to the right.*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

### 4.3.7. KPI7 – Waste heat utilization restrictors

The waste heat utilization restrictors (WHUR) is a new KPI that provides feedback on which part of the waste heat supplied to the building currently limits its further use. It takes into account both the needs of the building, the availability of energy from the data centre, and the quality of the available energy. Due to taking these parts into account, it should be noted that to use this KPI, a high degree of monitoring is necessary, meaning that it will not be applicable on many buildings currently but is instead meant as a KPI to be used in new buildings with advanced monitoring or when having done major renovations of a building, where the monitoring has been upgraded sufficiently.

It has three possible results:

- Supply temperature restriction: The supply temperature is too low to use more of the available heating energy, as seen in the top of Figure 4.11. This means that waste heat from the data centre must be dumped to the outside unless the supply temperature can be increased to the necessary level to use the rest of the energy.
- Energy restriction: No more heating energy is available, as seen in the middle of Figure 4.11. This means that the supply temperature can be lowered if that can improve the data centre performance; if not, there is no reason to take action.
- Surplus: There is a surplus of heating energy, meaning that the building cannot use any more of the waste heat, as seen in the bottom of Figure 4.11. This means that the waste heat can be supplied to the grid if the supply temperature is high enough, or the heating energy use of the building can be increased by either forcing some systems to use more energy or running them less efficiently (for example, turn off heat exchanger in AHU). If none of these solutions are possible, the excess waste heat must be dumped outside.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

The KPI is calculated using the following 6-step algorithm:

1. Sort all energy use and supply temperature pairs according to their temperature from low to high.
    1.1. Include all measurement pairs from the individual HVAC systems.
2. Calculate the cumulative sum of the energy use.
3. Identify the index where cumulative energy use exceeds the waste heat supplied from the data centre.
4. Identify the index where the necessary supply temperature exceeds the supply temperature from the data centre.
5. The restrictor is the lowest index from steps 3 and 4.
6. Depending on the restrictor, calculate the potentials.
    6.1. If the supply temperature is the restrictor.
        6.1.1. Calculate the necessary increase in supply temperature to utilize all the waste heat as the supply temperature at the index from step 3 minus the supply temperature at the index from step 4.
    6.2. If the waste heat available is the restrictor.
        6.2.1. Calculate the potential reduction of the supply temperature as the supply temperature at the index from step 3 minus the supply temperature at the index from step 4.
        6.2.2. Calculate how much more waste heat could be utilized in the building at the current supply temperature as the cumulative energy use at the index from step 4 minus the waste heat from the data centre.
    6.3. If none of the indexes are exceeded, there is a surplus of energy.
        6.3.1. Calculate the surplus energy as the waste heat from the data centre minus the maximum value of the cumulative energy use.

Depending on the configuration of the building's technical system there are currently two sets of measurement locations. The first is if the data centre supplies the HVAC systems directly, while the second one is if the data centre supplies the main heating energy supply. Both of the sets of measurement points can be seen in Figure 4.10.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

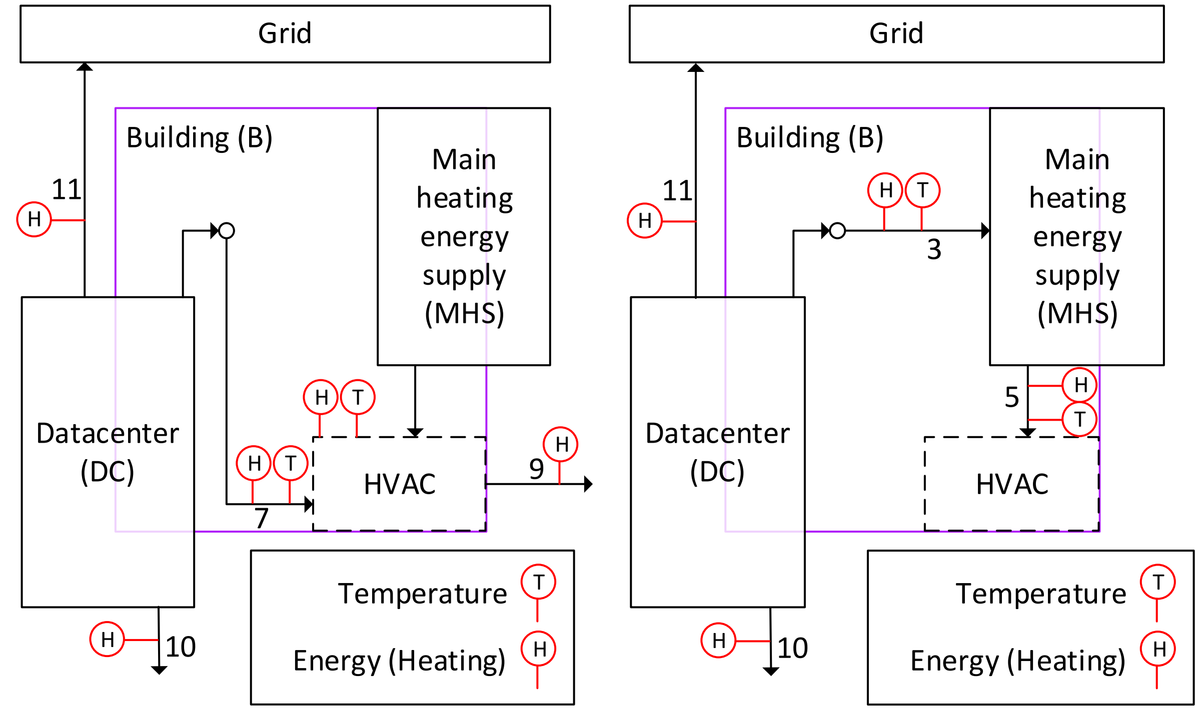

*Figure 4.10 Measurement locations for the case where the waste heat is supplied directly to the HVAC systems is shown on the left, and the case where the waste heat is supplied to the main heating energy supply is shown on the right.*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

### 4.3.7.1. Important measurement notes

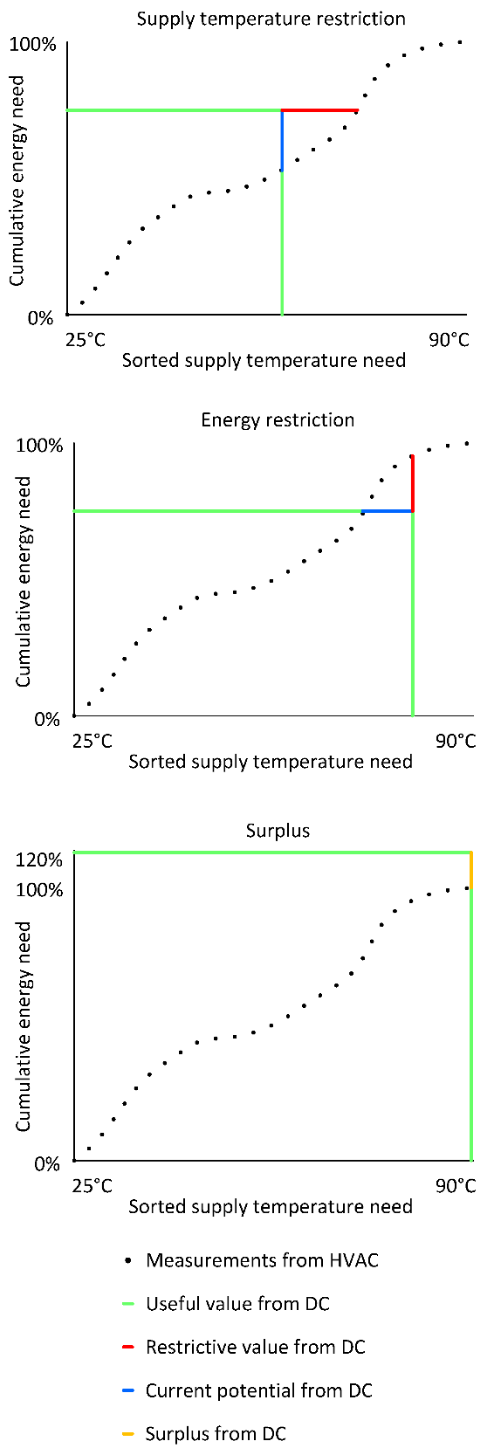

*Figure 4.11: WHUR cases.*

For the case where the data centre supplies the HVAC directly, the supply temperature must be measured in location T1, as seen in Figure 4.12. It is important because the temperature T1 is the actual temperature used by the system. In contrast, the temperatures T2 and T3 are more general temperatures of the hot water circulating in the main system, which is not necessarily representative of the individual systems. For more information, see deliverable 3.2.

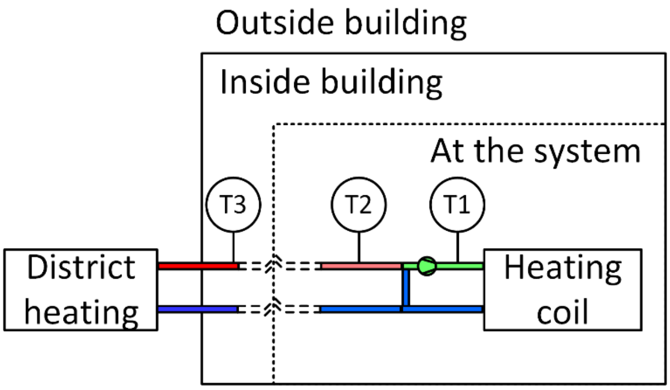

*Figure 4.12: Potential temperature measurement locations in HVAC systems when there is a mixing loop.*

The KPI result can either be visualized in the style of the graphs in Figure 4.11 or in a more compact form using Table 2.

*Table 2: Example of compact WHUR result overview.*

| Restrictor | Restrictor amount | Time over the period as the restrictor |
|---|---|---|
| Supply temperature | 50%: XX °C<br>100%: PP °C | AA h / BB % |
| Waste heat | YY kWh<br>ZZ °C | CC h / DD % |
| Surplus | VV kWh | EE h / FF % |

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

Table 2 shows the supply temperature restrictor with the necessary temperature increases to cover either 50% (XX) or 100% (PP) of the energy potential. The waste heat restrictor is shown with the energy potential at the current supply temperature (YY) and the potential decrease in supply temperature (ZZ). The surplus is shown with the amount of surplus energy (VV). All restrictors are shown with the number of hours and percentage of time where they are the restrictor.

When using this KPI, it is important to have high-resolution data, with each data point sampled at least once every fifteen minutes, as otherwise, the supply temperatures risk becoming too averaged or non-representative for the period.

## 4.4. Examples of using the selected KPIs on the pilots

This subsection includes the results of testing some of the KPIs on the pilots in the project, where the necessary historical data is already available.

### 4.4.1. Tests on the PSNC pilot

The KPIs 1 and 5 have been tested on the PSNC pilot. This pilot has a data centre with a mix of water- and air-cooled server racks, and it is connected to the building HVAC systems through a heat exchanger and a heat pump in front of each individual system, as can be seen in Figure 4.13.

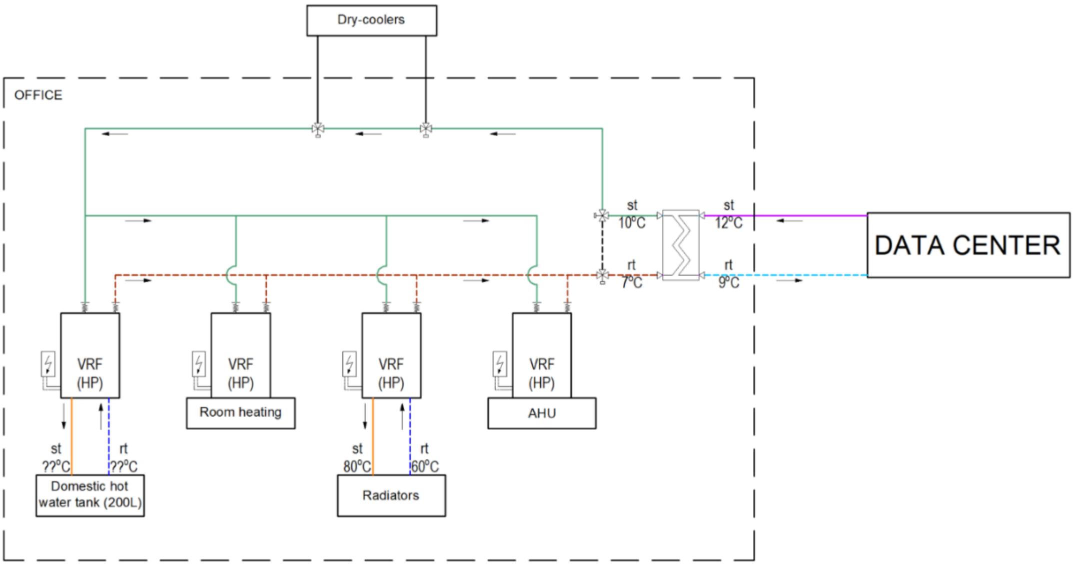

*Figure 4.13: Schematic of heat recovery including the glycol loop feeding the VRF system's compressor units – heating mode. (brown/green lines – glycol, orange/navy blue lines- water, purple/blue line – waste heat)*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

The WHU$_S$ has been tested on the PSNC pilot over a period of a year, the results can be seen in Figure 4.14. It becomes clear that the data centre is more than capable of supplying the necessary energy that the building needs, as the building generally does not utilize more than 30% of the data centre capacity. In this, it is though important to note that, as there is a heat pump on each system due to the low temperatures coming from the data centre, if the data centre could supply the energy with higher temperatures, more of the heating energy could be used instead of supplying with electrical energy.

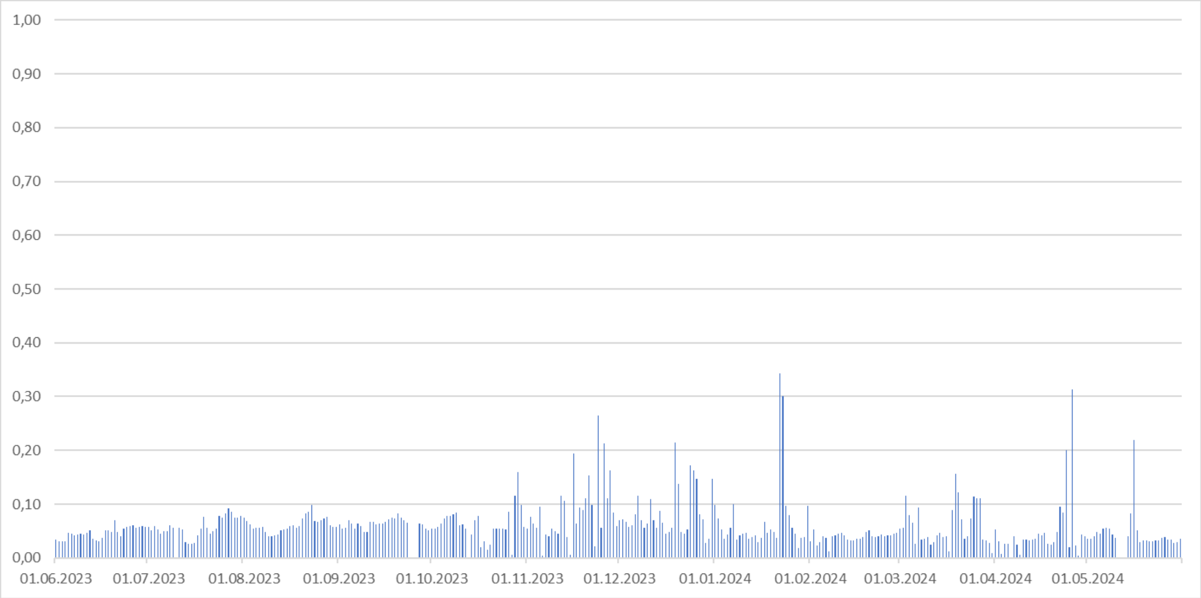

*Figure 4.14: WHU$_S$ calculated over a one year period in the PSNC pilot.*

The COP of waste heat utilization in building, seen in Figure 4.15, is rather low, which is caused by the data centre waste heat mainly acting as a low temperature source for the heat pumps, where the electricity supplies the majority of the energy.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

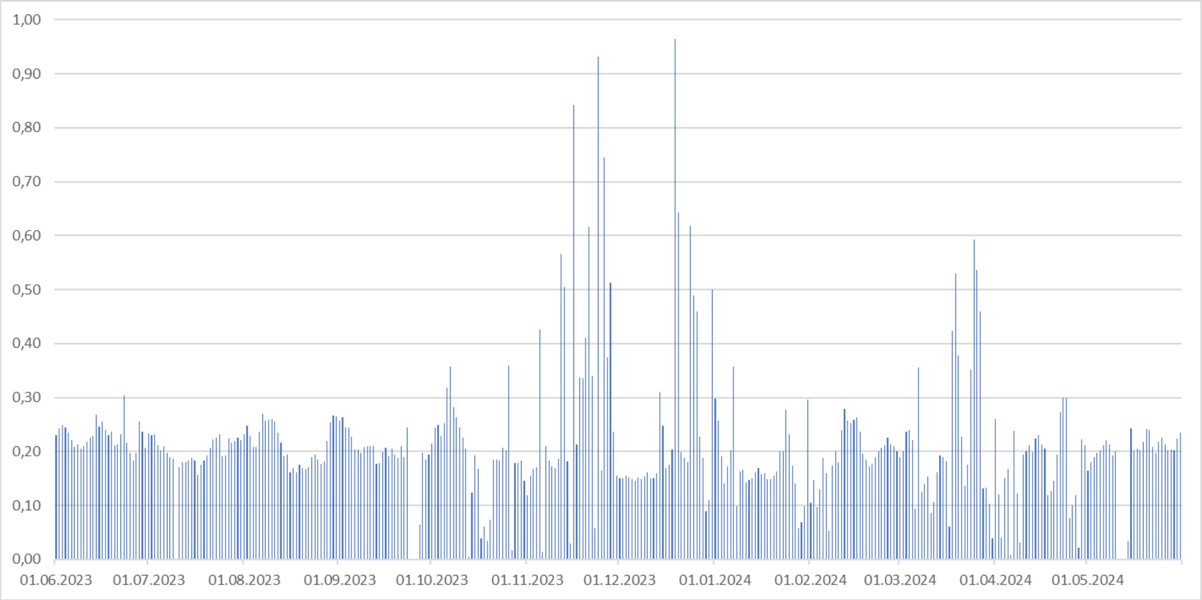

*Figure 4.15: $COP_{WHU,B,HPDC,S}$ calculated over a one year period in the PSNC pilot. It should be noted that there is some uncertainty regarding the measured electricity use, as it is unclear what exactly is coupled on the meter, meaning that there may be more than the intended energy uses included, causing the COP to be lower than it is in reality.*

## 4.4.2.Application to the Empa pilot

The Empa case study (NEST) relies on three distribution grids for the thermal energy: a high-temperature grid (≈65°C), a medium-temperature grid (≈35°C) and a low-temperature grid (≈12°C). A simplified schematic of the NEST system is depicted in Figure 4.16. The NEST system is interfaced with the campus distribution grid, which consists of a high-temperature network and a low-temperature one. When medium temperature heat is required in NEST and this cannot be produced locally, this is downgraded from the campus grid by means of a heat exchanger or upgraded from the low-temperature campus grid by means of a heat pump.

At the moment of writing, the data centre unit at NEST was cooled by air cooling technology and directly connected to the low-temperature network and the medium-temperature one. However, due to limited insulation of the rack and poor thermal efficiency, the heat was recovered at a temperature level below the required ones from the medium-temperature network. Consequently, all the heat generated by the data centre was dissipated by the cooling network. That is, most of the KPIs presented in this report assume 0 values when looking at the historical data for the Empa pilot.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

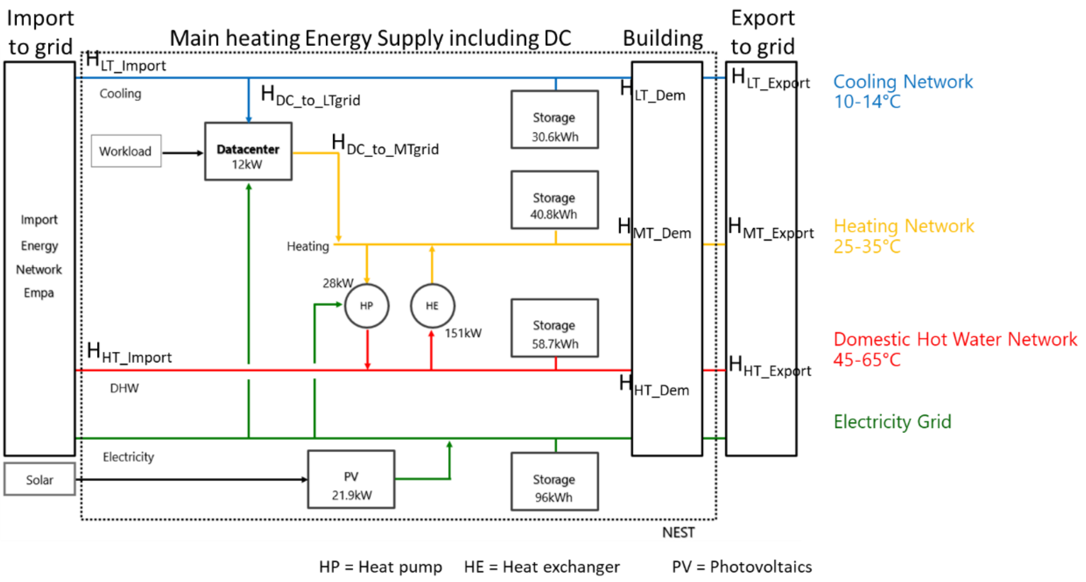

*Figure 4.16 Simplified schematic of the NEST building at Empa with integrated air cooled data center. The configuration will be updated in the course of the project.*

Nonetheless, this section presents the application of the KPIs concepts to the NEST system. No heat is wasted to ambient within the NEST system boundaries. If an excess is present, heat is exported to the campus grid. Therefore, the term $H_{HVAC\_to\_out}$ of equation (1) is always set to zero for the NEST case study. The heating system of the building entirely relies on the medium-temperature grid. Therefore, the heat consumption of the building is calculated as the sum of the thermal energy demand of all the units that compose the NEST building and it is indicated with $H_{HT\_dem}$. The Empa pilot does not present a clear distinguish between the amount of energy directed to the building and the energy exported to the external district heating network. The recovered heat, if temperature levels allow, is all injected in the building grid, and stored or exported during periods of excess. Consequently, it is not straighforward to calculate the amount of energy recovered from the data centre that is exported to the campus grid. As a first approximation, we consider all the exported energy from the building to be caused by the heat recovered from the data centre, as expressed in (22). Nonetheless, the formulation might be changed during the course of the projected depending on the calculated values.

$$WHU_S = \frac{H_{DC\_to\_MTgrid}}{H_{DC\_to\_MTgrid} + H_{DC\_to\_LTgrid}} \tag{18}$$

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

| | | |
|---|---|---|
| | $DOC_{B,S} = \frac{H_{DC\_to\_MTgrid}}{H_{HT\_dem}}$ | (19) |
| | $PWHC_{B,S} = \frac{H_{DC\_to\_MTgrid} + H_{DC\_to\_LTgrid}}{H_{HT\_dem}}$ | (20) |
| | $COP_{WHU,B,noHP,S} = \frac{H_{DC\_to\_MTgrid}}{E_{DC}}$ | (21) |
| | $COP_{WHU,G,noHP} = \frac{H_{MT\_Export}}{E_{pumping\_MTgrid} + E_{DC}}$ | (22) |

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

# 5. Conclusions

This deliverable has investigated the different existing KPIs for waste heat in data centres and in buildings. From these, seven KPIs were chosen or developed for use going forward.

These seven KPIs cover different aspects of using the waste heat from the data centre in the building and span from providing simple feedback to direct optimization feedback.

The waste heat utilization restrictor will mainly be used for optimization and decision-making for the data centre and the building, with a modified version appearing in deliverable 6.1.

The results from the test of the KPIs indicate that there is optimization potential in both the PSNC and EMPA pilots going forward, as the low temperature of the recovered waste heat is currently too low to be used directly and efficiently.

These KPIs provide a foundation for further assessing the optimization potential and evaluating different strategies in task 3.4.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

# 6. References

Ahmad, M., & Riffat, S. (2020). *Energy recovery technology for building applications: Green innovation towards a sustainable future.*

Bertrand, A., Aggoune, R., & Maréchal, F. (2017). In-building waste water heat recovery: An urban-scale method for the characterisation of water streams and the assessment of energy savings and costs. *Applied Energy, 192*, 110-125. Retrieved from http://dx.doi.org/10.1016/j.apenergy.2017.01.096

Burlacu, A., Sosoi, G., Vizitiu, R., Bărbuţă, M., Lăzărescu, C., Ciocan, V., & Şerbănoiu, A. (2018). Energy efficient heat pipe heat exchanger for waste heat recovery in buildings. *Procedia Manufacturing, 22*, 714-721. Retrieved from https://doi.org/10.1016/j.promfg.2018.03.103

Christodoulides, P., Aresti, L., Panayiotou, G., Tassou, S., & Florides, G. (2022). Adoption of Waste Heat Recovery Technologies: Reviewing the Relevant Barriers and Recommendations on How to Overcome Them. *Operations Research Forum, 3*(1). Retrieved from https://doi.org/10.1007/s43069-021-00108-6

Cuce, P., Cuce, E., & Riffat, S. (2016). A novel roof type heat recovery panel for low-carbon buildings: An experimental investigation. *Energy and Buildings, 113*, 133-138. Retrieved from http://dx.doi.org/10.1016/j.enbuild.2015.12.024

European Commission. (2024). Delegated Act on the establishment of a common Union rating scheme for data centres: Annexes 1 to 4. *C(2024) 1639 final*. Brussels.

Farhat, O., Faraj, J., Hachem, F., Castelain, C., & Khaled, M. (2022). A recent review on waste heat recovery methodologies and applications: Comprehensive review, critical analysis and potential recommendations. *Cleaner Engineering and Technology, 6*, 100387. Retrieved from https://doi.org/10.1016/j.clet.2021.100387

Fowler, K., Wang, N., Deru, M., & Romero, R. (2010). Performance Metrics for Commercial Buildings. 1 - 15. Retrieved from https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-19830.pdf

Guo, J., & Zhang, C. (2022). Utilization of Window System as Exhaust Air Heat Recovery Device and Its Energy Performance Evaluation: A Comparative Study. *Energies, 15*(9).

Klobut, K., Mäkeläinen, T., Huovila, A., Hyvärinen, J., & Shemeikka, J. (2016). KPI framework for energy efficient buildings and neighbourhoods. *eWork and eBusiness in Architecture, Engineering and Construction - Proceedings of the 11th*

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

*European Conference on Product and Process Modelling, ECPPM 2016*(June 2017), 309-314.

Korpela, T., Kuosa, M., Sarvelainen, H., Tuliniemi, E., Kiviranta, P., Tallinen, K., & Koponen, H. (2022). Waste heat recovery potential in residential apartment buildings in Finland's Kymenlaakso region by using mechanical exhaust air ventilation and heat pumps. *International Journal of Thermofluids, 13*(October 2021), 100127. Retrieved from https://doi.org/10.1016/j.ijft.2021.100127

Li, H., Hong, T., Lee, S., & Sofos, M. (2020). System-level key performance indicators for building performance evaluation. *Energy and Buildings, 209*.

Mardiana-Idayu, A., & Riffat, S. (2012). Review on heat recovery technologies for building applications. *Renewable and Sustainable Energy Reviews, 16*(2), 1241-1255. Retrieved from http://dx.doi.org/10.1016/j.rser.2011.09.026

Perez, A., Stadler, I., Janocha, S., Ferrando, C., Bonvicini, G., & Tillmann, G. (2016). Heat recovery from sewage water using heat pumps in cologne: A case study. *2016 International Energy and Sustainability Conference, IESC 2016*, 1-7.

Piotrowska, B., & Słyś, D. (2023). Analysis of the Life Cycle Cost of a Heat Recovery System from Greywater Using a Vertical “Tube-in-Tube” Heat Exchanger: Case Study of Poland. *Resources, 12*(9).

Pokhrel, S., Amiri, L., Poncet, S., Sasmito, A., & Ghoreishi-Madiseh, S. (2022). Renewable heating solutions for buildings; a techno-economic comparative study of sewage heat recovery and Solar Borehole Thermal Energy Storage System. *Energy and Buildings, 259*, 111892. Retrieved from https://doi.org/10.1016/j.enbuild.2022.111892

Porta, M., & Oliver, N. (2021). *D4.1 - SO WHAT TOOL KPI PANEL.*

Reddy, C., Bonfochi Vinhaes, V., Naber, J., Robinett, R., & Shahbakhti, M. (2023). Model predictive control of a dual fuel engine integrated with waste heat recovery used for electric power in buildings. *Optimal Control Applications and Methods, 44*(2), 699-718.

Sunu, P., Anakottapary, D., Suirya, I., Puspa Indra, I., Rahtika, I., Putra, D., . . . Wijayantara, I. (2020). A brief comparative thermodynamics review of domestic air conditioning system with or without installed heat recovery. *Journal of Physics: Conference Series, 1450*(1), 0-4.

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION. (2024). Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

Vizitiu, R. S., Burlacu, A., Abid, C., Verdes, M., Balan, M. C., & Branoaea, M. (2021). Experimental and Numerical Study of Thermal Performance of an Innovative Waste Heat Recovery System. *Applied Sciences*.

Vizitiu, R., Burlacu, A., Abid, C., Verdes, M., Balan, M., & Branoaea, M. (2021). Experimental and numerical study of thermal performance of an innovative waste heat recovery system. *Applied Sciences (Switzerland), 11*(23).

Wallin, J., Madani, H., & Claesson, J. (2012). Run-around coil ventilation heat recovery system: A comparative study between different system configurations. *Applied Energy, 90*(1), 258-265.

Wehbi, Z., Taher, R., Faraj, J., Ramadan, M., Castelain, C., & Khaled, M. (2022). A short review of recent studies on wastewater heat recovery systems: Types and applications. *Energy Reports, 8*, 896-907.

Wu, W., Du, Y., Qian, H., Fan, H., Jiang, Z., Huang, S., & Zhang, X. (2024). Industrial Park low-carbon energy system planning framework: Heat pump based energy conjugation between industry and buildings. *Applied Energy, 369*(June), 123594. Retrieved from https://doi.org/10.1016/j.apenergy.2024.123594

Zabihi Tari, A., Khosravi, M., Maleki Dastjerdi, S., Khoshnevisan, A., & Ahmadi, P. (2023). Multi objectives optimization and transient analysis of an off-grid building with water desalination and waste heat recovery units. *Sustainable Energy Technologies and Assessments, 59*(June), 103406. Retrieved from https://doi.org/10.1016/j.seta.2023.103406

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.

# 7. List of figures

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project N° 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract N° 23.00606.

# 8. List of tables

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement for Project Nº 101138491 and the Swiss Secretariat for Education, Research, and Innovation (SERI) under contract Nº 23.00606.