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HOLISTIC ENERGY MANAGEMENT AND THERMAL WASTE INTEGRATED SYSTEM FOR ENERGY OPTIMIZATION

HEATWISE

Waste heat potential report

Project ID: 101138491

Prepared by: Aalborg University

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Waste heat potential report

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Executive Summary

When assessing whether the waste heat from datacenters can be used in buildings or the surrounding neighborhood, it is important to first understand what the potential of the building or neighborhood is for utilizing the waste heat.

This assessment can be done from two paths, either taking offset in the design values of the building and different systems using hot water, or by using actual operational data for the building and systems. In this report, the methodology presented in section 1.1 mainly takes offset in the later, and is applied on the AAU pilot (section 2.1) and EMPA pilot (section 2.2). For the TOFAS pilot (section 2.3) and PSNC pilot (section 2.4) there is not enough available historical data to apply the methodology, and they have therefore been analyzed using the qualitative approach taking into account the design values.

The methodology presented in section 1.1 consists of six steps, ranging from gathering the necessary data, to analyzing the data at different levels of the building and systems under different conditions. The final part provides focus points and considerations for making the best decision for the individual building on whether to use the waste heat, and if it should be used, where should it be.

The four pilots investigated in this report are briefly discussed in section 1.2 and further detailed in their respective sections. They are located in different areas and climates, with the AAU pilot being an educational building located in Aalborg, Denmark. The EMPA pilot is a mixed-use building located in Dübendorf, Switzerland. The TOFAS pilot is an office building with an integrated datacenter located in Bursa, Turkey. The last pilot, the PSNC pilot, is located in Poznań, Poland, and is a supercomputing center consisting of an office building with an integrated datacenter.

The AAU pilot currently have a connection to district heating for supplying all the heating needs of the building. Due to this connection, it was investigated what the potential for using waste heat in the building was if it is connected to the main district heating supply, or if it is provided directly to the individual systems using heating (space heating, heating coils in air handling units, domestic hot water, and a heating coil in a warm air curtain system). The main conclusion for this pilot was that utilizing the waste heat on the individual system level provides a significantly higher potential compared to providing it on the main district heating supply. The reason for this was that the temperatures required on the individual systems were significantly lower than those needed on the main supply. Besides this, it was also checked what the impact of using the design values

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for the systems would change in terms of their potential, here it was found that using the design values instead of the actual values would show a significantly lower potential, thus underestimating the potential.

The EMPA pilot had four "individual" buildings, representing different use cases, such as residential or office buildings. Generally, it showed that TABS and heating coils in ventilation systems have a large potential for using waste heat due to their low supply temperature requirements. It also matched the findings of the AAU pilot, that supplying the waste heat at the system level will lower the supply temperature requirements, although in this case, as there was access to different temperature grids, the effect was lower.

The TOFAS pilot had only an air-based space heating system using fan coils. It had no supply temperature measurements, but as the expected supply temperature for the heating needs is still among the lower area (<50°C), it was still evaluated that its heating demand could be meet using the waste heat from datacenters in most cases. In this case, as there was only a single system type, it was possible to perform the evaluation as if individual system measurements were available.

The PSNC pilot is a modern and highly monitored building, but it turned out to be missing the necessary measurement points needed for this assessment. It thereby showed that even modern and highly monitored buildings may not have all the necessary sensors and sensor placements to accurately access a buildings potential for using waste heat as a standard, as they are generally not necessary for control. It was though found that having at least the design values can indicate if the system will be a candidate for using waste heat.

Having assessed the different pilots, the considerations of using the waste heat were expanded to the surrounding area. To do this, a cost-focused methodology was developed to gain an understanding of how much waste heat is necessary to provide, and at which supply temperatures, for it to be profitable to supply the waste heat to other buildings or grid. This methodology was evaluated for the different price structures of the four countries of the pilots, to understand the difference in profitability when having the same initial conditions. In future deliveries a tool is envisioned, to allow other projects to easily analyze their potential for connecting the datacenter to a district heating grid, and under which conditions it would be profitable.

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One of the conclusions on this report was that depending on the supply temperature available at the waste heat source, supplying waste heat on the individual systems tend to have a higher potential compared to supplying on the main supply point, though the difference in potential diminishes as the waste heat supply temperature increases. This was seen at the AAU pilot, as It had a potential of supplying up to 79% of the buildings annual heating use with a supply temperature of 70°C if supplied directly at the systems, or 23% if supplied at the main supply point.

It was also concluded that to assess the potential properly, it is not enough to use design values, instead the historical operational values must be used. Though the measurement location of these values also had a significant impact. If the measurements of the supply temperature are not done after all mixing loops or similar, the “needed” supply temperature will be overestimated, thus causing the potential to be underestimated.

In the cases where there are no measurements of the supply temperatures available, it will be necessary to take offset in the design or expected operation values. If this is the case, as long as energy use for the different systems are measured individually or at least per system type, it is possible to give an estimate of the potential. This will though lack the difference in supply temperature dependency, which must be supplemented by expert knowledge. If assessing the potential this way there is a high risk of underestimating the potential, as design values, at least, tend to be higher than the actual temperatures supplied in large parts of the year.

It was also found that there was a high variability in the temperatures needed for the different systems, with the hydronic underfloor requiring the lowest temperatures, followed by the heating coils in ventilation, then followed by either the radiator system or the domestic hot water system, depending on the design of the radiator system.

Finally, when looking towards utilizing the waste heat energy in the building, potentially as the only “heat sink” for the datacenter, it is important to consider the temporal variations, as some system have high variations in their energy need over both the day and the year. It may, therefore, be necessary to investigate strategies for how to better control the building in order to match the energy output of the datacenter. This will be looked further into in deliverable 3.4, where different types of control strategies will be analyzed ranging from those not affecting the building, to some with a substantial impact on either the indoor climate or electric energy use.

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List of abbreviations

Acronym	Meaning
AHU	Air Handling Unit
HC	Heating Coil
HE	Heat Exchanger
DH	District Heating
DHW	Domestic Hot Water
AAU	Aalborg University (pilot)
PSNC	Poznan Supercomputing and Networking Center (pilot)
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt (pilot)
TOFAS	Türk Otomobil Fabrikası Anonim Şirketi (pilot)
ROI	Return Of Investment
VRF	Variable Refrigerant Flow
CAPEX	Capital Expenses
HPC	High-Performance Computing
TABS	Thermally Activated Building Systems
DC	Data Center

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1 Introduction and methodology

This chapter describes the methodology for evaluating the building waste heat utilization potential, along with a brief description of the four pilot cases.

In this project, there are two research-oriented pilot buildings (AAU and EMPA) and two commercial pilot buildings (PSNC and TOFAS). The main difference between research-oriented and commercial buildings is the level at which they are instrumented. The research-oriented buildings have many sensors (submeters including supply and return temperatures, flow rate and energy use of the hot water using systems) which are necessary for carrying out the assessment of the waste heat potential using the following methodology at all levels. Normally, the commercial buildings do not have the same number of sensors, as most of these sensors are not necessary for operation. They will therefore have to be assessed using the data available along with expert knowledge and design values.

1.1 Methodology

With the main purpose of this report being to assess the potential for using waste heat water in buildings, a generic methodology is proposed.

This current proposed methodology is focused on using the measurements from buildings already in operation and assuming that no changes in the operation are needed. This approach was selected because even though one may have the design values for the different systems, the way they are operated may be drastically different, for better or worse. In the cases where no measurement values are available, the design values, along with knowledge of the current operational parameters of the building, must be used instead.

Later methodologies will expand on this approach to analyze different scenarios, either as the case of renovating/new building design or the case of changes in the building operation to better align with the data center's potential for generating waste heat. These later methodologies will be included in D3.4.

This methodology consists of six steps, summarized in Figure 1.1 and further explained below.

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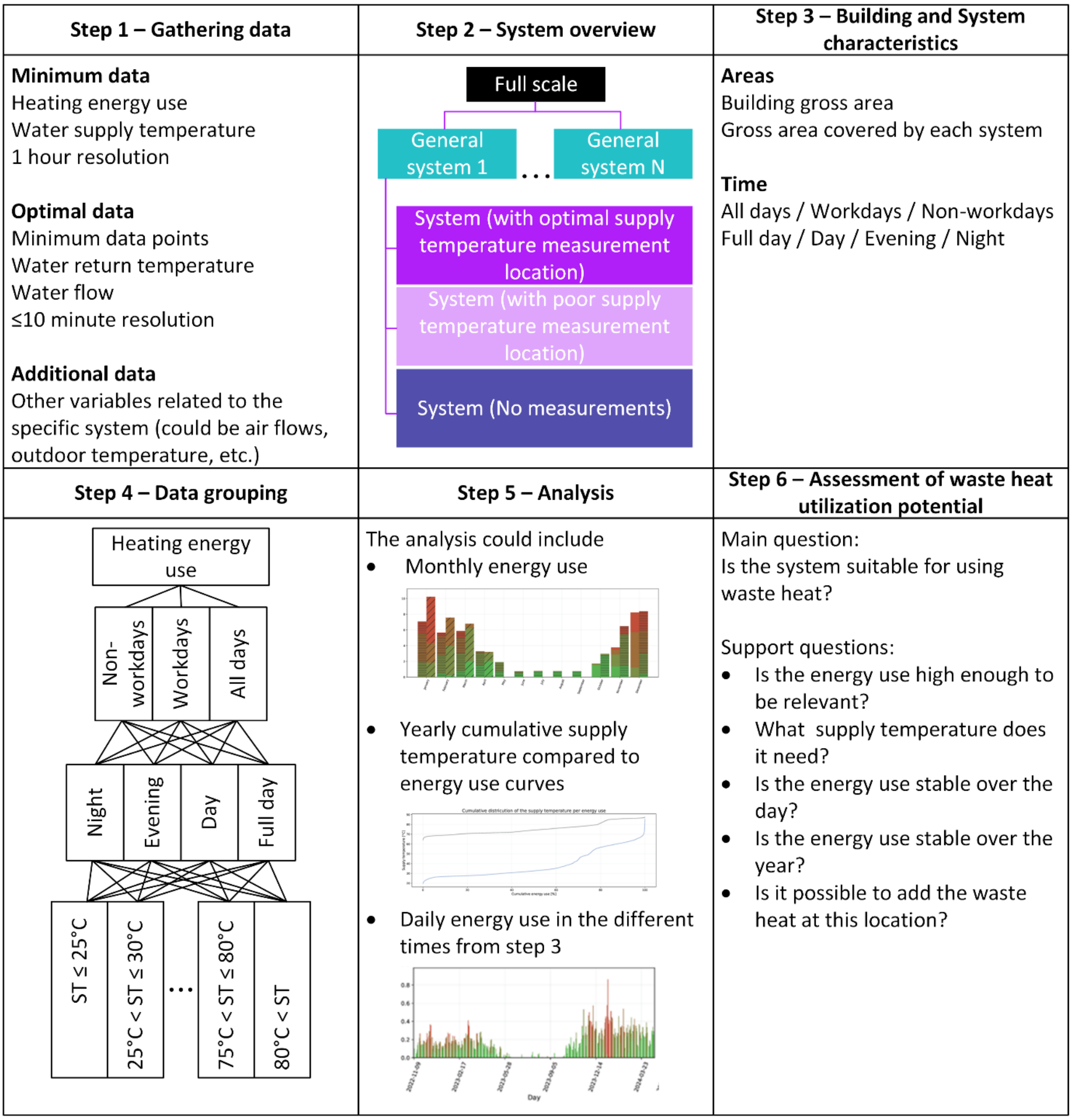

Figure 1.1: Summary of the methodology.

The first step is to gather data related to all the different systems in the building that utilize a waterborne heat source. This data needs, as a minimum, to include the energy use and the water supply temperature measured as close to the system as possible with a reasonable time resolution (preferably as low as possible, but maximum 1-hour resolution). The reason the resolution is of high importance is that many systems use heat in brief pulses, having a low resolution, would therefore mean that the measurements are

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either averaged too much or sampled too infrequently to catch the behavior of the system. Optimally, the water return temperature and flow rate are also measured, along with additional variables that may be able to supplement the analysis with more explanation of when the energy is used. The measurement location needs to be as close as possible to the system, to give the correct picture of the system's needs instead of what is just available. This will mainly be an issue when the systems have an individual mixing loop, meaning that if the temperature before this mixing loop is used, it will provide a wrong indication of what the system needs. An example of this can be seen for many of the ventilation systems in the AAU pilot shown in Figure 2.16, where the systems with measurements before the mixing loop indicate a need of 10-30°C higher than the actual need.

The second step is to make the system overview, where the different systems are categorized according to their purpose to group similar systems. This is done to understand what the different systems and levels need as the supply temperature, thereby enabling the understanding of where to supply the waste heat water. The three levels that are available are full scale, general systems, and systems.

Full scale includes the building's main supply of hot water. Many different system types can cover it, such as district heating, heat pumps, boilers, and more.

The general system level contains a high-level overview of similar systems. For some buildings, this will be the lowest level available and, thus, where the measurements are performed, while for others, it will be an aggregation of measurements from similar systems. It can contain categories such as heating (waterborne), ventilation, domestic hot water, outdoor, and miscellaneous (for systems not fitting in the other categories). The inclusion and coverage of each general system type will depend on the individual building and what is available in it.

The lowest level contains the individual systems and is for when measurements are available directly at the system. This could include a single heating coil in an AHU, a radiator circuit, a domestic hot water circuit, and more.

An example of the levels from the AAU pilot can be seen in Figure 2.4, where there is a full-scale system (the building's district heating supply), four general systems, and several systems underneath each general system.

The third step is to define the building and system characteristics. This includes parameters such as the area covered and the time the results are split into.

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The area covered could be the total heated building gross area and the gross area covered by each system (for systems that are supposed to cover the entire building, the sum of the individual areas should match the total building area).

The time splits include different temporal sizes. One of the splits is on a weekly level, which includes “workdays”, “non-workdays”, and “all days”. On a daily level, the splits are “day”, “evening”, “night”, and “full day”. For both the weekly and daily levels, it is necessary to specify specific days or hours included in the split, except for “all days” and “full day”, as they always include everything.

As an example, the splits on the weekly level of the AAU pilot is shown below:

- “workdays” include Monday to Friday.
- “non-workdays” include Saturday and Sunday.

For the daily level of the AAU pilot:

- “day” includes the hours between 08.00 and 15.59.
- “evening” includes the hours between 16.00 and 23.59.
- “night” includes the hours between 00.00 and 07.59.

The fourth step is to separate the energy use according to the supply temperature level and different time constraints from the third step. The supply temperature levels are split into 5°C intervals spanning from “below 25°C” as the lowest to “above 80°C” as the highest. The reason for doing this is to get a general understanding of which intervals of temperatures are needed, as different waste heat sources may provide the water at different temperatures.

The fifth step is to use the supply temperature intervals and analyze the results. This can be done in many ways depending on the purpose and available data. In this report, it is mainly done in the following way (when data is available).

- On a yearly basis, to understand the general supply temperature needs compared to when the energy is used. This is done as there may be peak periods for the systems where there is an insignificant energy use (when seen in the total perspective) but a need for high temperatures, while most energy use occurs at low supply temperatures.

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- On a monthly basis, to understand the seasonality of the building's heating energy use, because the output from the data center may be stable over the year, but the needs of the building may not be.
- According to the days, to see if workdays differ from non-workdays.
- According to the different hours of the day, to see if the different systems are mainly using energy during the day, the evening, the night, or all day. This is important as it will limit the potential if the heat is only used in certain periods of the day.

The sixth step is to use the different results to assess the waste heat utilization potential of the different systems and, generally, of the building.

The main question that needs to be answered for each system, general system, and full scale level: Is the system/general system/full scale suitable for using waste heat?

The following questions should be addressed to form the basis of what needs to be answered for each.

- Is the energy use high enough to be relevant?
    - At what point does the return of interest become low enough to be relevant?
    - Does the system save enough emissions compared to the emissions from the installation?
- Which supply temperature is necessary?
    - Is the supply temperature critical for the system, or can it be compensated by maintaining a higher flow rate?
    - Is it constant over time (monthly, weekly, daily)?
    - Does it depend on external factors such as outdoor temperature?
- Is the energy use stable over the day?
- Is the energy use stable over the year?
    - Is there seasonality? If yes, does it depend on external factors such as outdoor temperature or the number of people in the area?
- Is it possible to add the waste heat at this location?

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- Is the supply of heat to the system critical?
- Are there any safety concerns?
- Do external factors limit it?

1.2 Pilots

The project has four different pilot buildings located in different climates. The different locations of the pilots can be seen in Figure 1.2.

The AAU pilot is an educational building located in Aalborg, Denmark. It is situated at the divide between the Continental and Maritime North climate zones. The EMPA NEST (Next Evolution in Sustainable Building Technologies) pilot is a test building containing many different building types located in Dübendorf on the campus from Empa & Eawag, Switzerland. It is situated at the divide between the Pannonian and Boreal South climate zones. The PSNC pilot is a supercomputing center located in Poznań, Poland. It is situated at the divide between the Pannonian and Continental climate zones. The TOFAS pilot is an IT building, combining a large datacenter and accompanying office facilities, located in Bursa, Turkey. It is situated in the Maritime South climate zone. For more information on the specific pilots, see section 2.1 for the AAU pilot, section 2.2 for the EMPA pilot, section 2.3 for the TOFAS pilot, and section 2.4 for the PSNC pilot.

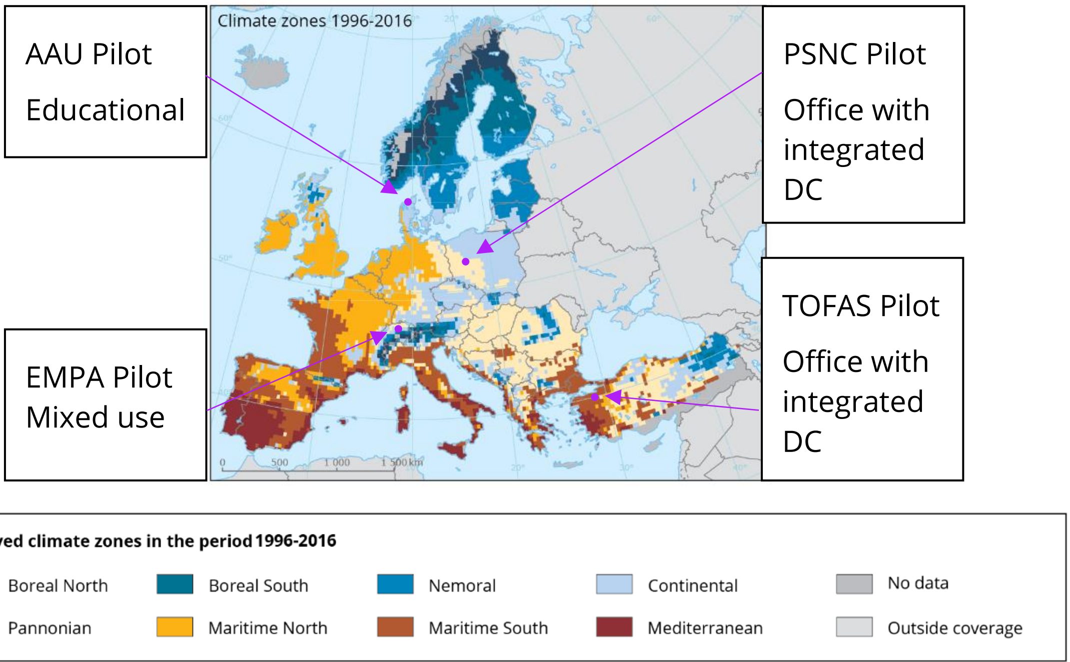

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Figure 1.2: Location of the four pilots in relation to the European climate zones. The image is modified from "Ceglar, A., Zampieri, M., Toreti, A., Dentener, F., Observed northward migration of agro-climate zones in Europe will further accelerate under climate change. Submitted to Earth's Future" (https://www.eea.europa.eu/data-and-maps/figures/observed-climate-zones-in-the)

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2 Results and discussion

In this section, each of the four pilot buildings is analyzed individually to find their waste heat utilization potential with their current operating conditions according to the methodology described earlier. Each pilot has their own subsection, which will describe the building and its systems, as well as show the results and conclusions for them.

2.1 AAU Pilot

2.1.1 AAU Pilot description

2.1.1.1 General building description

The AAU pilot building is located at the main campus of Aalborg University in Aalborg, Denmark, and houses the Department of the Built Environment. The building has a heated gross area of 8153 m^2 and was built in 2016 according to the Danish building regulation "BR class 2015". It is an educational building comprising a combination of laboratories and workshops on the ground, 1st floor, and 4th floor. Offices, group rooms, meeting rooms, and lecture rooms can be found on the 1st to 3rd floor, and technical rooms in the basement. It houses around 150 employees and 600 students. For more information on the building, see this report by (Johra, 2023). The building is generally considered to be in normal operation from Monday to Friday between 08.00 and 16.00.

Figure 2.1: AAU pilot (Picture by Thomas Pedersen)

The different room types in the building can be seen in Figure 2.2. In the figure, the utility room category covers storage rooms, toilets, showers, kitchenettes, and printer rooms,

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while technical rooms cover the main technical installations and systems, such as the ventilation units and electrical boards.

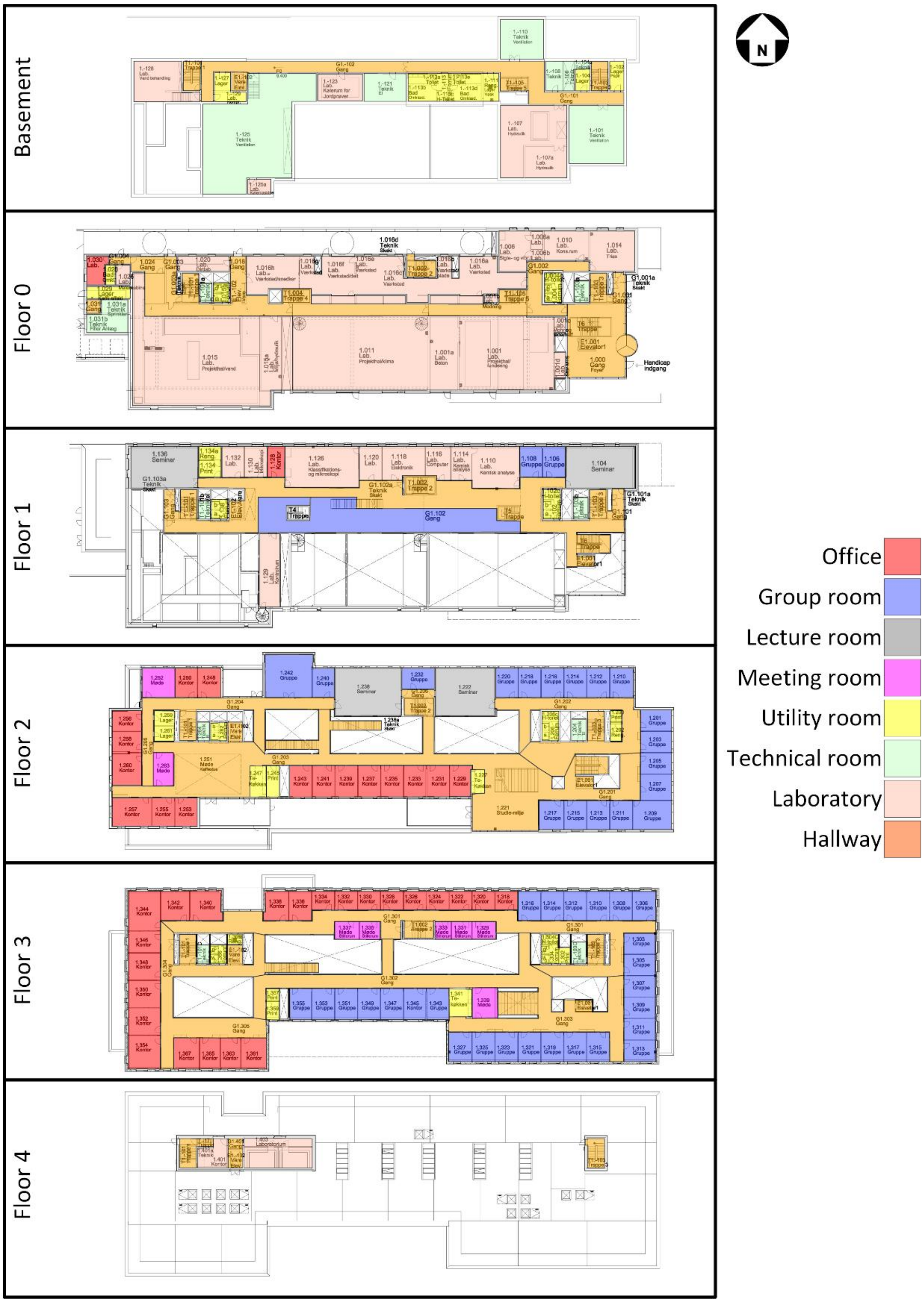

Figure 2.2: Room types in the AAU pilot building.

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2.1.1.2 System description

The heating system in the AAU pilot is based on DH supplied from a DH plant located in Aalborg, supplying most of the city. The DH company guarantees a supply temperature of at least 60°C in the main pipes in the street. As seen in Figure 2.3, the supply temperature of the DH water fluctuates between 60°C in the warm periods and 85°C in the cold periods.

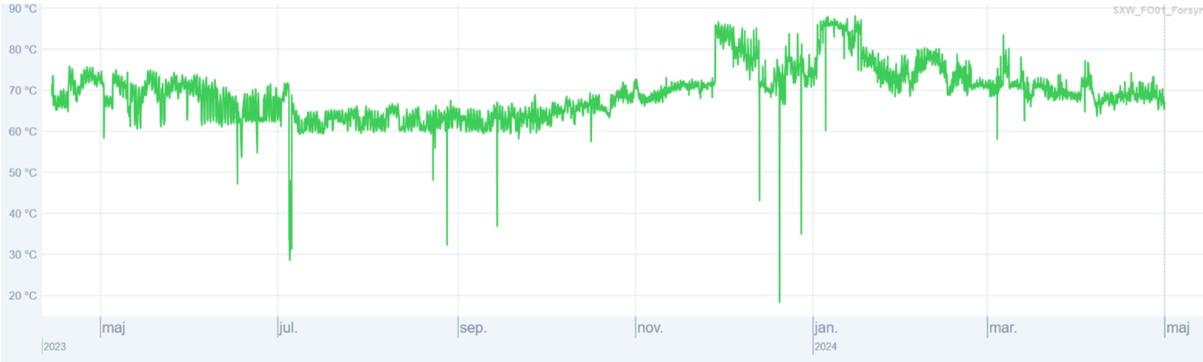

Figure 2.3: District heating supply temperature for the AAU pilot. Image coming directly from the BMS.

The DH principle used in this building is direct DH, meaning that the DH water is circulated inside the building. Once the DH water has entered the building, it is split out for the different systems. The systems using heating in the building can be divided into four main categories: waterborne heating systems, heating coils in the AHUs, heat exchangers for domestic hot water, and miscellaneous heating which do not fall under the other categories. The data available for the different systems (except for the ceiling radiators) can be seen in Figure 2.5. All systems had a data resolution of 1-2 minutes but were down sampled to 10-minute resolution to ensure proper overlap between the sensors, as they were not necessarily sampled simultaneously. The only exceptions were the GV02 and Door01 systems, which had an initial sampling rate of 10 minutes, and were down sampled to 30-minute resolution.

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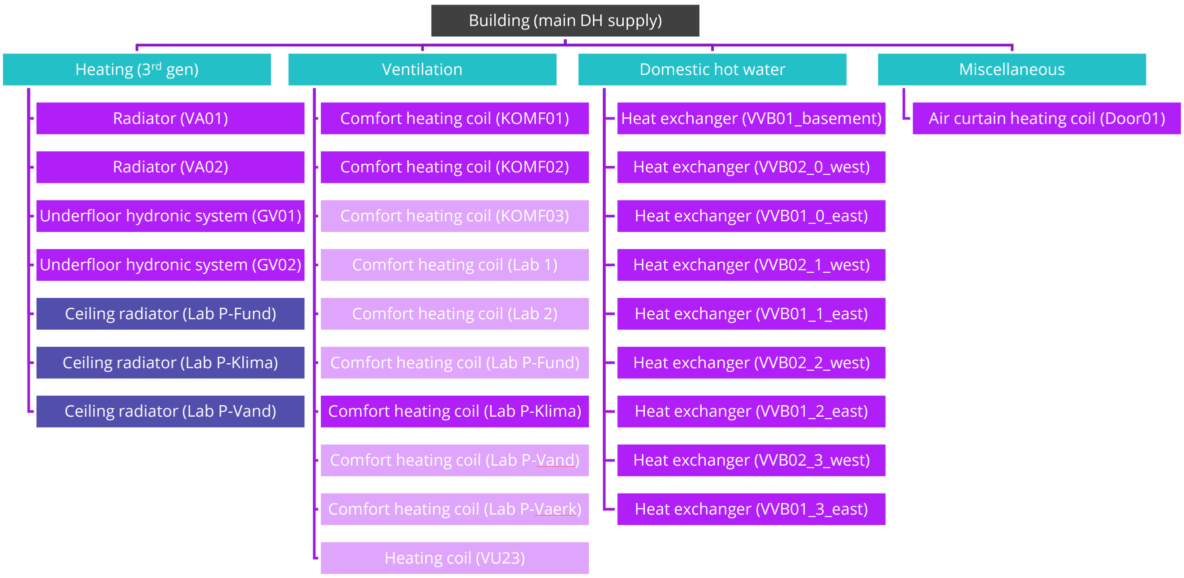

Figure 2.4: AAU pilot system overview (Dark purple indicates that the supply temperature used is after the mixing loop or there is no mixing loop. Light purple indicates that the supply temperature is measured before the mixing loop, thus not being the temperature directly used by the system. Those in dark blue are missing energy use measurements, thus not allowing them to be analyzed directly).

Figure 2.5: Available data for the AAU pilot.

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Heating systems

The waterborne heating systems (those under the Heating (3rd gen) category in Figure 2.4) share a similar structure, as seen in Figure 2.6. Each system has a direct DH supply and return (on the left), as well as the supply and return for the radiator/ceiling radiator/underfloor hydronic circuit (on the right), with a mixing loop in between to keep the needed supply temperature.

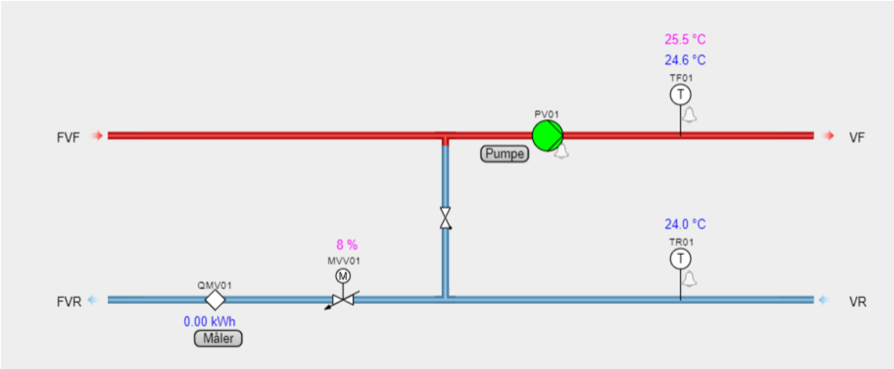

Figure 2.6: General structure of the mixing loop for the waterborne heating systems in the AAU pilot. The left side is the DH part (FVF and FVR), with the mixing loop in the middle and the supply to the system on the right (VF and VR).

The areas covered by the different heating systems can be seen in Figure 2.7. The main systems are the VA01 and VA02, which cover the eastern and western areas of the building.

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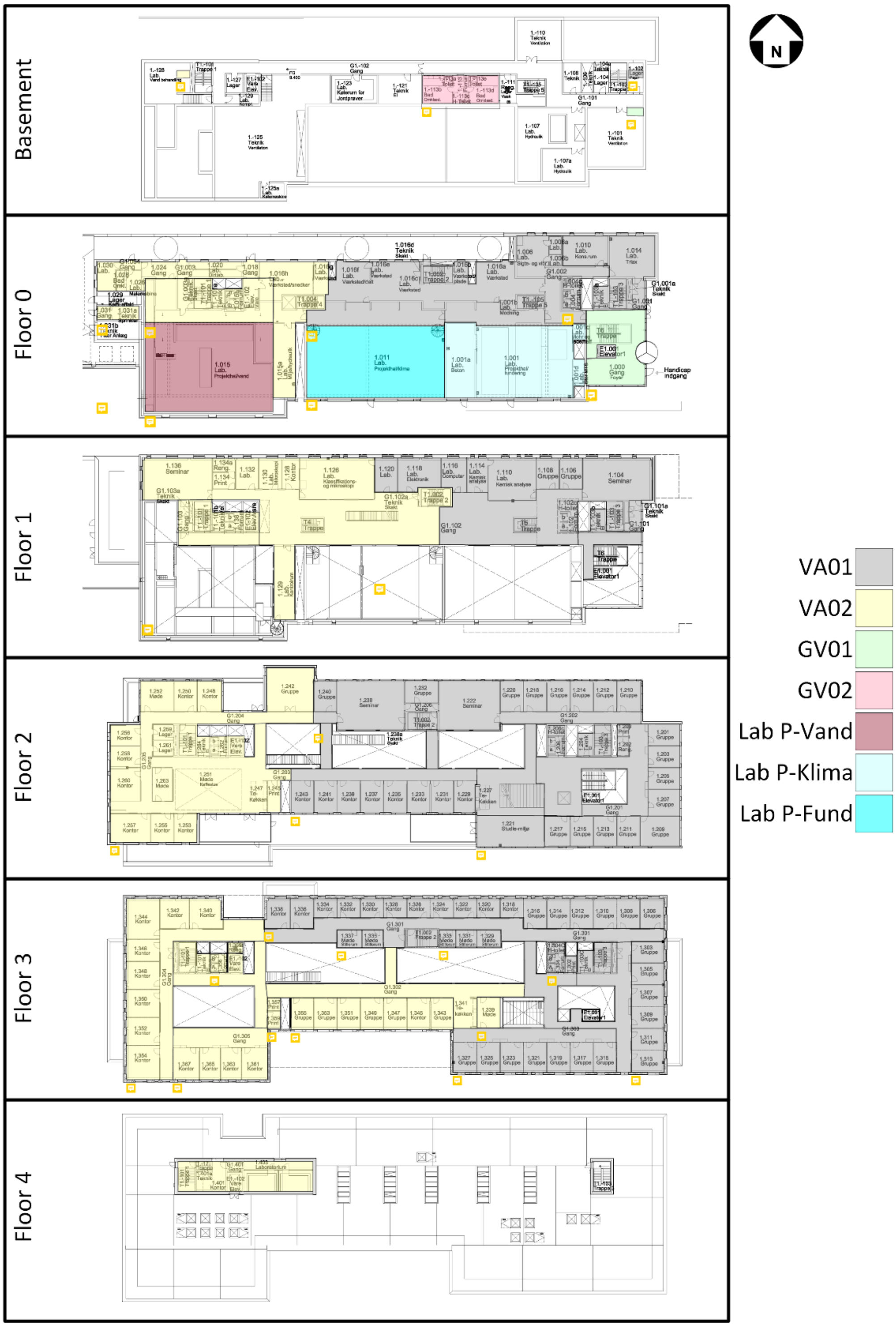

Figure 2.7: Areas covered by the different heating systems in the AAU pilot.

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Ventilation systems

The AHUs in the AAU pilot all have a comfort heating coil located after a heat recovery unit, as seen in Figure 2.8. Depending on the AHU, the type of heat recovery unit differs according to the needs of the rooms it supplies. Lab 1 and Lab 2 use a fluid-coupled heat exchanger due to a strict requirement of no risk of air recirculation, while all the others use rotary heat exchangers due to their efficiency and compactness. The Lab 1, Lab 2, and Lab P-Klima AHUs also have a water-based cooling coil right after the heating coil.

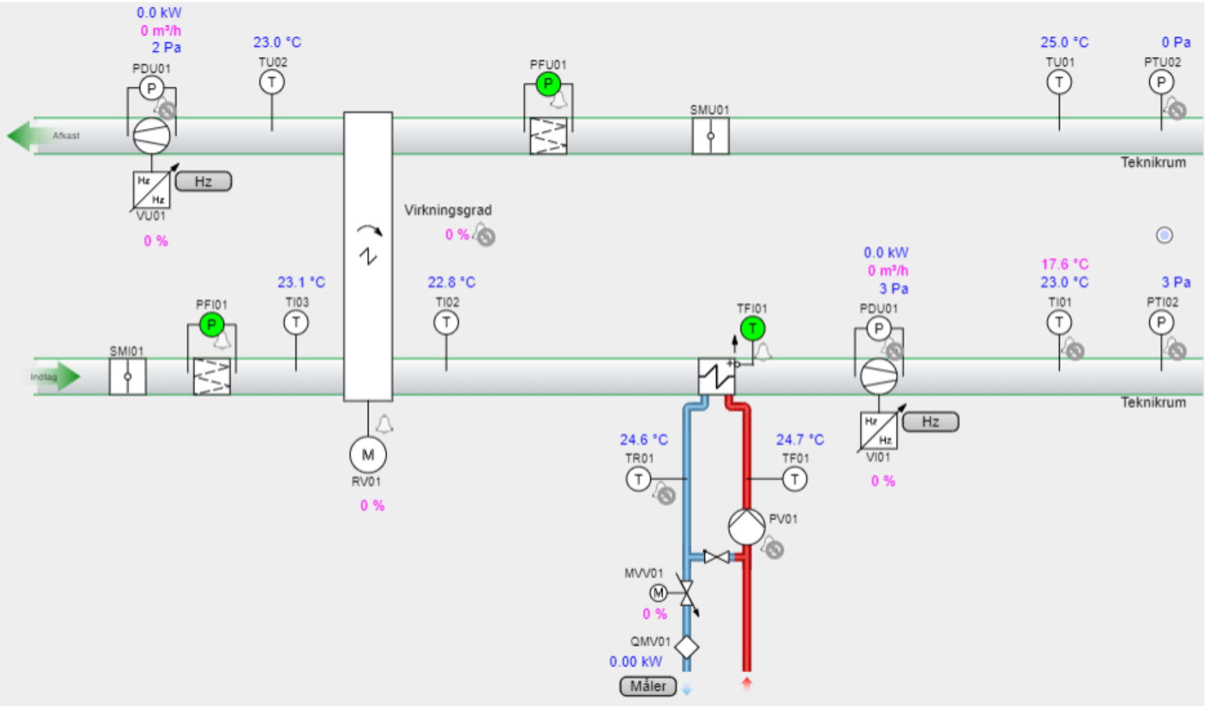

Figure 2.8: General structure of the AHUs in the AAU pilot. The heating coil is positioned on the supply air side after the heat recovery unit. The heating coil consists of the DH connection at the bottom, the mixing loop in the middle, and the coil on top. For the AHUs in Figure 2.4, where the supply temperature is measured before the mixing loop, it is measured on the red pipe before the pump, while those with the measurement after the mixing loop are measured on the red pipe after the pump (named TF01 in this figure).

The areas covered by the different ventilation systems in the pilot can be seen in Figure 2.9. The KOMF01 – KOMF03 units mainly focus on comfort ventilation in the offices, group-, meeting-, and lecture rooms. The rest of the units are meant to ventilate the laboratories and workshops, though some also cover a few offices and group rooms due to their proximity or changes in the use of rooms over the years.

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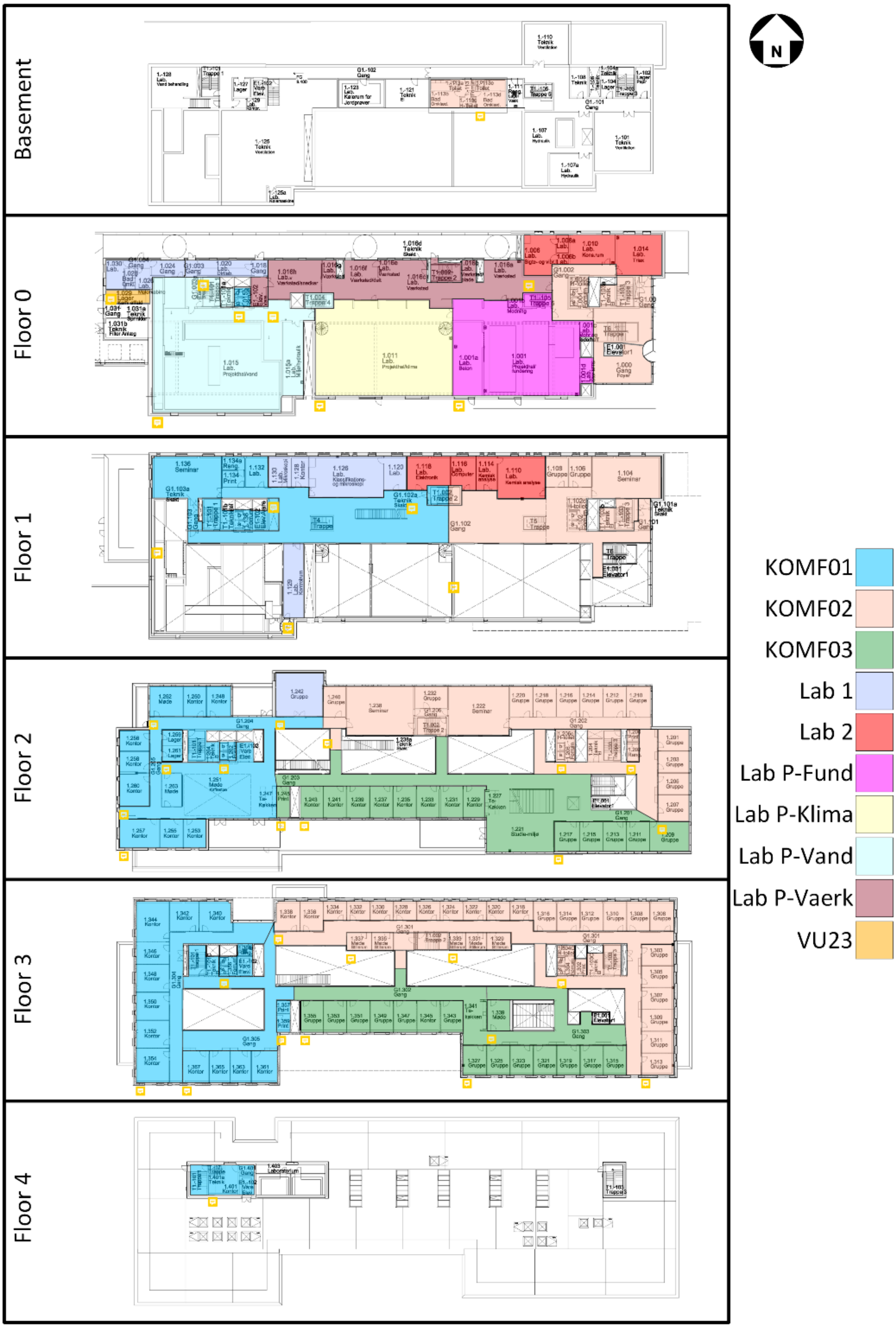

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Figure 2.9: Areas covered by the different ventilation systems in the AAU pilot.

Domestic hot water systems

The domestic hot water systems in the AAU pilot all share the structure seen in Figure 2.10, where the DH supply and return on the left side are used to heat the recirculation and cold water on the right side through a heat exchanger in order to maintain the required DHW supply temperature. The cold water is only supplied when water is tapped from the system; otherwise, it is just the water being circulated that is reheated.

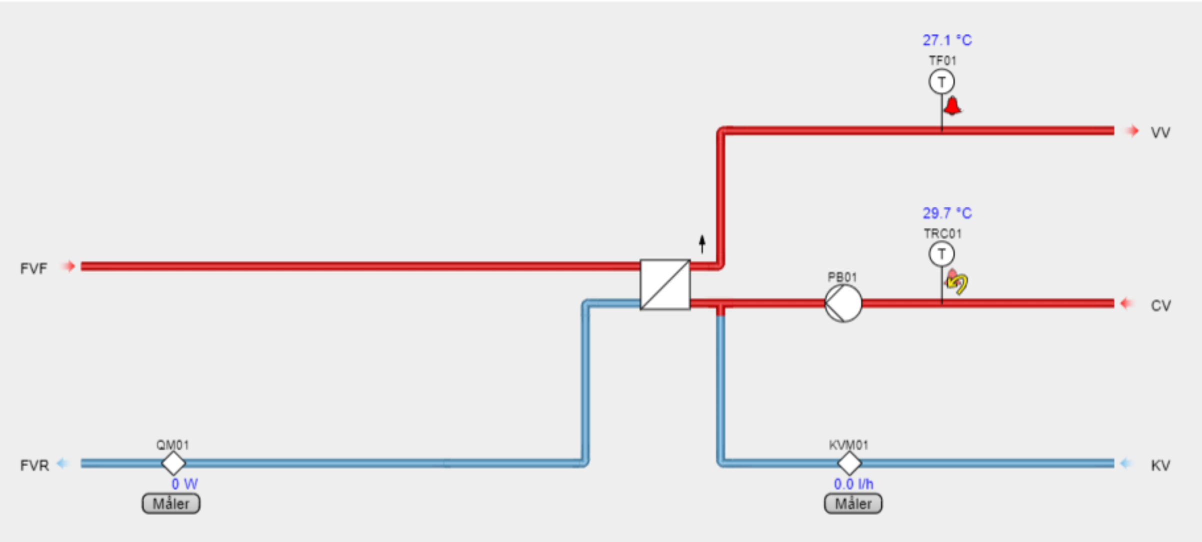

Figure 2.10: General structure of the domestic hot water systems in the AAU pilot. The DHW system has the DH supply (FVF) on the left, supplying a heat exchanger, which the combination of recirculated (CV) and cold water (KV) is fed into, producing the DHW (VV) shown in the top right.

The areas covered by the different DHW circuits in the pilot are shown in Figure 2.11. The distribution system is split into two main pipes, supplying either the eastern or western part of the building. Each main pipe supplies a heat exchanger on each floor, which supplies the DHW for its part of the floor.

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Figure 2.11: Areas covered by the different domestic hot water systems in the AAU pilot. The X denotes the floor, going between 0 and 3 for both, while the VVB01 also has the basement.

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Miscellaneous systems

The miscellaneous systems currently only contain the air curtain in the main entrance, with the system's structure shown in Figure 2.12.

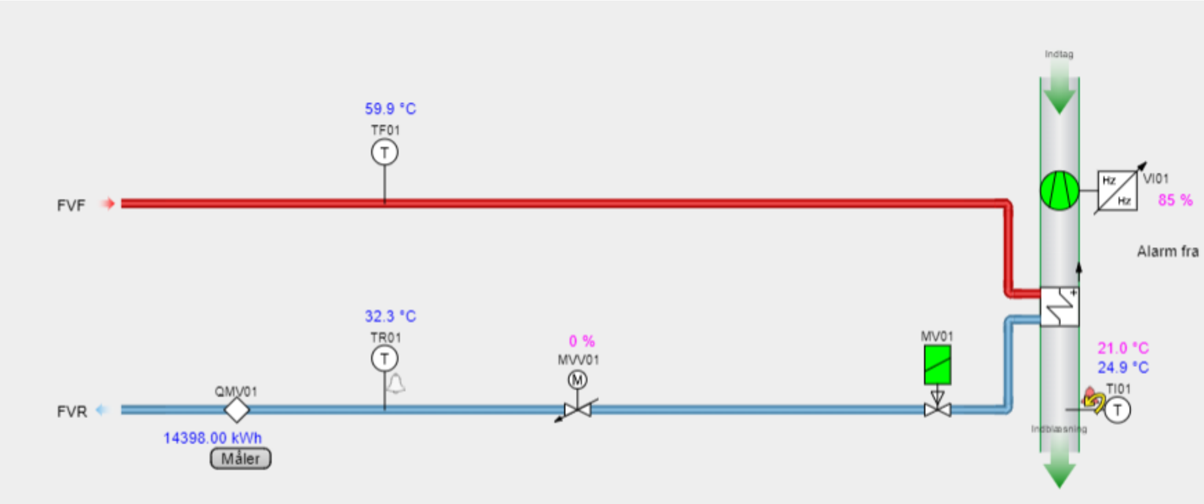

Figure 2.12: Structure of the Door01 air curtain system in the AAU pilot. In this case, the heating coil is supplied directly by the DH.

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2.1.2 Results

This section describes the main outcomes of the analysis using the available data seen in Figure 2.5. For more details on the individual systems, see the following subsections.

In this pilot, the systems with the highest waste heat utilization potential, as seen in Table 2.1, are the heating coils for the ventilation units, as they can use the highest amount of energy at the lowest necessary supply temperatures. The only downside is their significant seasonality, meaning their potential is mainly in the heating and transition periods.

The heating system also has some potential, but only the underfloor hydronic circuits can use very low supply temperatures, whereas the radiator circuits, which account for most of the heating energy use, need relatively high supply temperatures. It also has the same seasonality issue as the ventilation heating coils, as the potential is mainly in the heating and transition periods.

No matter the system, though, the main conclusion is that unless the waste heat source has a very high supply temperature (≥70-80°C) for the building, it is not feasible to supply directly to the main supply. Therefore, the waste heat energy should be supplied directly to the system, as the temperature requirements are significantly lower. If the potential at the different supply temperatures is utilized fully, the building could cover 38% of the total heating energy use with a supply temperature of 40°C. The potential at other supply temperatures is shown in Table 2.1.

Table 2.1: Potential specific energy [kWh/m^2] possible to cover at different supply temperatures if the waste heat is supplied directly at the system level.

Supply temperature	Heating	Ventilation	Domestic hot water	Miscellaneous	Total savings potential
30°C	1.4	5.3 – 5.7	0	<0.1	15%
40°C	1.8	15.3 – 18.1	0	<0.1	38%
50°C	3.3	18.7 – 19.2	0.8	<0.1	51%
60°C	11.2	19.3	1.8	<0.1	72%
70°C	14.0	19.3	1.8	0.1	79%

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2.1.2.1 Building level (Full scale)

On the building level of this pilot is the main DH connection, measured at the supply point in the building. As seen in Table 2.2, the temperature needs to be at least 65°C and preferably higher to supply any energy at this point.

Table 2.2: Energy use at the different temperature levels for the main DH supply.

Supply temperature intervals (X)	kWh/m² per year for 2023
All temperatures	44.5
X ≤ 25°C	<0.1
25°C < X ≤ 30°C	<0.1
30°C < X ≤ 35°C	<0.1
35°C < X ≤ 40°C	<0.1
40°C < X ≤ 45°C	<0.1
45°C < X ≤ 50°C	<0.1
50°C < X ≤ 55°C	<0.1
55°C < X ≤ 60°C	<0.1
60°C < X ≤ 65°C	2.2
65°C < X ≤ 70°C	8.0
70°C < X ≤ 75°C	16.6
75°C < X ≤ 80°C	11.2
80°C < X	6.4

Due to the climate in Denmark, the heating energy use is season dependent, as seen in Figure 2.13. This means that the heating energy needed in the summer is limited and mainly used for DHW production.

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In terms of covering the building's energy use with waste heat, it quickly becomes clear that the waste heat should not be assumed to be able to be supplied on the main supply level due to the high-temperature needs. This becomes clear when compared to the actual supply temperature need of the systems, which is significantly lower, as seen in Figure 2.14. Roughly 70% of the building's heating energy use for the first four months of 2024 can be covered with a supply temperature of 40°C, instead of 78°C if supplying to the main supply point.

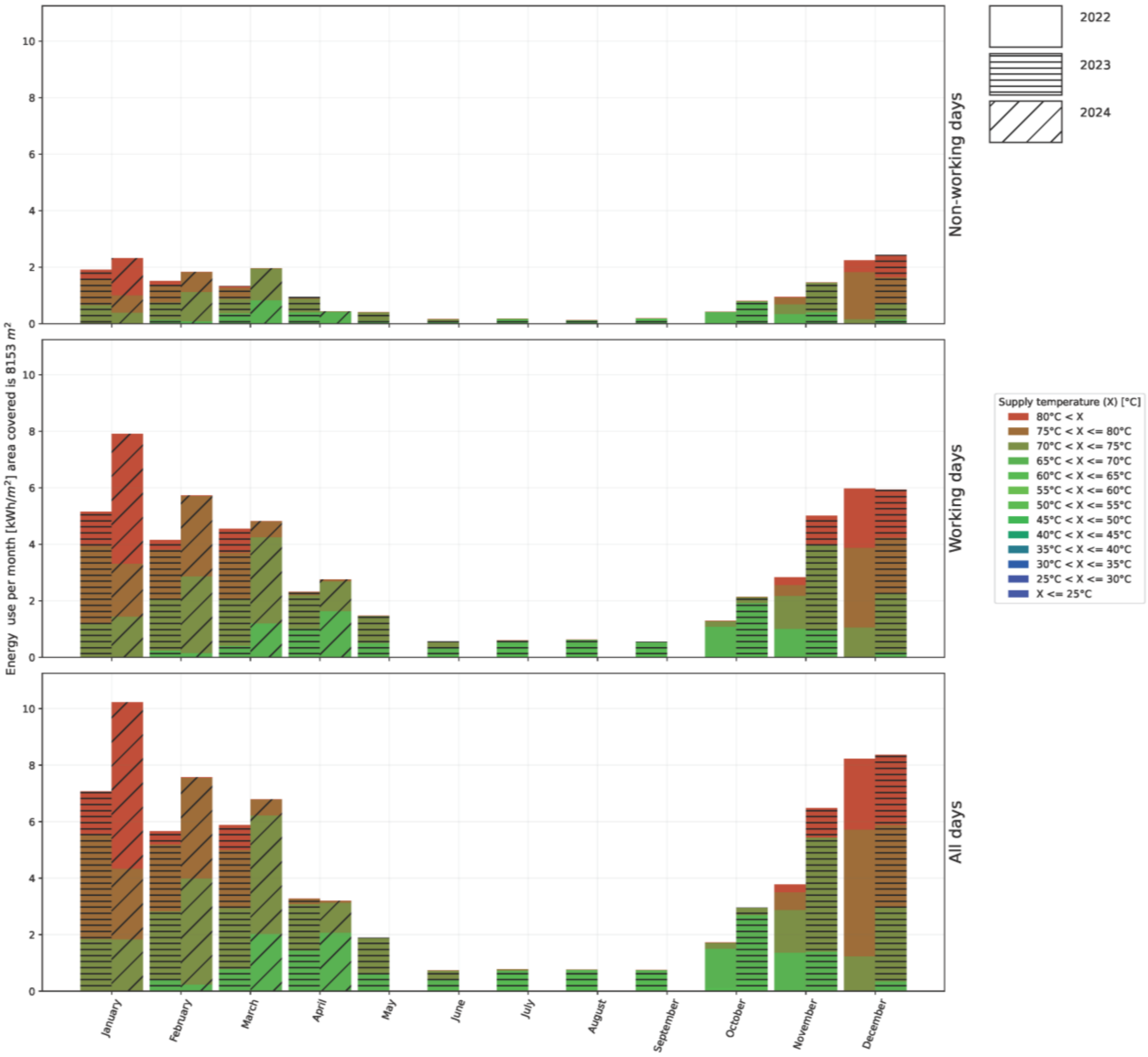

Figure 2.13: Specific heating energy use per month for the full-scale building. The working days cover Monday through Friday.

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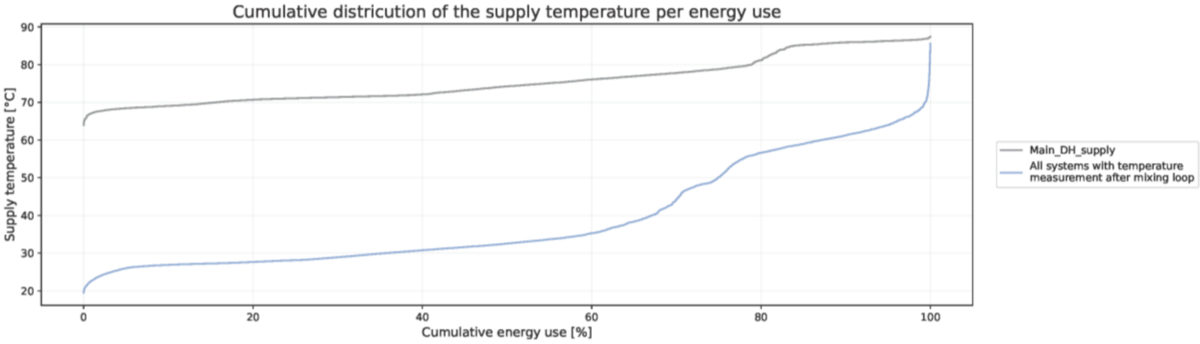

Figure 2.14: Supply temperature compared to the cumulative energy use for all systems from the 1st of January 2024 until the 19th of April 2024. The peak from 98 to 100% cumulative energy use is caused by a potential issue with the mixing loop in KOMF01 (heating coil for ventilation).

2.1.2.2 General systems

The four general system types shown in Figure 2.4 are summed up from their individual systems. These four system types are shown at their different supply temperature levels and the total specific energy use in Table 2.3 and visualized in Figure 2.15.

No assumptions have been made for the heating systems, as data for the full year of 2023 was available. The heating energy used for the heating systems is generally used by the two radiator circuits, VA01 and VA02, accounting for 48% and 39%, respectively, while the two underfloor hydronic circuits use the rest. For the heating system, it is important to remember that these numbers do not consider the energy use of the three ceiling radiators, as they do not have submeters. Their energy use is, therefore, part of the unaccounted-for heating energy use in the main DH supply.

For the ventilation systems, the P-FUND, P-VAND, P-VAERK, and VU23 units only had data available for three full months (January – March 2024), as seen in Figure 2.5. They have, therefore, been calculated for "2023" by using a correction factor based on the ratio between the energy use in those months and the energy use of 2023 for Lab 1, Lab 2, and P-KLIMA, as these are the most representative systems. This correction has a miniscule impact on the total result as these four systems only account for 3% of the total heating energy used for ventilation. The major contributions for the ventilation heating energy use are P-KLIMA, Lab 1, and Lab 2, with 45%, 25%, and 23%, respectively. As seen in Figure 2.4, some of the ventilation systems have the supply temperature after the mixing loop available, while others only have the supply temperature before the mixing loop (corresponding closely to the DH supply temperature).

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The domestic hot water system data availability differs for each circuit. The lack of data was handled by using the full months available for each circuit, multiplying the value by 12 and dividing by the number of months available, as neither the energy use nor the supply temperature was seen to have a dependence on the season, thus gaining a full year value.

The miscellaneous systems currently only comprise the air curtain in the main entrance, covering a small area but still accounting for 0.2 kWh/m^2 of the total specific heating energy use. The system only had trustworthy data for the first three months of 2024, it was therefore multiplied with the correction factor used for the ventilation systems. This was because they were deemed the most representative for the yearly profile, as both system types are based on heating the outdoor air.

Table 2.3: Specific energy use by the different general systems at different supply temperature levels. The systems all use the total gross area of the building. For the ventilation system, three values are given, "Total" is comparable to the values from the other systems, "After" is the energy used when the temperature is measured after the mixing loop, while "Before" is when the temperature is measured before the mixing loop (corresponding to the DH supply temperature).

Supply temperature intervals (X)	kWh/m^2 for one full year			
	Heating	Ventilation Total (After / Before)	Domestic hot water	Miscellaneous
All temperatures	14.1	19.3 (9.0 / 10.3)	1.8	0.1
X ≤ 25°C	<0.1	0.4 (0.4 / <0.1)	<0.1	0
25°C < X ≤ 30°C	1.4	2.2 (2.2 / <0.1)	<0.1	0
30°C < X ≤ 35°C	0.3	4.1 (4.1 / <0.1)	<0.1	0
35°C < X ≤ 40°C	0.1	1.7 (1.7 / <0.1)	<0.1	0
40°C < X ≤ 45°C	0.4	0.5 (0.5 / <0.1)	0.1	0
45°C < X ≤ 50°C	1.1	0.2 (0.1 / 0.1)	0.6	0
50°C < X ≤ 55°C	3.6	0.1 (<0.1 / 0.1)	0.8	<0.1

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55°C < X ≤ 60°C	4.3	0.2 (<0.1 / 0.2)	0.2	<0.1
60°C < X ≤ 65°C	2.4	1.1 (<0.1 / 1.1)	<0.1	<0.1
65°C < X ≤ 70°C	0.4	3.4 (0 / 3.4)	<0.1	<0.1
70°C < X ≤ 75°C	0.1	3.1 (0 / 3.1)	0	<0.1
75°C < X ≤ 80°C	<0.1	1.5 (0 / 1.5)	0	<0.1
80°C < X	0	0.7 (0 / 0.7)	0	0

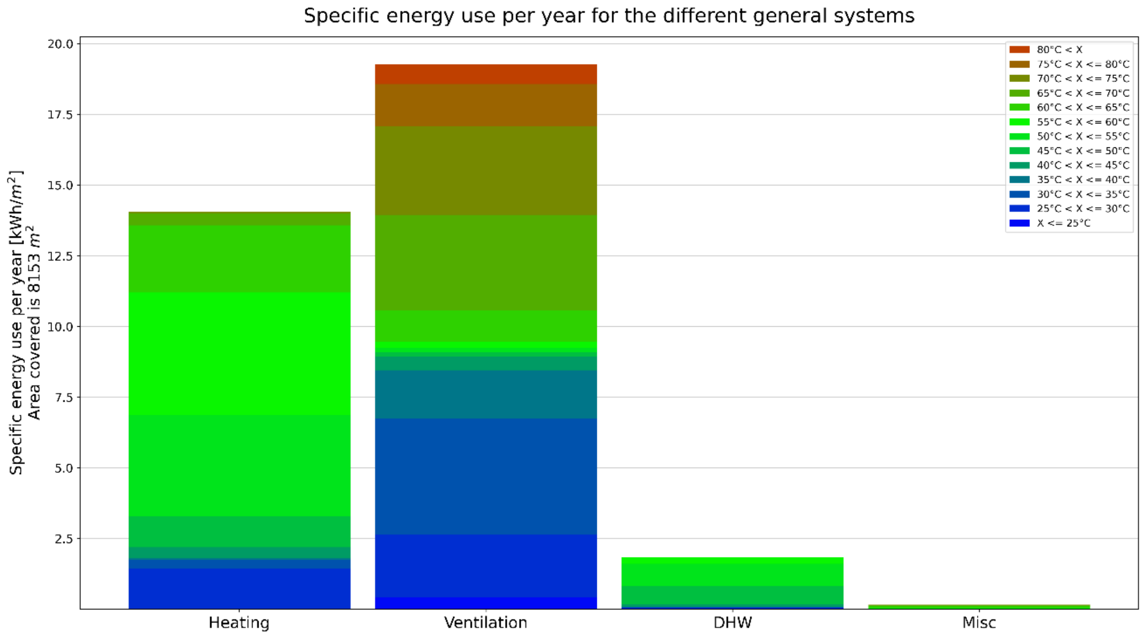

Figure 2.15: Specific energy use at the supply temperature levels for the different general systems, recalculated to 2023 when data was missing. The ventilation bar would most likely be blue/green (<50°C) if supply temperature data after the mixing loop had been available for all the heating coils.

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Ventilation

Looking at the supply temperatures for the different ventilation systems, shown in Figure 2.16, it becomes clear that when looking at the systems where the supply temperature is measured after the mixing loop, a majority of the energy use can be covered by relatively low temperatures, especially when considering that P-Klima, which can be covered 95% using temperatures lower than 40°C, accounts for 45% of the entire heating energy use for ventilation in 2023. For KOMF02 (one of the office ventilation units), 67% of its heating energy use can be covered using a supply temperature of 40°C. This potential is also assumed to be similar for the other office units (KOMF01 and KOMF03). However, for KOMF01, there appears to be a fault in the mixing loop causing high supply temperatures after the mixing loop, while for KOMF03, the temperature measurement available is before the mixing loop, meaning that the supply temperature potential cannot be confirmed.

Assuming that both of these units (KOMF02 and P-KLIMA) are representative of the other units, this means that for ventilation, there is a potential to cover 15.3 kWh/m^2 with a 40°C supply temperature if KOMF02 is assumed to be representative of all systems except for P-KLIMA. If KOMF02 is only assumed to be representative of the KOMF units and P-KLIMA is representative of all the other units, it is possible to cover 17.9 kWh/m^2 with a 40°C supply temperature.

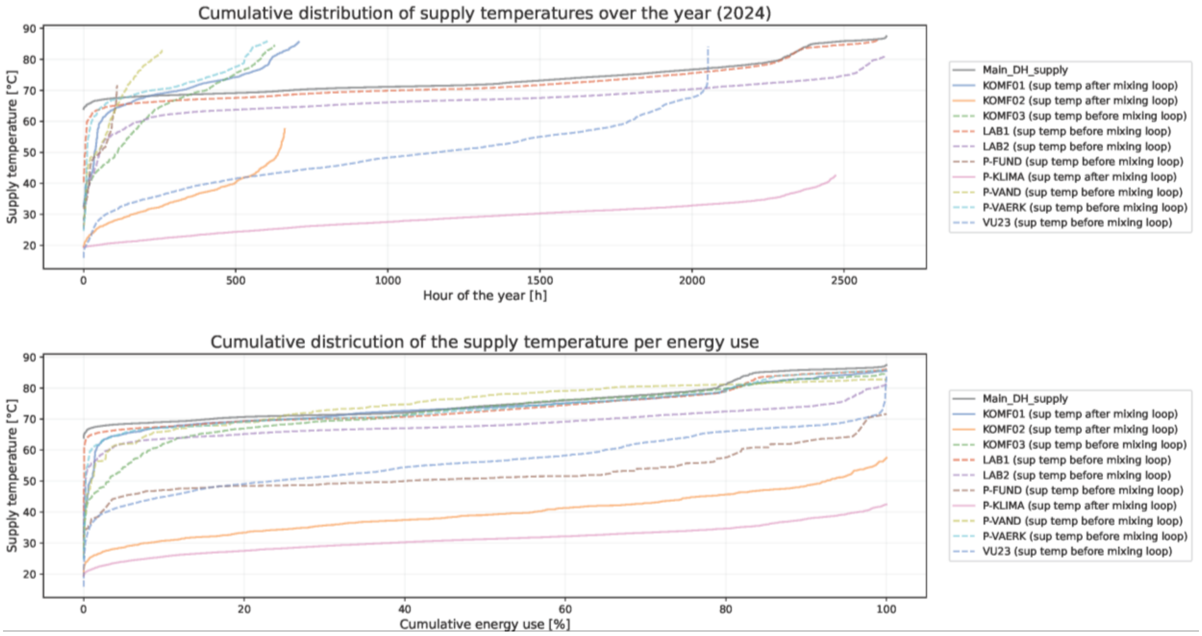

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Figure 2.16: Supply temperature compared to the cumulative energy use for the different ventilation systems from the 1st of January 2024 until the 19th of April 2024. The parenthesis in the legend indicates where the supply temperature was measured, with three possibilities, before the mixing loop, after the mixing loop, or not relevant.

Table 2.4: Specific energy use for the different individual ventilation units in 2023.

Supply temperature intervals (X)	kWh/m² for one full year									
	KOMF01	KOMF02	KOMF03	Lab 1	Lab 2	P-Fund	P-Klima	P-Vand	P-Vaerk	VU23
All temperatures	0.3	0.4	0.2	4.9	4.5	<0.1	8.6	0.1	0.2	0.2
X ≤ 25°C	0	<0.1	0	0	0	0	0.4	0	0	0
25°C < X ≤ 30°C	0	0.1	0	0	0	0	2.2	0	0	0
30°C < X ≤ 35°C	0	0.1	0	0	<0.1	0	4.0	0	0	0
35°C < X ≤ 40°C	0	0.1	0	0	<0.1	0	1.6	0	0	<0.1
40°C < X ≤ 45°C	0	0.1	0	0	<0.1	0	0.4	0	0	<0.1
45°C < X ≤ 50°C	0	<0.1	0	0	<0.1	0	<0.1	0	0	<0.1
50°C < X ≤ 55°C	<0.1	<0.1	<0.1	0	0.1	<0.1	0	0	0	<0.1
55°C < X ≤ 60°C	<0.1	0	<0.1	<0.1	0.2	<0.1	0	0	0	<0.1
60°C < X ≤ 65°C	<0.1	0	<0.1	0.3	0.8	<0.1	0	0	0	<0.1
65°C < X ≤ 70°C	0.1	0	<0.1	1.4	1.8	<0.1	0	<0.1	<0.1	<0.1
70°C < X ≤ 75°C	0.1	0	<0.1	1.7	1.2	0	0	<0.1	0.1	<0.1
75°C < X ≤ 80°C	<0.1	0	<0.1	1.0	0.4	0	0	<0.1	0.1	0
80°C < X	<0.1	0	<0.1	0.5	<0.1	0	0	<0.1	0.1	0

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Space heating

When analyzing the space heating, it can be deduced from Table 2.5 that the radiator circuits used roughly 88% of the energy, while the underfloor hydronic systems accounted for only 12% of the energy use. The underfloor hydronic systems can, as seen in Figure 2.17, have their entire energy need covered by a supply temperature of 40°C, while 95% of the energy use can be covered even if the supply temperature is only 35°C. The radiator circuits, on the other hand, need a supply temperature of 60°C to cover 80% of the energy use.

Using the values from Table 2.5, it becomes clear that if a supply temperature of 40°C is available, 1.8 kWh/m^2 can be covered, while if the supply temperature is raised to 60°C, it is possible to cover 11.2 kWh/m^2.

Table 2.5: Specific energy use for the different individual heating circuits in 2023.

Supply temperature intervals (X)	kWh/m^2 for one full year			
	VA01	VA02	GV01	GV02
All temperatures	6.8	5.5	1.2	0.5
X ≤ 25°C	0	0	0	0
25°C < X ≤ 30°C	<0.1	0	1.1	0.3
30°C < X ≤ 35°C	<0.1	0	0.1	0.2
35°C < X ≤ 40°C	0.1	<0.1	0	0
40°C < X ≤ 45°C	0.2	0.1	0	0
45°C < X ≤ 50°C	0.8	0.3	0	0
50°C < X ≤ 55°C	2.0	1.6	0	0
55°C < X ≤ 60°C	2.2	2.1	0	0
60°C < X ≤ 65°C	1.2	1.2	0	0

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65°C < X ≤ 70°C	0.2	0.2	0	0
70°C < X ≤ 75°C	<0.1	<0.1	0	0
75°C < X ≤ 80°C	<0.1	0	0	0
80°C < X	0	0	0	0

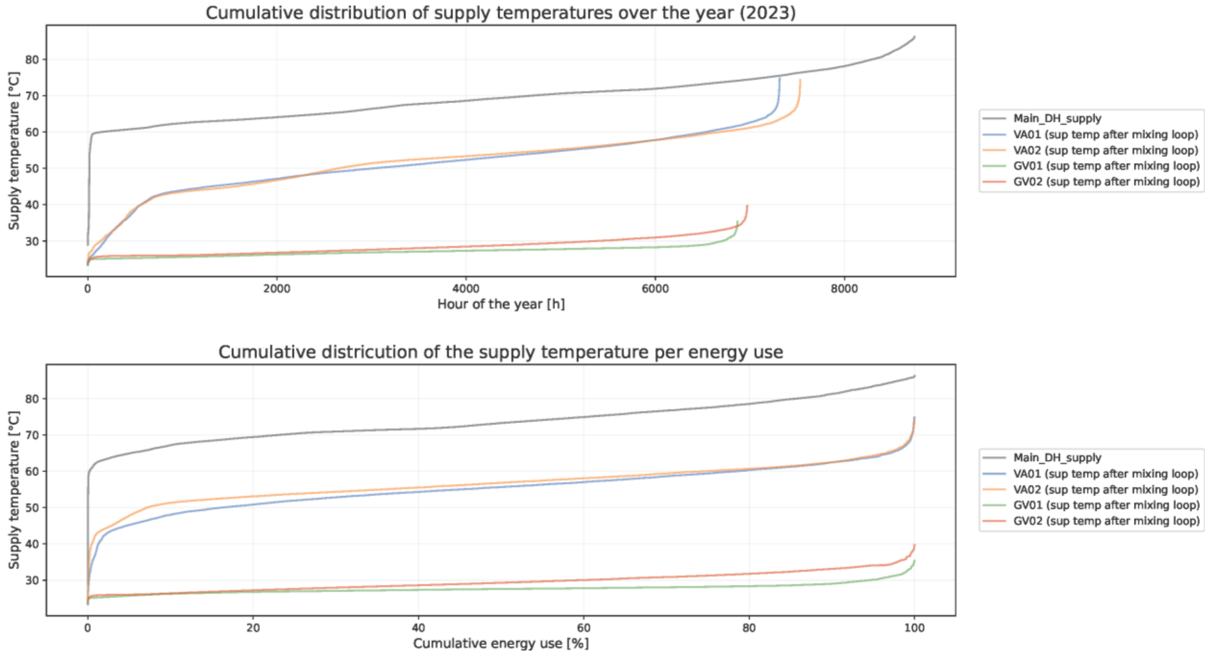

Figure 2.17: Supply temperature compared to the cumulative energy use for the different heating systems in 2023. The parenthesis in the legend indicates where the supply temperature was measured, with three possibilities, before the mixing loop, after the mixing loop, or not relevant.

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Domestic hot water

For the domestic hot water circuits, it becomes clear that they generally need a supply temperature of between 50°C and 60°C. These limits are due to both use and comfort concerns and to prevent legionella, which is important, as Denmark ranked among the countries in Europe with the highest infection rate (European Centre for Disease Prevention and Control, 2023). It is thus not reasonable to use supply temperatures of less than these unless there is local heating to prevent legionella. If a supply temperature of 50°C is provided, 45% of the energy use can be covered, while 60°C can cover roughly the entire energy need, as seen in Figure 2.18 and Table 2.6.

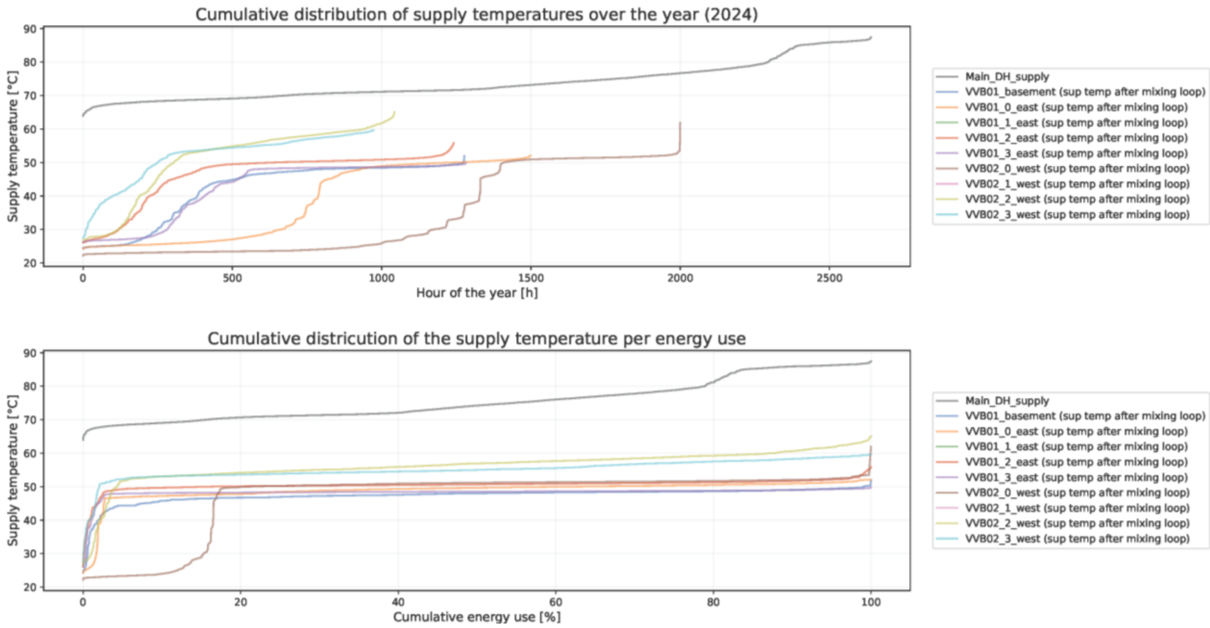

Figure 2.18: Supply temperature compared to the cumulative energy use for the different domestic hot water circuits from the 1st of January 2024 until the 19th of April 2024. The parenthesis in the legend indicates where the supply temperature was measured, with three possibilities, before the mixing loop, after the mixing loop, or not relevant.

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Table 2.6: Specific energy use for the different individual domestic hot water circuits in a full year.

Supply temperature intervals (X)	kWh/m² for one full year								
	WB01_basement	WB01_0_east	WB01_1_east	WB01_2_east	WB01_3_east	WB02_0_west	WB02_1_west	WB02_2_west	WB02_3_west
All temperatures	0.3	0.2	0.2	0.4	0.1	0.2	0.2	0.1	0.1
X ≤ 25°C	<0.1	<0.1	0	0	0	<0.1	0	0	0
25°C < X ≤ 30°C	<0.1	<0.1	0	0	0	<0.1	0	0	0
30°C < X ≤ 35°C	<0.1	0	0	0	0	<0.1	0	0	0
35°C < X ≤ 40°C	<0.1	0	<0.1	0	0	0	0	0	0
40°C < X ≤ 45°C	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	0
45°C < X ≤ 50°C	0.2	0.1	<0.1	0.1	0.1	<0.1	0.1	<0.1	<0.1
50°C < X ≤ 55°C	0.1	0.1	0.1	0.3	0	0.1	0.1	<0.1	<0.1
55°C < X ≤ 60°C	<0.1	0.1	<0.1	<0.1	0	<0.1	<0.1	<0.1	<0.1
60°C < X ≤ 65°C	0	0	0	0	0	0	0	<0.1	0
65°C < X ≤ 70°C	0	0	0	0	0	0	0	0	0
70°C < X ≤ 75°C	0	0	0	0	0	0	0	0	0
75°C < X ≤ 80°C	0	0	0	0	0	0	0	0	0
80°C < X	0	0	0	0	0	0	0	0	0

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Miscellaneous

For the miscellaneous systems, which only include the Door01 air curtain, it becomes clear in Figure 2.19 that this system generally uses relatively high temperatures due to the lack of a mixing loop, meaning that the system is currently limited to using only the DH directly. If this system had a mixing loop, it could have a similar potential to the ventilation units, where relatively low temperatures could cover significant parts of the energy. This would also require that the heating coil is dimensioned to fit the lower temperatures. In this pilot, the system does not have a large influence due to the comparatively low energy use of 0.1 kWh/m^2.

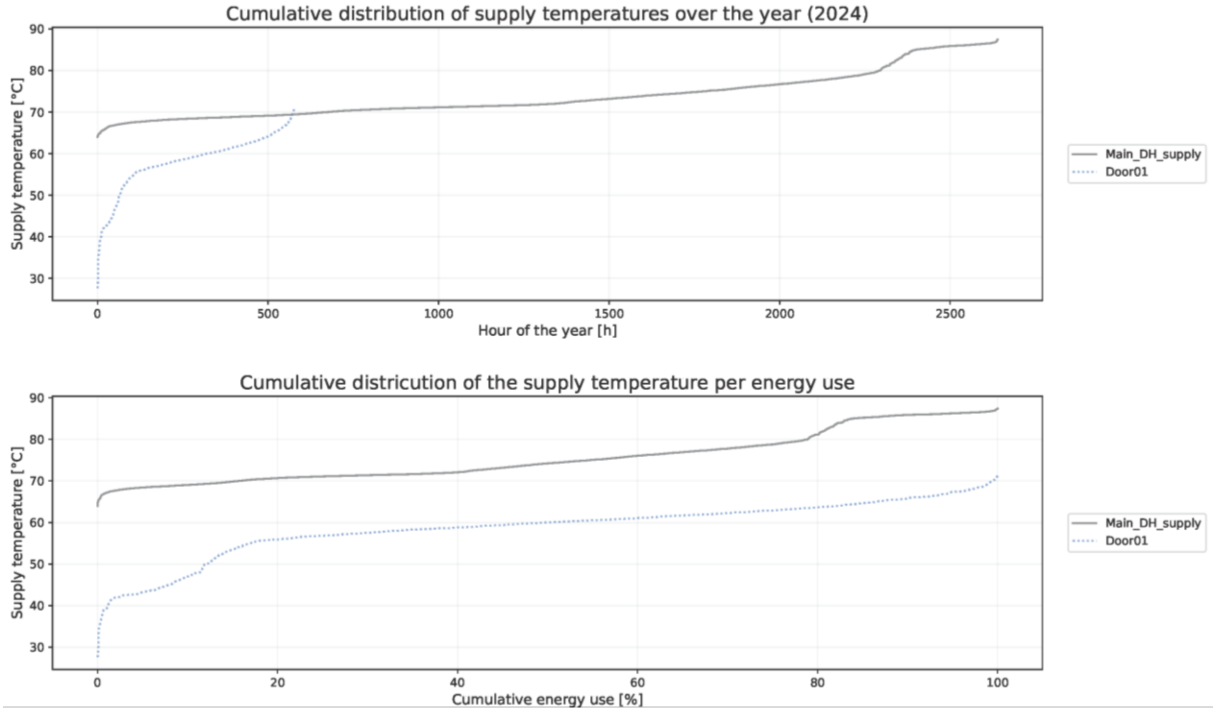

Figure 2.19: Supply temperature compared to the cumulative energy use for the miscellaneous systems from the 1st of January 2024 until the 19th of April 2024.

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2.1.2.3 Systems (Ventilation)

In this section, the results for the different ventilation units are shown, along with any individual considerations. Be aware that the specific energy use shown in this section is not equivalent to the one used in previous sections, as it is now only based on the actual gross area covered by the specific system unless stated otherwise.

Comfort heating coil – KOMF01

The KOMF01 AHU supplies ventilation air to offices, group rooms, meeting rooms, and similar rooms in the western part of the building. It is normally only active during the working days from 08.00 to 18.00, as seen in Figure 2.20. It also becomes clear from Figure 2.21 that the heating coil's energy use is highly seasonal, with no energy use in the period from May to September, but also that the months cannot necessarily be used as a direct prediction for the energy use, but instead it should be based on the outdoor temperature going forward. KOMF01 can be seen to require rather high supply temperatures (>60°C), which is suspected to be caused by an issue with the mixing loop or settings, as the temperature is measured after the mixing loop and was expected to be similar to the temperatures measured in KOMF02.

Table 2.7: Supply temperature and energy use for KOMF01.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
>80°C (55°C if the assumption of the need being similar to KOMF02 is correct)	1.0	0.3

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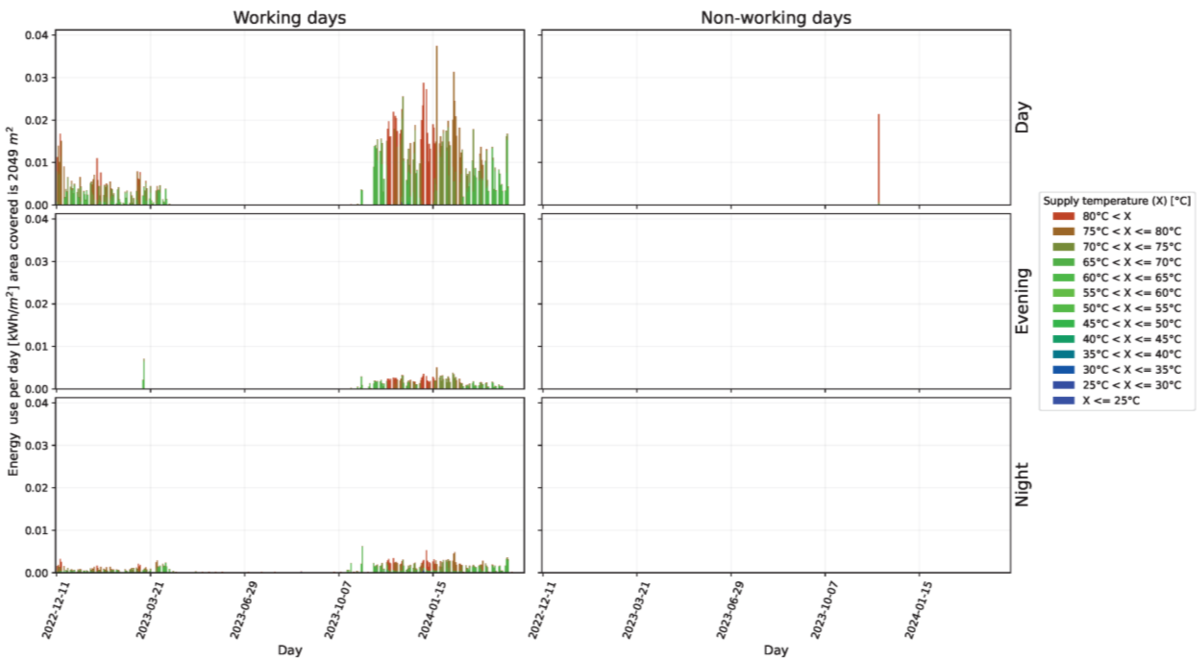

Figure 2.20: Specific heating energy use for the heating coil in KOMF01 in the different periods of each day. For each of the periods (day, evening, and night), the energy use is summed over the hours. The peak during non-working days is for a test on the AHU and is not normal operation.

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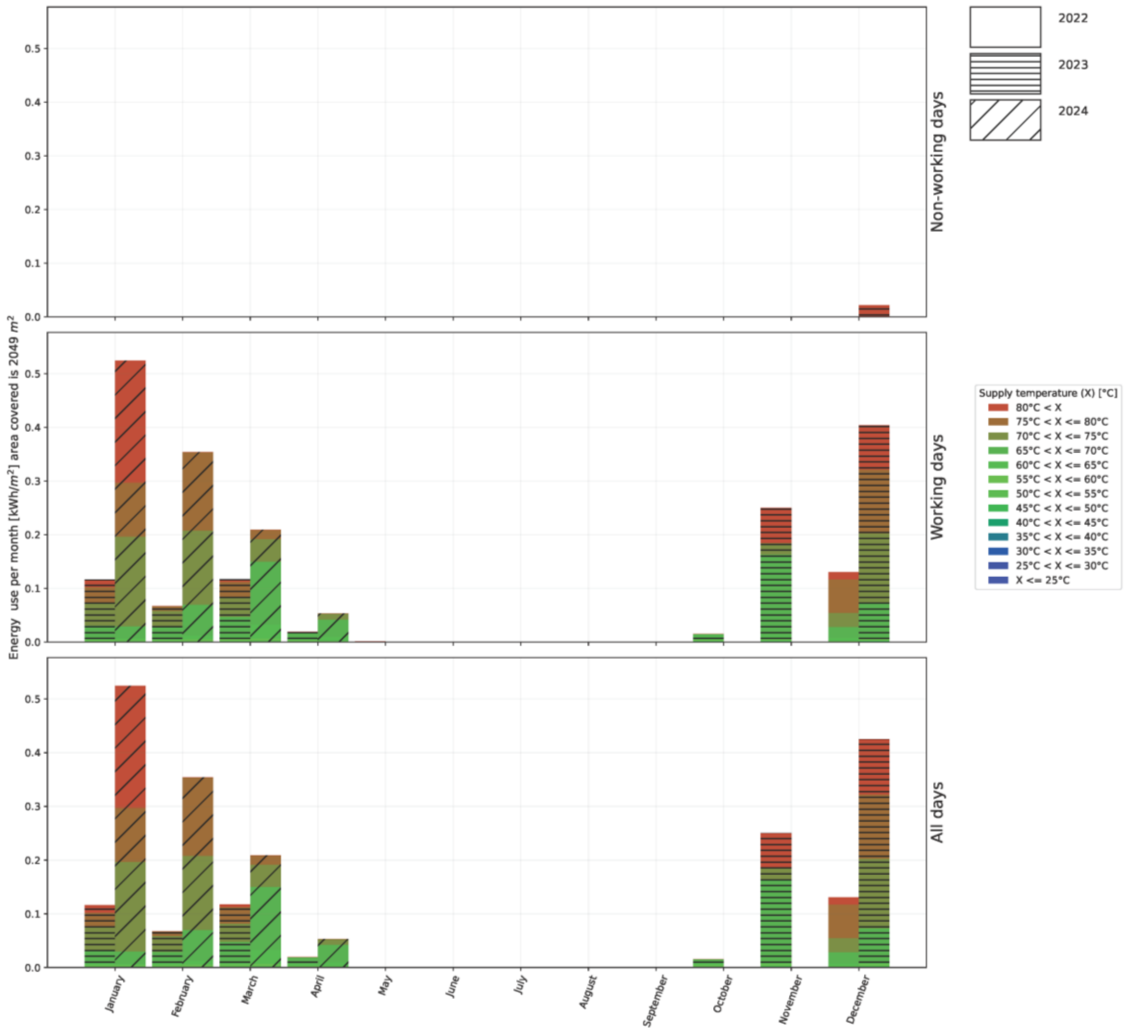

Figure 2.21: Specific monthly energy use for the heating coil in KOMF01.

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Comfort heating coil – KOMF02

The KOMF02 AHU supplies ventilation air to offices, group rooms, meeting rooms, and similar rooms in the northern and eastern parts of the building. It is normally only active during the workdays from 07.15 to 16.00, as seen in Figure 2.22, where there is only energy use during the day and night. In terms of seasonality, as seen in Figure 2.23, it has the same tendencies as KOMF01, with high seasonality but also appears to be outdoor temperature dependent. It can be seen that it generally needs between 30°C and 50°C as a supply temperature, which is expected since the air supply temperature generally has to reach around 18-22°C.

Table 2.8: Supply temperature and energy use for KOMF02.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
55°C	1.2	0.4

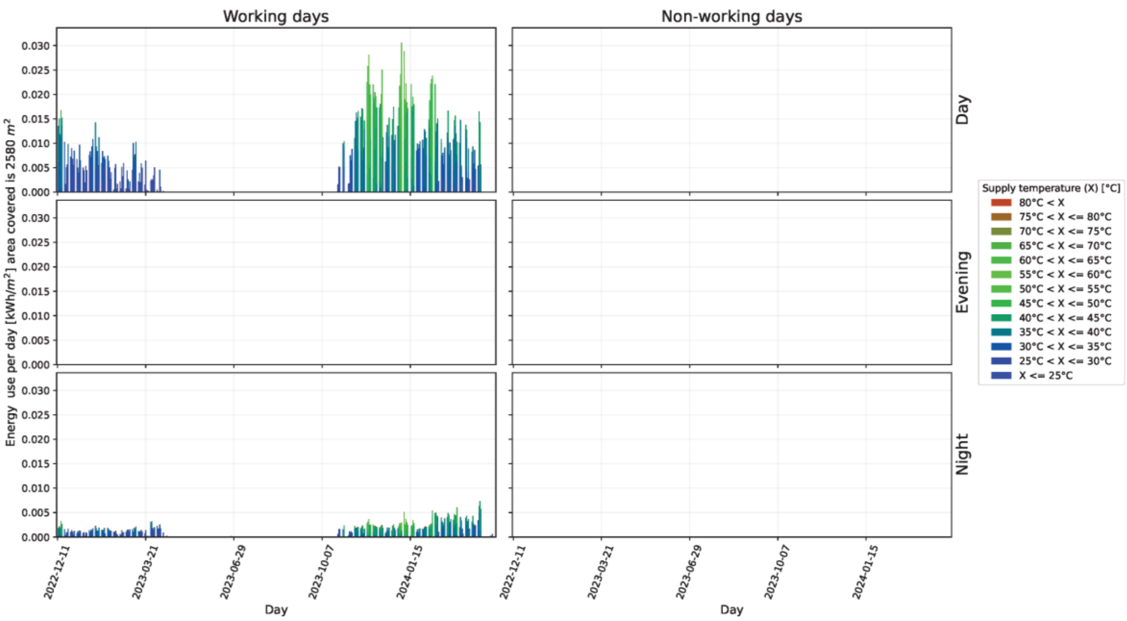

Figure 2.22: Specific heating energy used for the heating coil in KOMF02 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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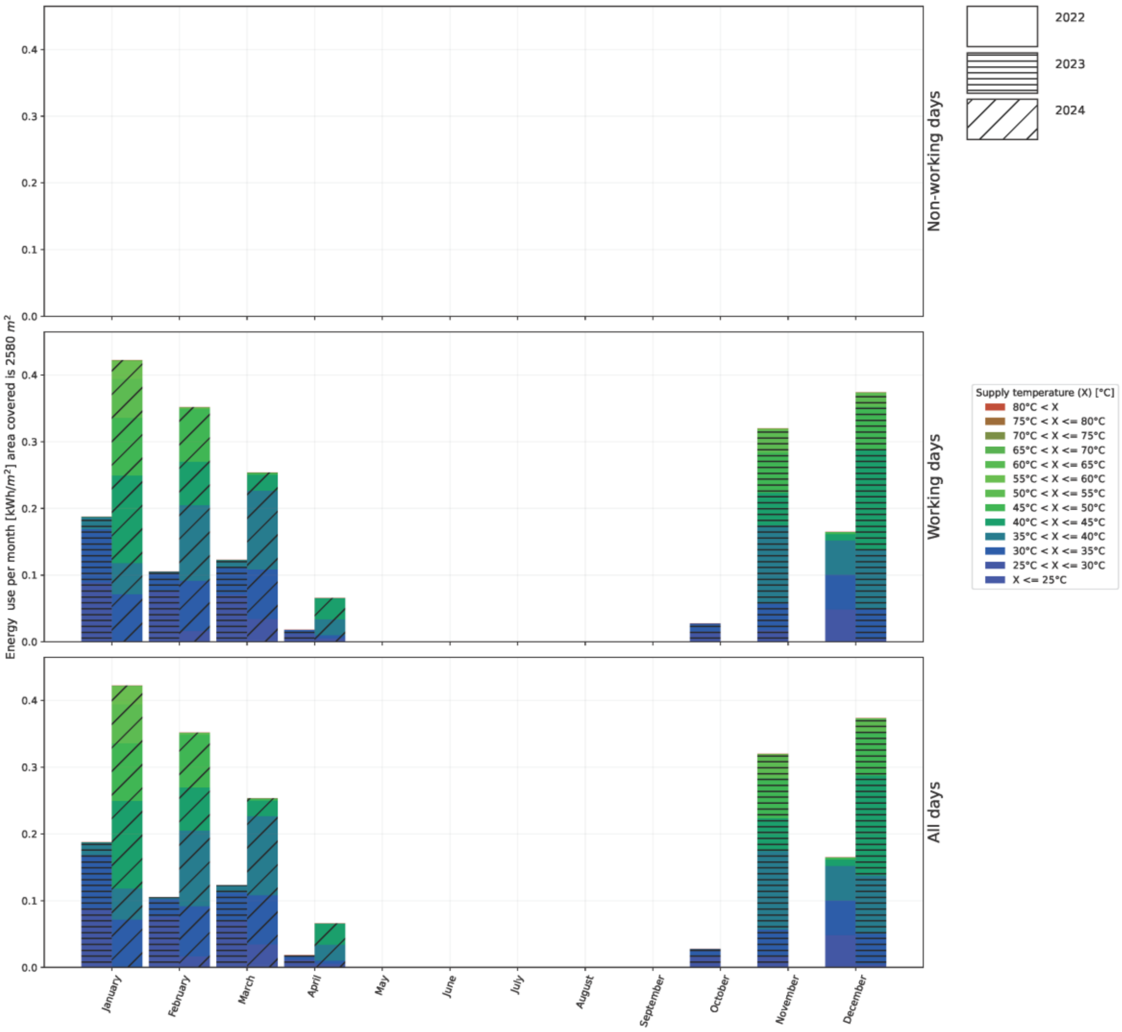

Figure 2.23: Specific monthly energy used for the heating coil in KOMF02.

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Comfort heating coil – KOMF03

The KOMF03 AHU supplies ventilation air to offices, group rooms, meeting rooms, and similar rooms in the southern part of the building. It is normally only active during workdays from 08.00 to 16.00, as seen in Figure 2.24, where there is mainly energy use during the day. In terms of seasonality, as seen in Figure 2.25, it has the same tendencies as KOMF01, with high seasonality but also appears to be outdoor temperature dependent. It can be seen that it generally needs high supply temperatures because the supply temperature is measured before the mixing loop, thus not properly representing the needs of the system itself.

Table 2.9: Supply temperature and energy use for KOMF03.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
>80°C (55°C if the assumption of the need being similar to KOMF02 is correct)	0.9	0.2

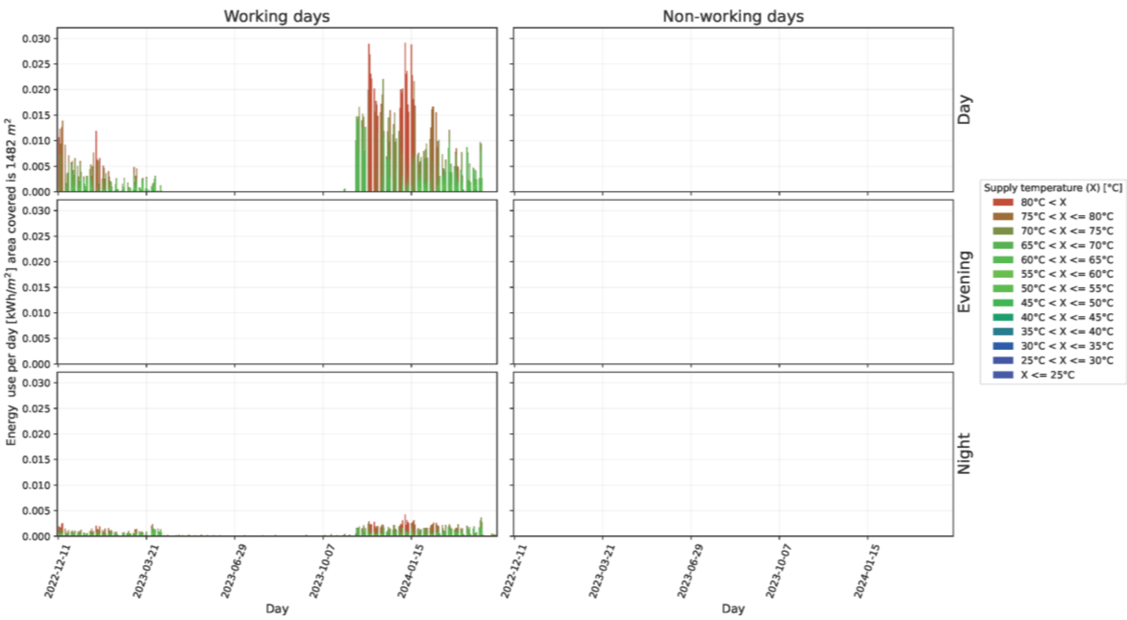

Figure 2.24: Specific heating energy used for the heating coil in KOMF03 in the different periods of each day. The energy use is summed up over the hours for each period (day, evening, and night).

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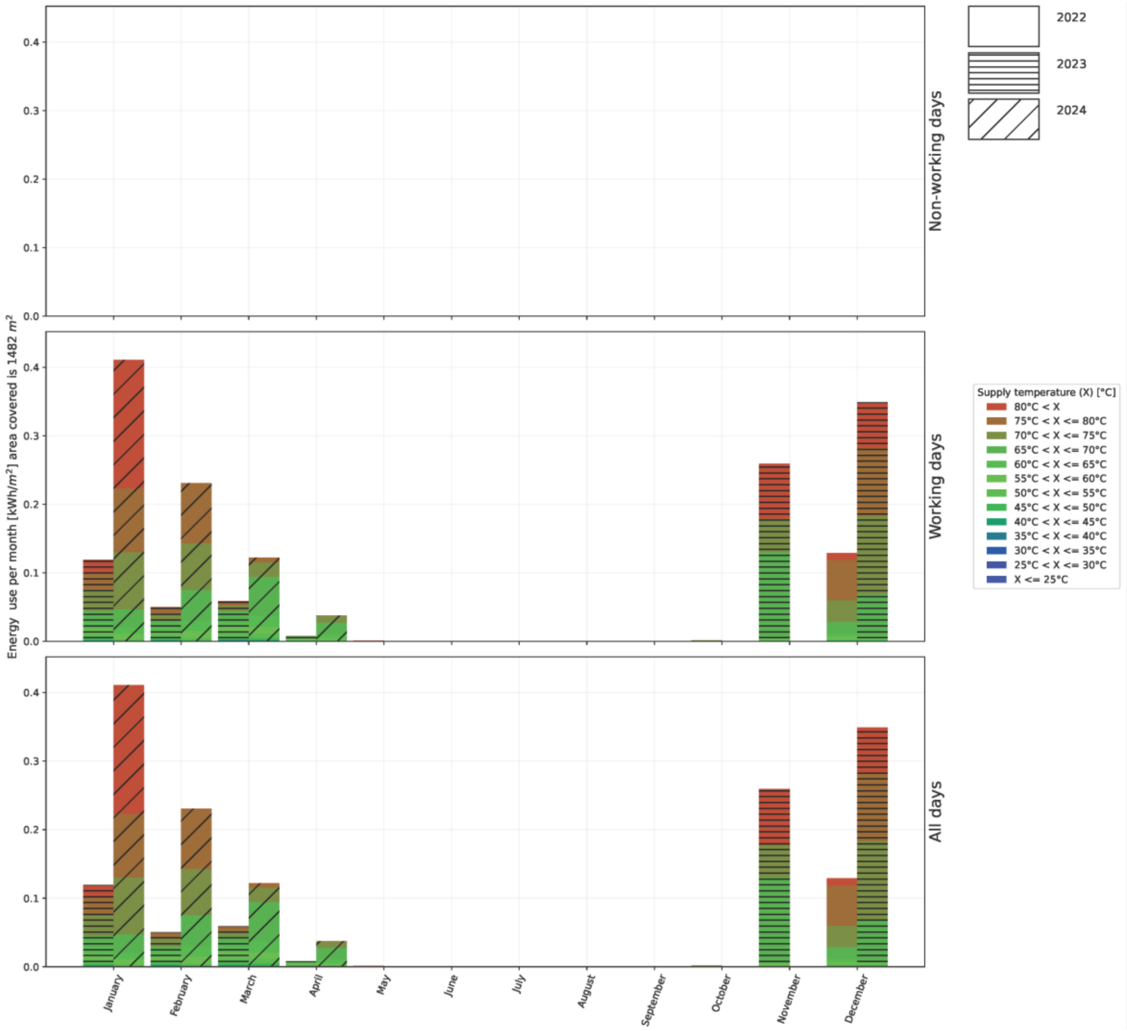

Figure 2.25: Specific monthly energy use for the heating coil in KOMF03.

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Comfort heating coil – Lab 1

The Lab 1 AHU supplies several smaller laboratories and offices. The Lab 1 AHU is in operation at all hours of the day on all days, which can be seen in Figure 2.26, as there is no distinct change in the energy use patterns for any of the periods. This means that even though there is a low energy use during some periods (cooling season), as seen in Figure 2.27, once there is a need, the heating is needed during the entire period.

As the supply temperature is measured before the mixing loop, it is not representative of the actual temperature needed in the heating coil.

Table 2.10: Supply temperature and energy use for Lab 1.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
>80°C (50°C if the assumption of the need being similar to Lab P-Klima is correct)	117.9	4.9

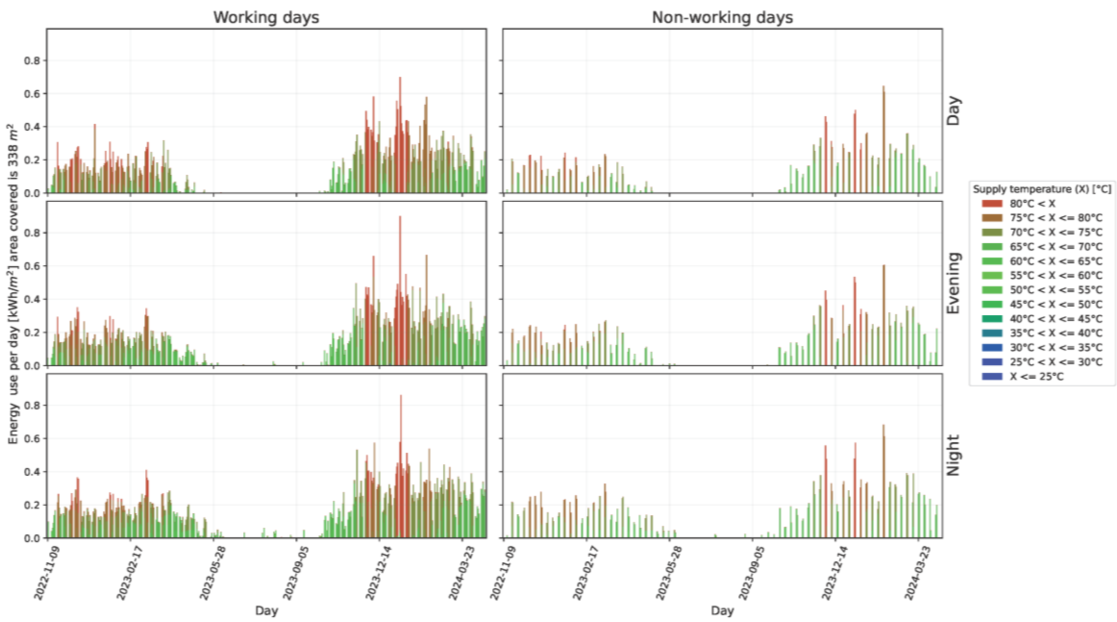

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Figure 2.26: Specific heating energy used for the heating coil in Lab 1 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

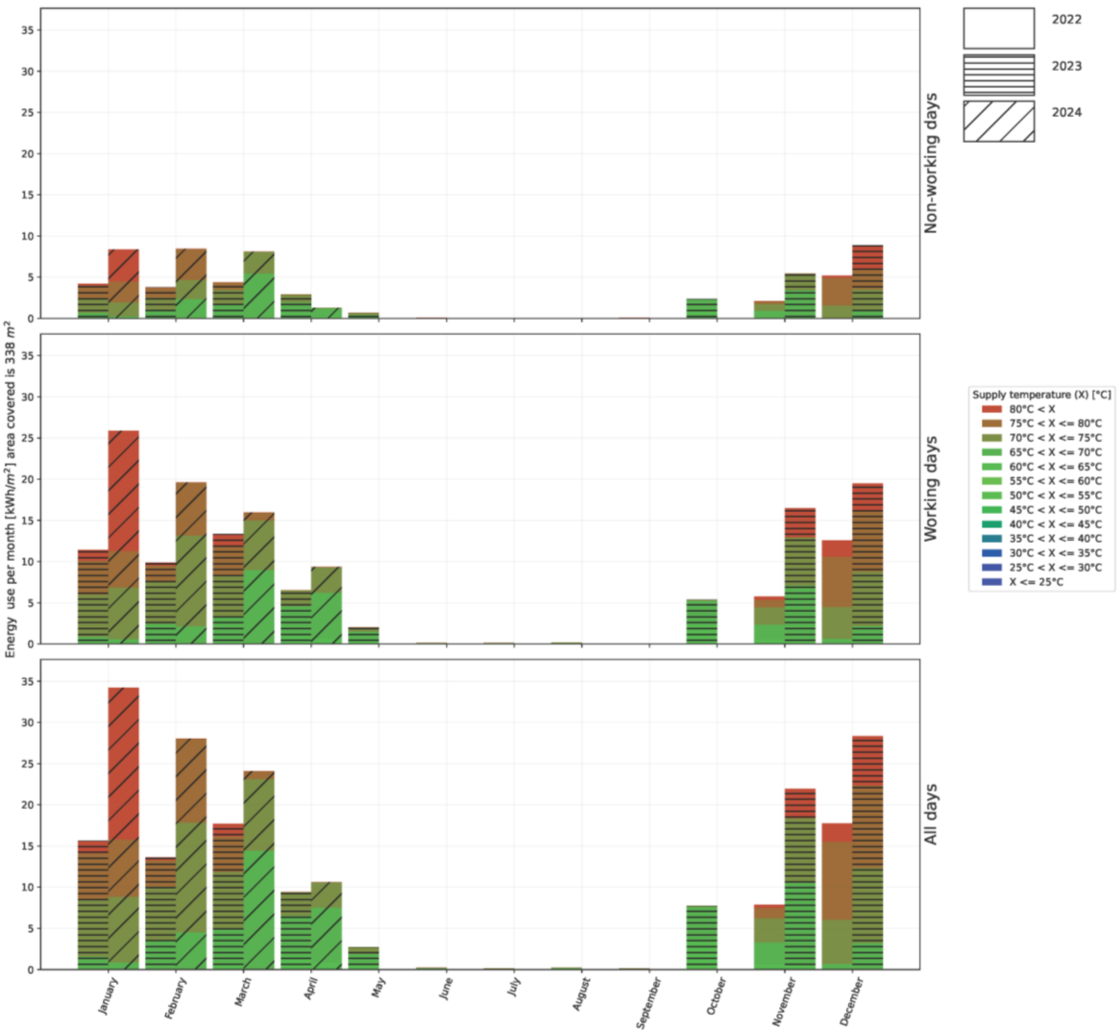

Figure 2.27: Specific monthly energy used for the heating coil in Lab 1.

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Comfort heating coil – Lab 2

The Lab 2 AHU supplies several smaller laboratories and offices. The Lab 2 AHU is in operation at all hours of the day on all days, which can be seen in Figure 2.28, as there is no distinct change in the energy use patterns for any of the periods. This means that even though there is a low energy use during some periods (cooling season), as seen in Figure 2.29, once there is a need, the heating is needed during the entire period.

As the supply temperature is measured before the mixing loop, it is not representative of the actual temperature needed in the heating coil.

Table 2.11: Supply temperature and energy use for Lab 2.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
80°C (50°C if the assumption of the need being similar to Lab P-Klima is correct)	141.1	4.5

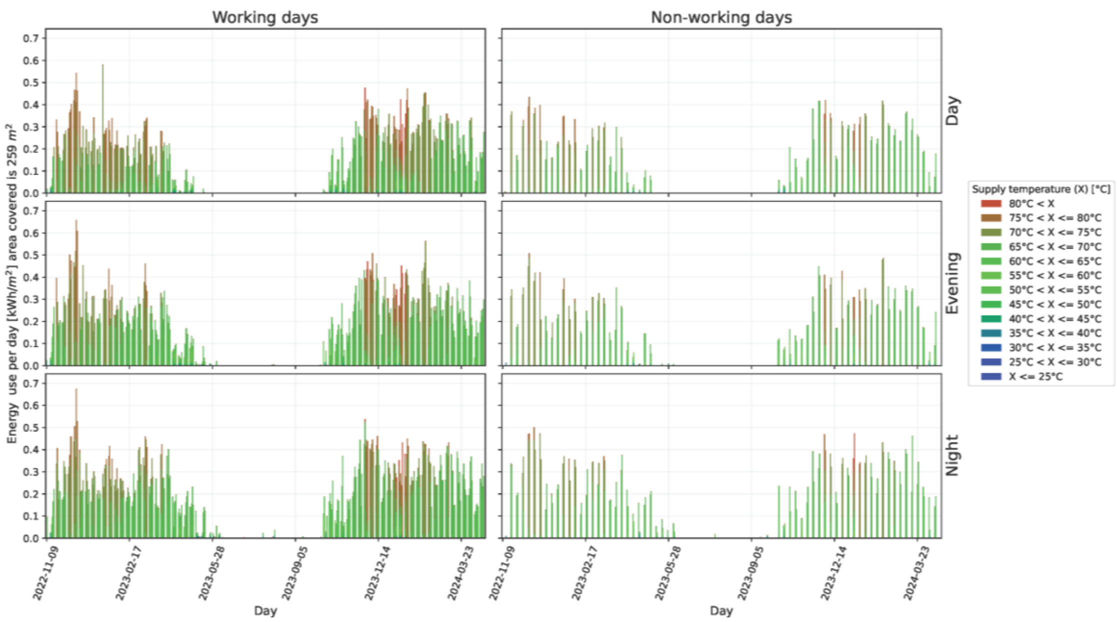

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Figure 2.28: Specific heating energy used for the heating coil in Lab 2 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

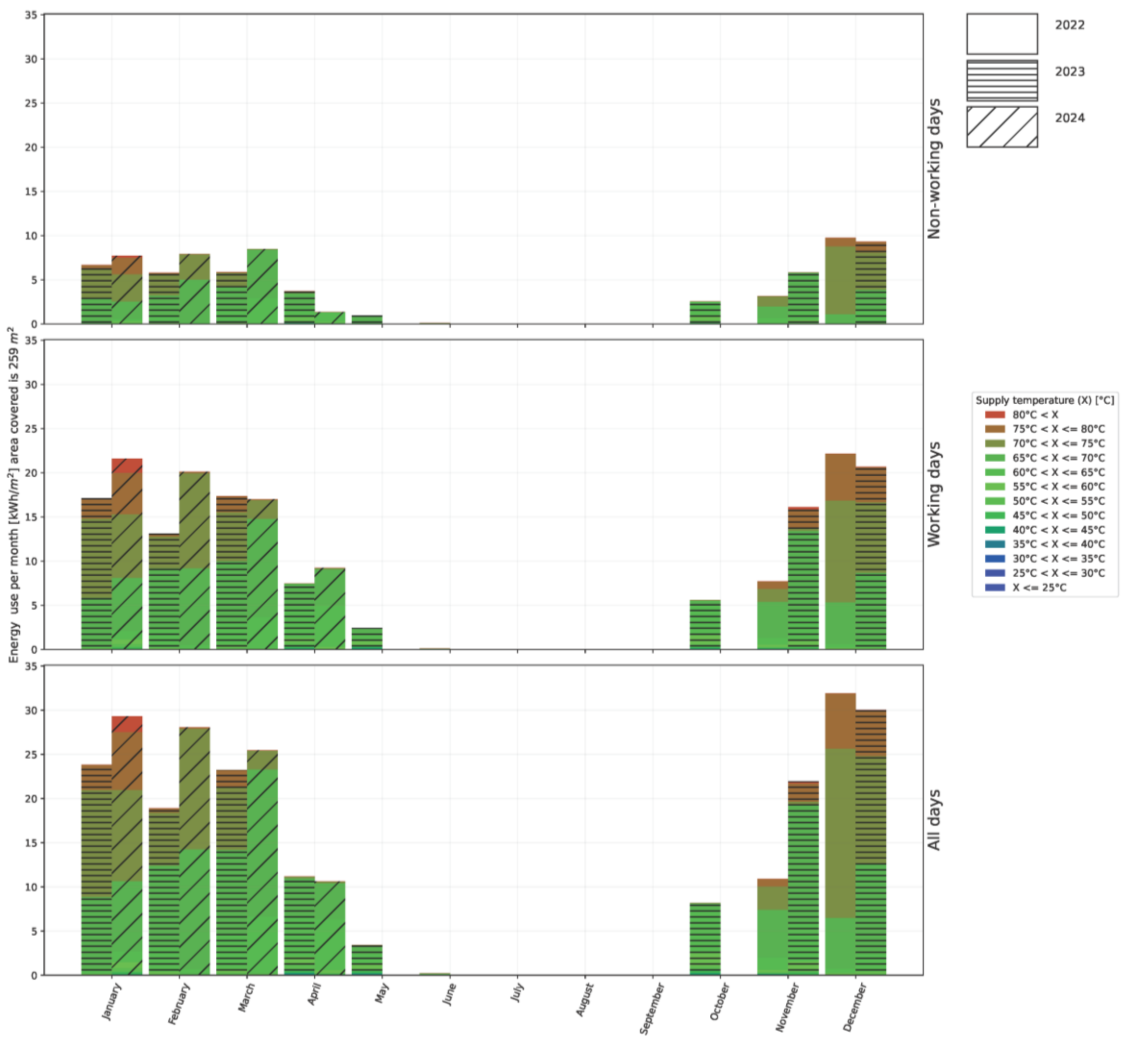

Figure 2.29: Specific monthly energy used for the heating coil in Lab 2.

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Comfort heating coil – Lab P-Fund

The P-Fund AHU supplies the foundation, construction, and geotechnical laboratory. The heating coil in Lab P-Fund operates to maintain a supply air temperature between 20°C and 21.5°C, but the way it does this is with a brief opening of the valve due to low morning temperatures, causing a high spike of hot water into the mixing loop in the morning, followed by almost no use the rest of the day. This and the low energy need, as seen in Figure 2.30 and Figure 2.31, mean that this heating coil is unsuitable for utilizing waste heat directly.

Table 2.12: Supply temperature and energy use for Lab P-Fund.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
70°C (50°C if the assumption of the need being similar to Lab P-Klima is correct)	0.7	<0.1

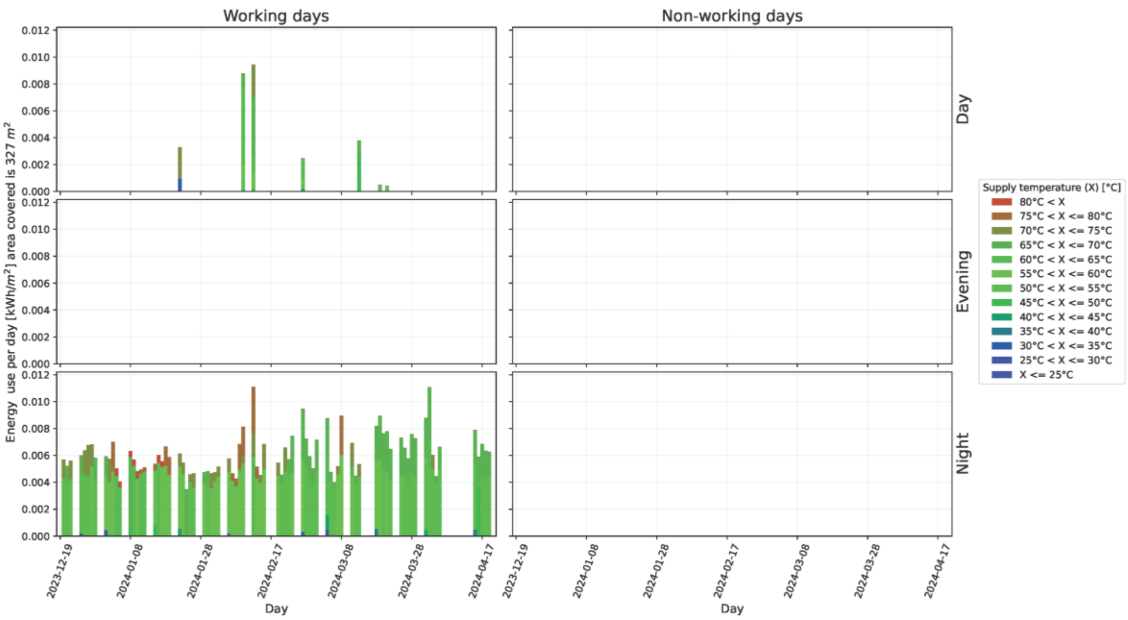

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Figure 2.30: Specific heating energy used for the heating coil in Lab P-Fund in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

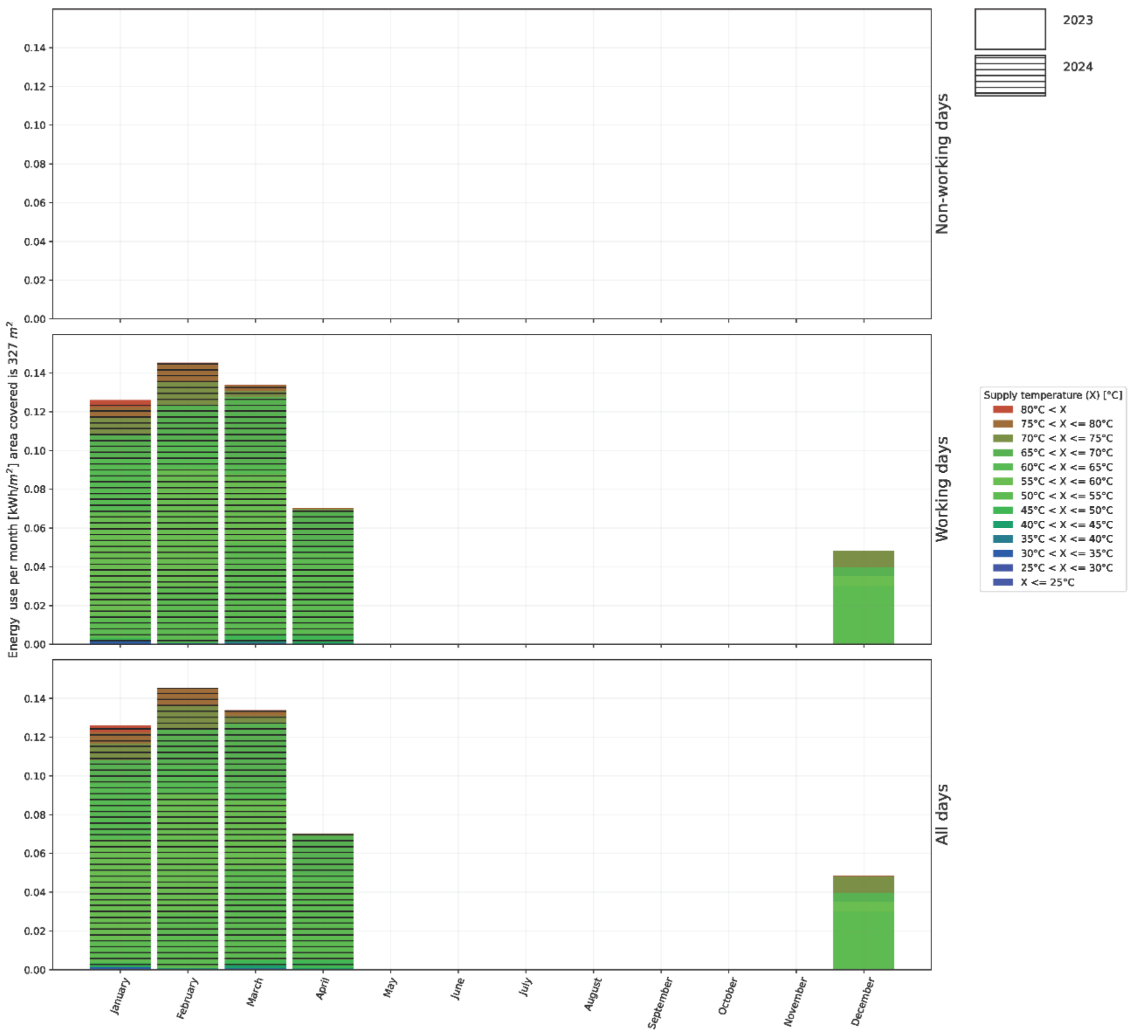

Figure 2.31: Specific monthly energy used for the heating coil in Lab P-Fund.

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Comfort heating coil – Lab P-Klima

The P-Klima AHU supplies the indoor climate and energy laboratory. The heating coil in Lab P-Klima operates to maintain a supply air temperature between 19°C and 23°C. This temperature is kept over the entire day to maintain strict indoor temperature requirements in the covered area, which means there is an energy need over the entire day, as seen in Figure 2.32. Due to the strict requirements in the zone it supplies air to, it has some energy use during the normal cooling period, as seen in Figure 2.33. It is also worth noting that the supply temperature measurement is after the mixing loop, and it shows that energy use mainly happens at low supply temperatures.

Table 2.13: Supply temperature and energy use for Lab P-Klima.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
50°C	209.1	8.6

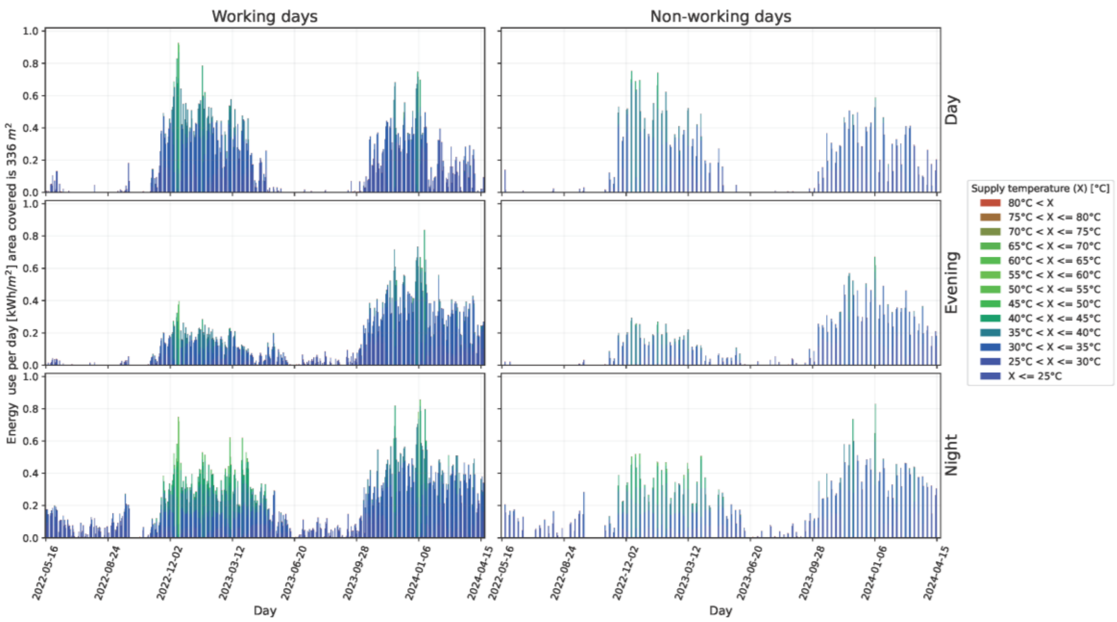

Figure 2.32: Specific heating energy used for the heating coil in Lab P-Klima in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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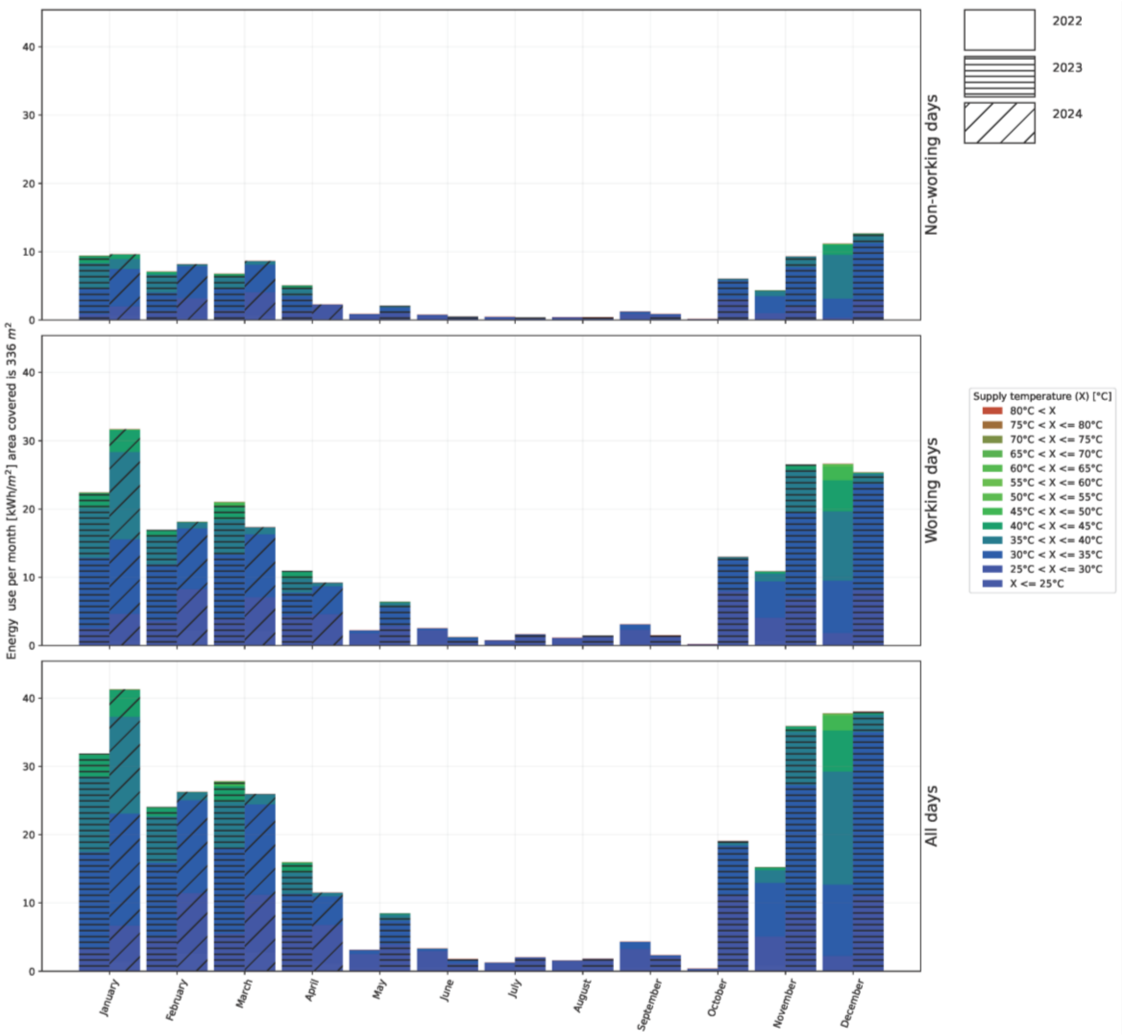

Figure 2.33: Specific monthly energy used for the heating coil in Lab P-Klima.

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Comfort heating coil – Lab P-Vand

The P-Vand AHU supplies the water laboratory. P-Vand can be seen to have a highly irregular and low heating energy use in Figure 2.34 and Figure 2.35. This makes it unsuitable for using waste heat.

Table 2.14: Supply temperature and energy use for Lab P-Vand.

Max supply temperature	Specific energy need [kWh/m²]	
	Actual gross area covered	Full building gross area
>80°C (50°C if the assumption of the need being similar to Lab P-Klima is correct)	1.1	0.1

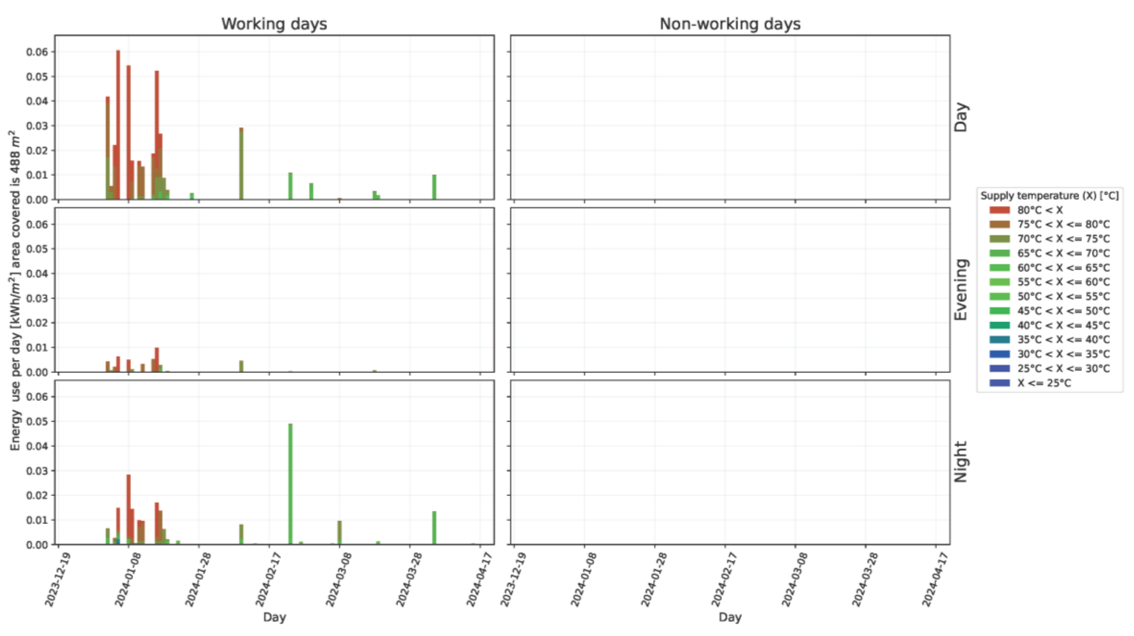

Figure 2.34: Specific heating energy used for the heating coil in Lab P-Vand in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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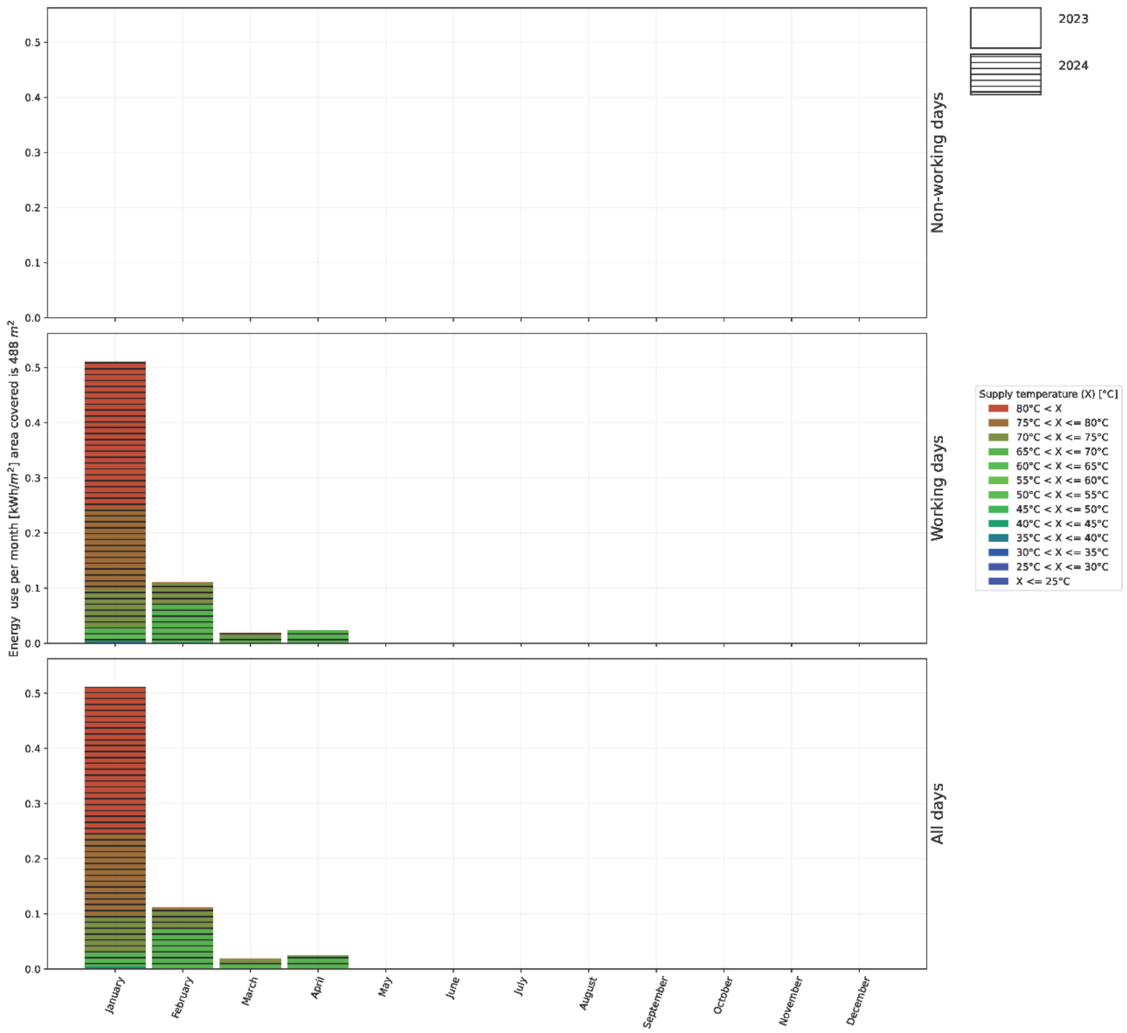

Figure 2.35: Specific monthly energy used for the heating coil in Lab P-Vand.

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Comfort heating coil – Lab P-Vaerk

The P-Vaerk AHU supplies the workshops located next to the laboratories. The comfort heating coil in Lab P-Vaerk can, in Figure 2.36, be seen to use energy during the day consistently, but in Figure 2.37, it can be seen that the total energy use is low, meaning that it should not be a high priority for using waste heat.

Table 2.15: Supply temperature and energy use for Lab P-Vaerk.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
80°C (50°C if the assumption of the need being similar to Lab P-Klima is correct)	7.1	0.2

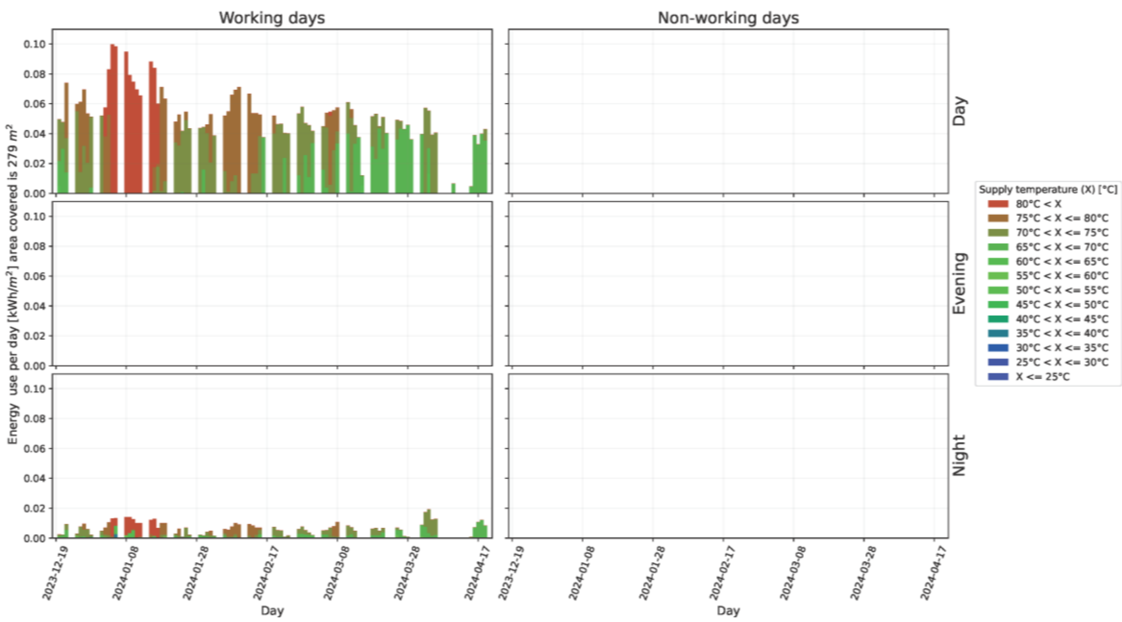

Figure 2.36: Specific heating energy used for the heating coil in Lab P-Vaerk in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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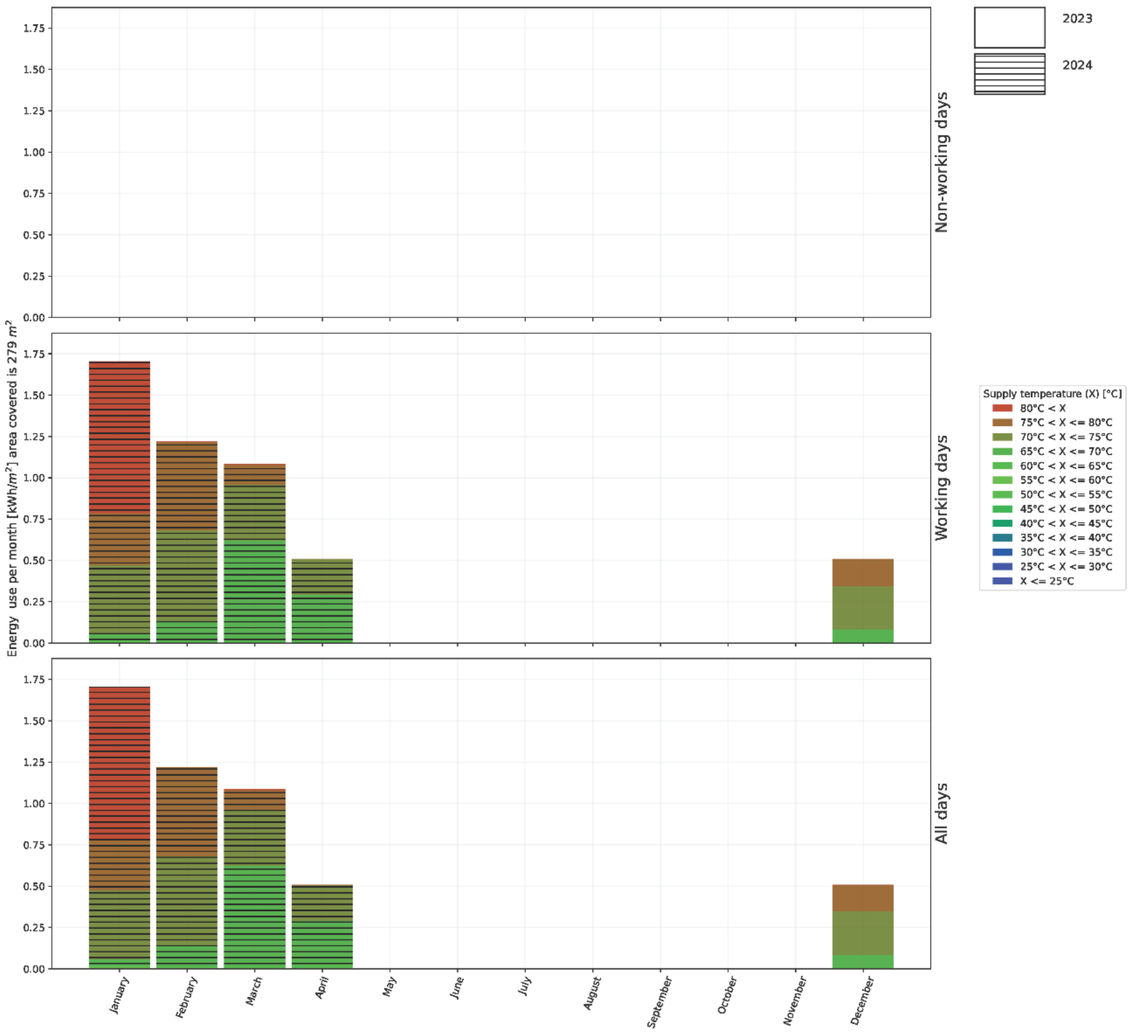

Figure 2.37: Specific monthly energy used for the heating coil in Lab P-Vaerk.

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Comfort heating coil – VU23

VU23 is an air extraction unit that covers a storage area for chemicals. The heating coil can, in Figure 2.38, be seen to have an energy need spanning all days and times. Along with the high specific energy need per month seen in Figure 2.39, it would look like a potentially good case for using waste heat. The drawback is that it only covers a small area, meaning that even though it has a high specific energy use, the actual energy use is low. However, the room type could be interesting if found in other buildings.

Table 2.16: Supply temperature and energy use for VU23.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
75°C (50°C if the assumption of the need being similar to Lab P-Klima is correct)	97.1	0.2

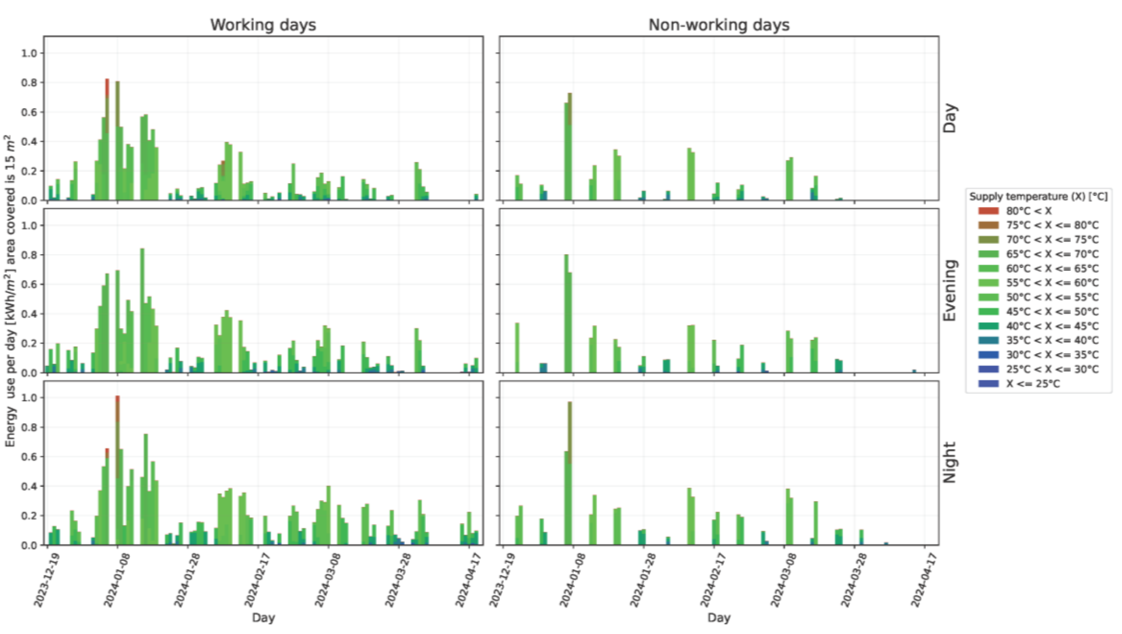

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Figure 2.38: Specific heating energy used for the heating coil in VU23 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

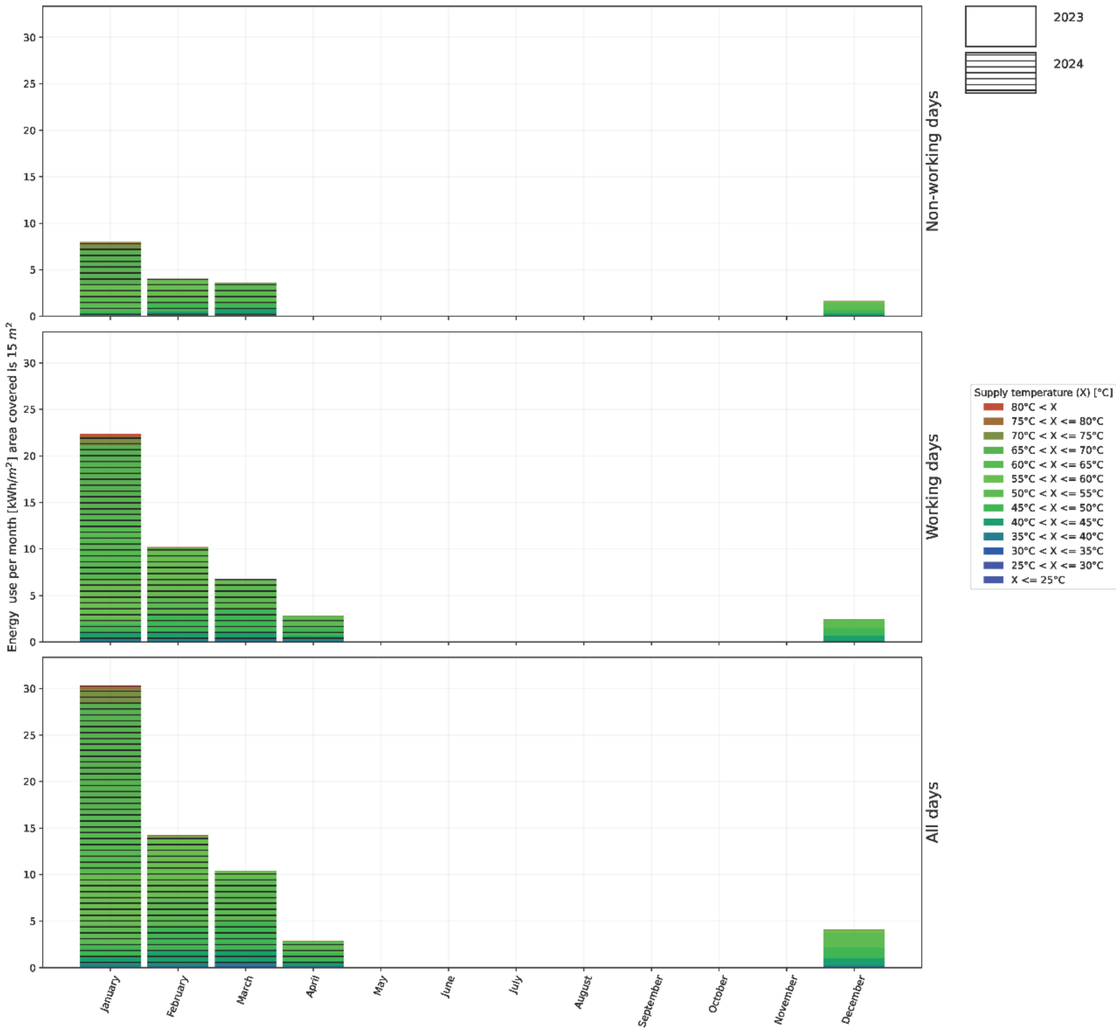

Figure 2.39: Specific monthly energy used for the heating coil in VU23.

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2.1.2.4 Systems (Space heating)

In this section, the results for the different space heating units are shown along with any individual considerations. Be aware that the specific energy use shown in this section is not equivalent to the one used in previous sections, as it is now only based on the actual gross area covered by the specific system.

Radiator – VA01

The radiator system VA01 covers the eastern part of the building. The system is in operation all day, as shown in Figure 2.40. It has a relatively high supply temperature after the mixing loop, as seen in Figure 2.41, meaning it could be challenging to supply high enough temperatures in the most critical times. If it is possible to meet the temperature need, the system is suitable for using waste heat, as it has a high constant energy need due to covering a large area and some energy needed during the classic cooling season.

Table 2.17: Supply temperature and energy use for VA01.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
70°C	13.7	6.8

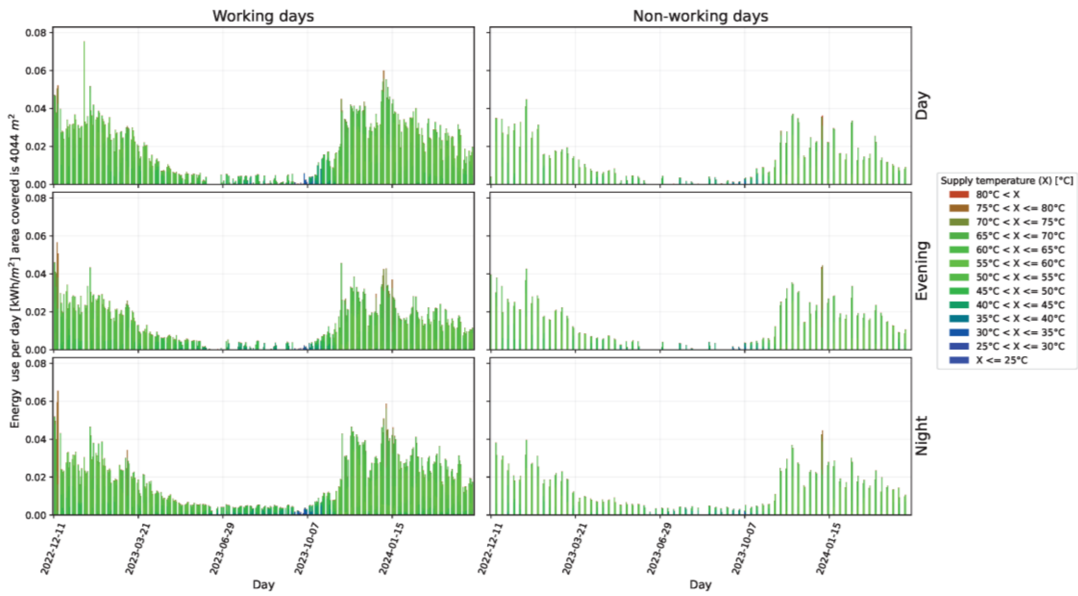

Figure 2.40: Specific heating energy used for the space heating system VA01 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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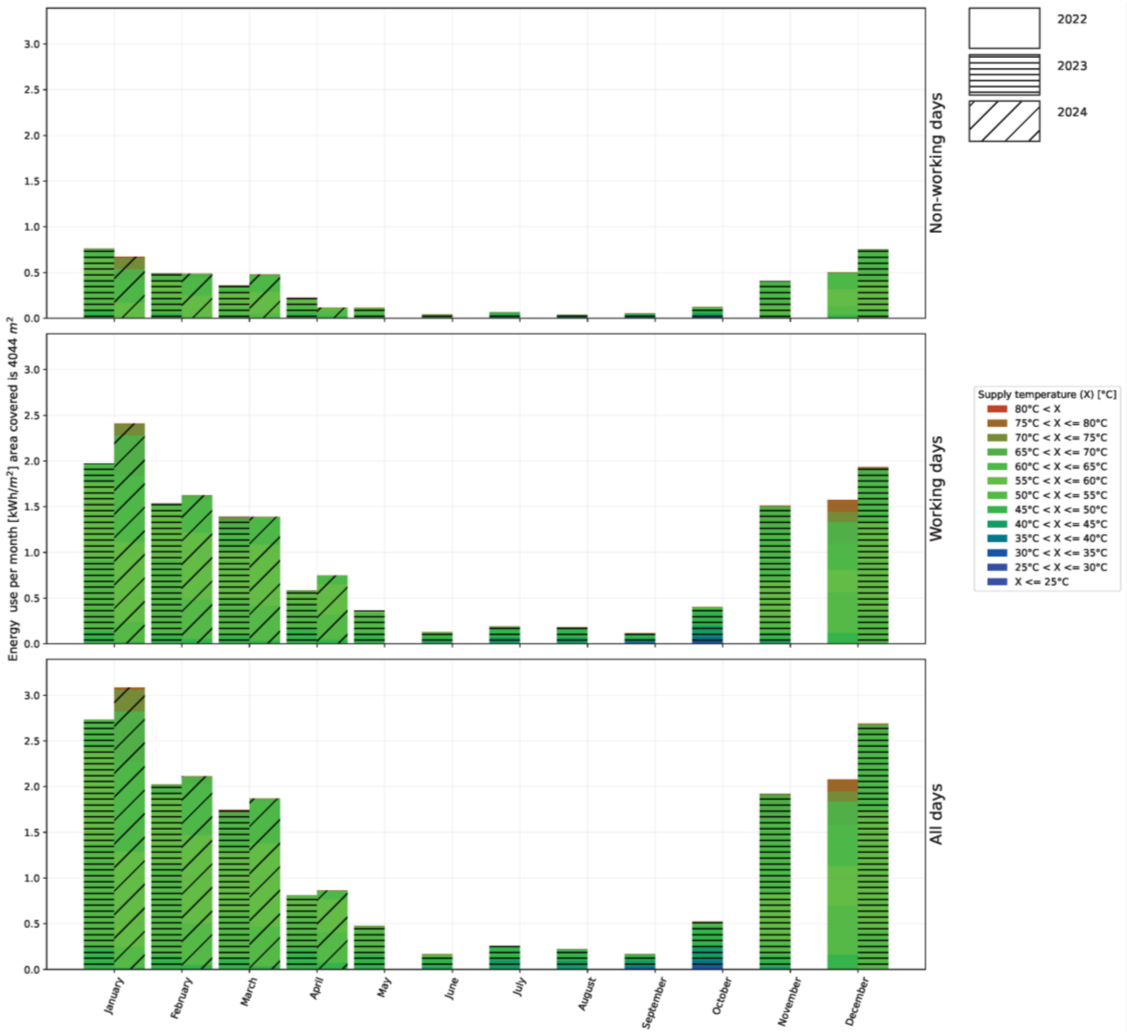

Figure 2.41: Specific monthly energy used for the space heating system VA01.

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Radiator – VA02

The radiator system VA02 covers the western part of the building. The system is in operation all day, as shown in Figure 2.42. It has a relatively high supply temperature after the mixing loop, as seen in Figure 2.43, meaning it could be challenging to supply high enough temperatures in the most critical times. If it is possible to meet the temperature need, the system is suitable for using waste heat, as it has a high constant energy need due to covering a large area and some energy needed during the classic cooling season.

Table 2.18: Supply temperature and energy use for VA02.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
70°C	14.5	5.5

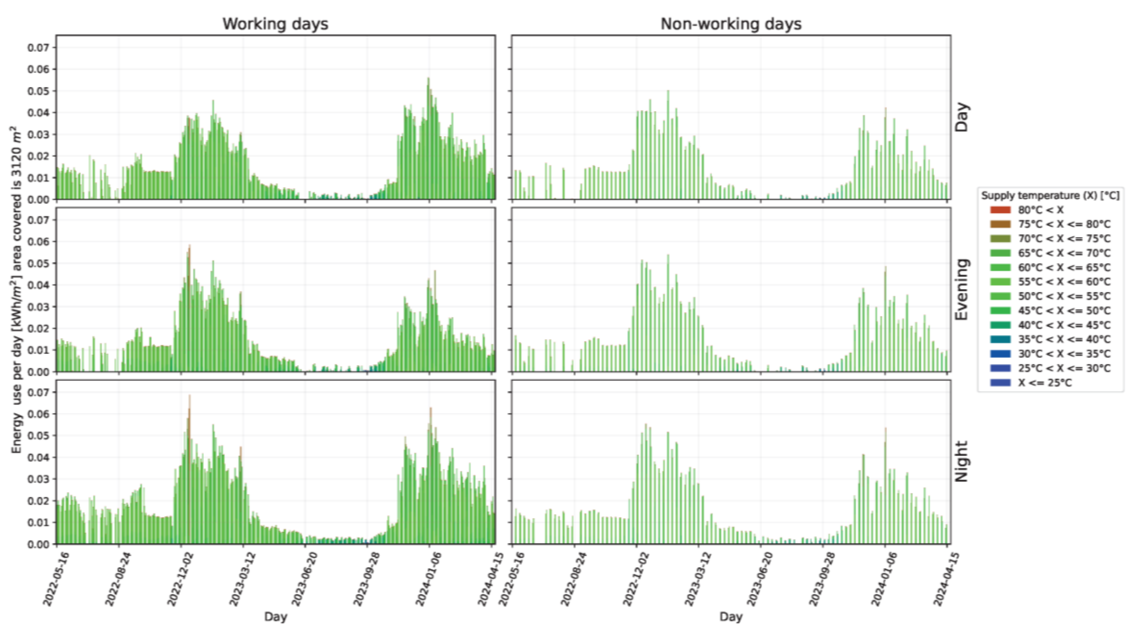

Figure 2.42: Specific heating energy used for the space heating system VA02 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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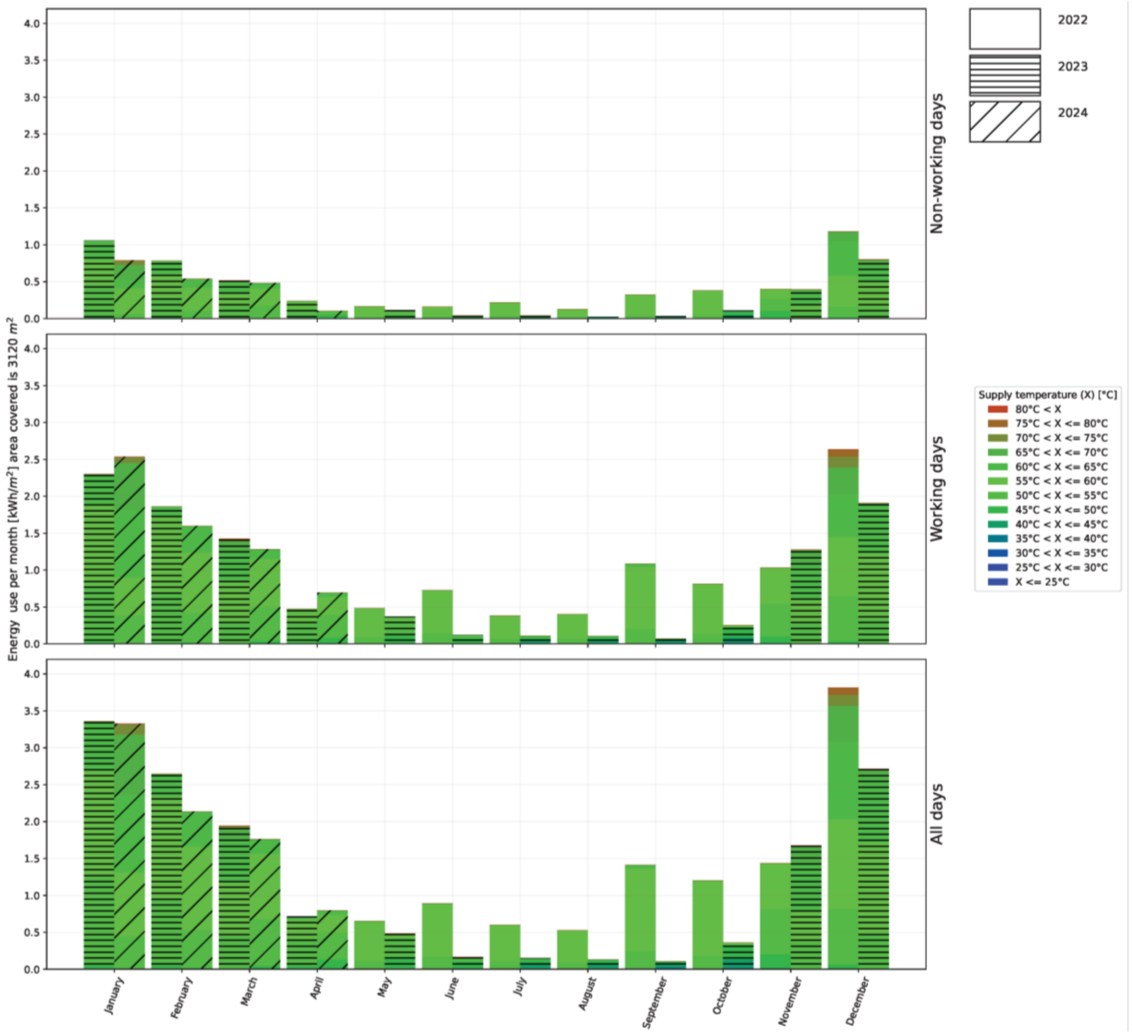

Figure 2.43: Specific monthly energy used for the space heating system VA02.

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Underfloor hydronic system – GV01

The underfloor hydronic system GV01 covers the area near the main entrance. This system has an energy need during all times of the day and all days, as shown in Figure 2.44. Besides this, it needs a low supply temperature and has a high specific energy use, as seen in Figure 2.45. This means that the system type could be highly suitable for using waste heat, though in this case, it has a small total floor area covered, meaning that it cannot use large amounts of energy.

Table 2.19: Supply temperature and energy use for GV01.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
35°C	88.2	1.2

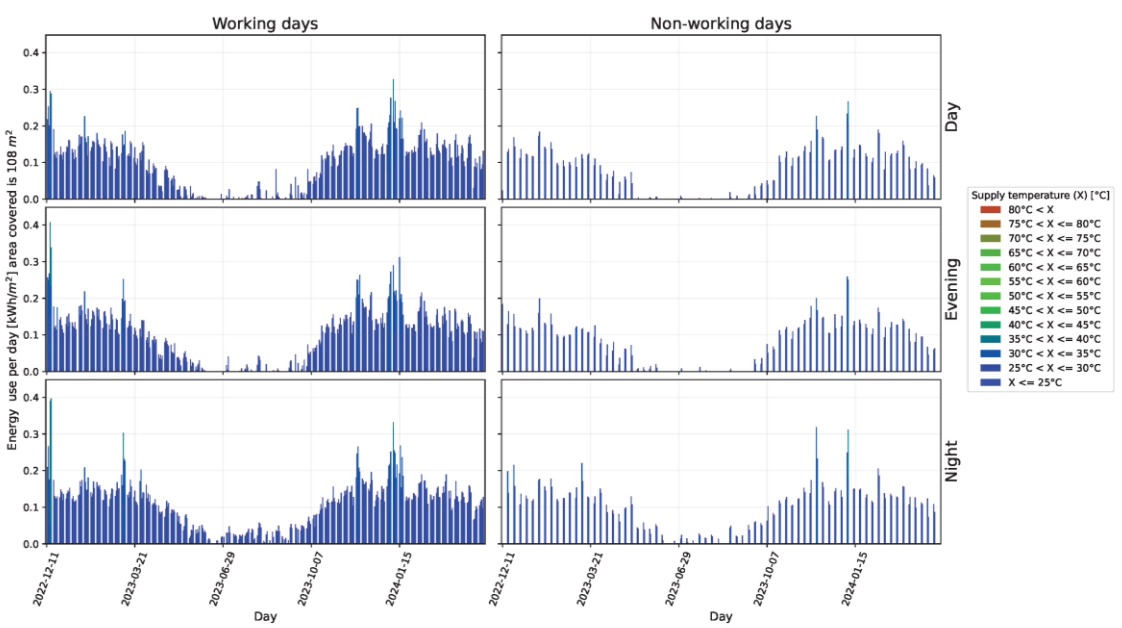

Figure 2.44: Specific heating energy used for the space heating system GV01 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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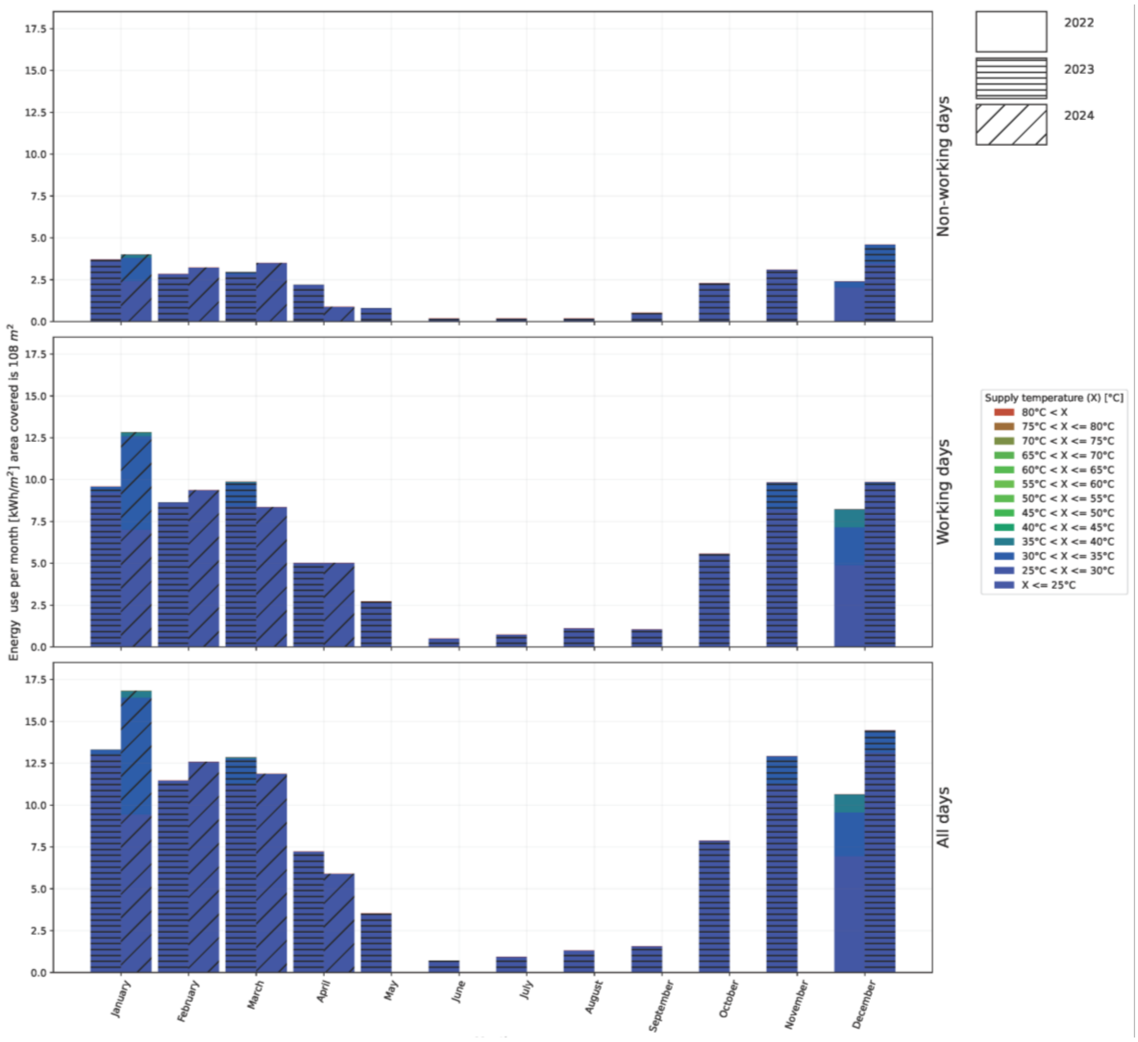

Figure 2.45: Specific monthly energy used for the space heating system GV01.

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.

Underfloor hydronic system – GV02

The underfloor hydronic system GV02 covers a shower and dressing room in the basement. This system has an energy need during all times of the day and all days, as shown in Figure 2.46. Besides this, it needs a low supply temperature and has a high specific energy use, as seen in Figure 2.47. This means that the system type could be highly suitable for using waste heat, though in this case, it has a small total floor area covered, meaning that it cannot use large amounts of energy.

Table 2.20: Supply temperature and energy use for GV02.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
40°C	56.5	0.5

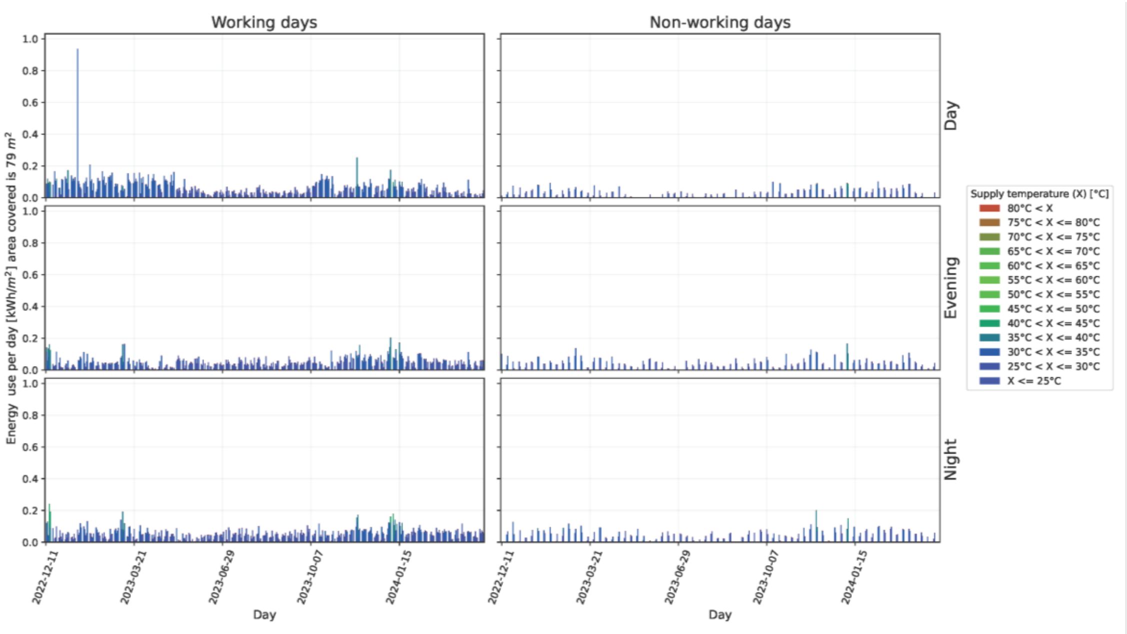

Figure 2.46: Specific heating energy used for the space heating system GV02 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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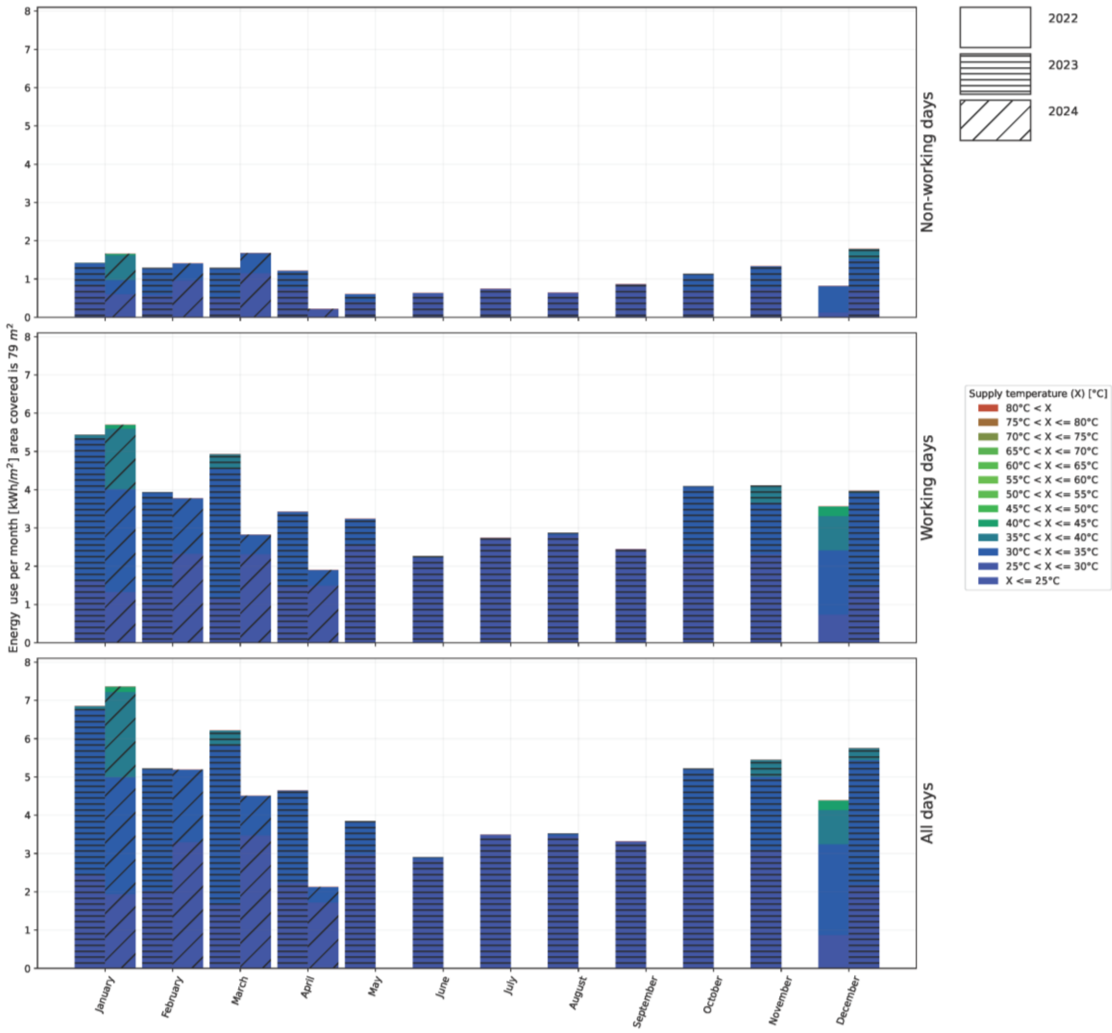

Figure 2.47: Specific monthly energy used for the space heating system GV02.

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2.1.2.5 Systems (Domestic hot water)

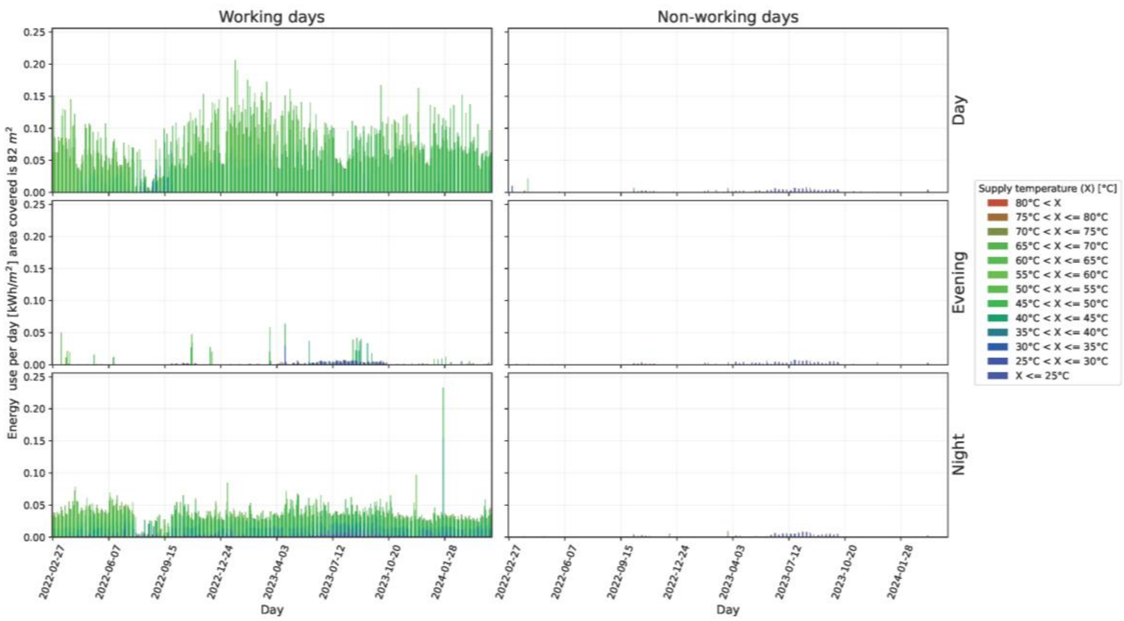
In this section, the results for the different domestic hot water units are shown, along with any individual considerations. Be aware that the specific energy use shown in this section is not equivalent to the one used in previous sections, as it is now only based on the actual gross area covered by the specific system.

Heat exchanger – VVB01_basement

This system covers two shower rooms and three toilet sinks. As the system mainly covers the shower rooms, it can be seen in Figure 2.48 that the daily energy use has a relatively low variance, which is even smaller when aggregated to monthly results, as seen in Figure 2.49. Compared to the area covered by the system, it has a relatively high specific energy use, as seen in Table 2.21, though when looked at from the full building perspective, it has a low energy use and a relatively high supply temperature need.

Table 2.21: Supply temperature and energy use for VVB01_basement.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	34.3	0.3



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 2.48: Specific heating energy use for the DHW system VVB01_basement in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

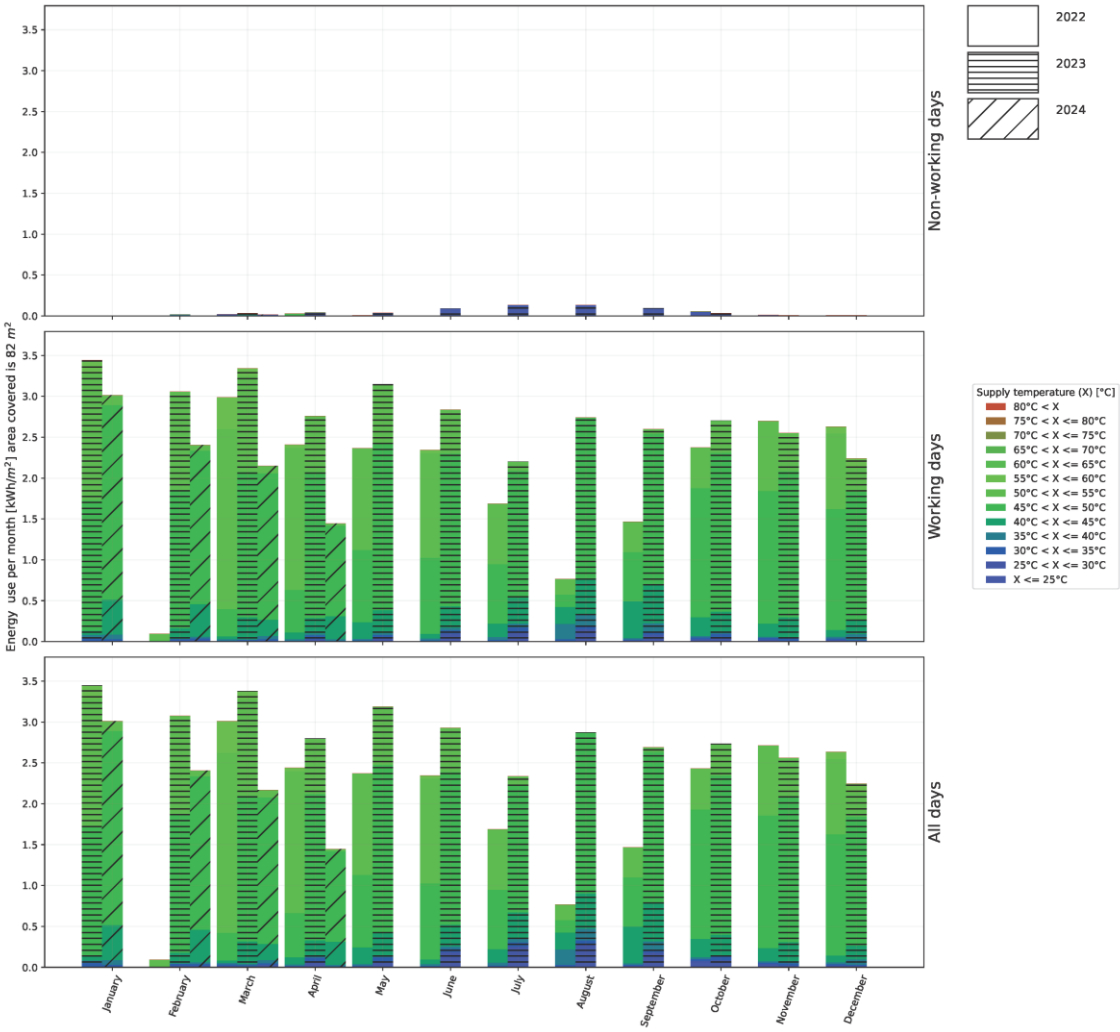


Figure 2.49: Specific monthly energy used for the DHW system VVB01_basement.

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.

Heat exchanger – VVB01_0_east

This system covers seven laboratory sinks and three toilet sinks. It can be seen in Figure 2.50 that there is not any significant difference in the daily energy; this is most likely due to the energy use being dominated by low use and high circulation losses. The energy is mainly used during working days. Regarding the monthly energy use, it can be seen in Figure 2.51 that except for the summer vacation period (July and August) and the start of the new university year (September), there is no noticeable seasonality.

Table 2.22: Supply temperature and energy use for VVB01_0_east.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	2.6	0.2

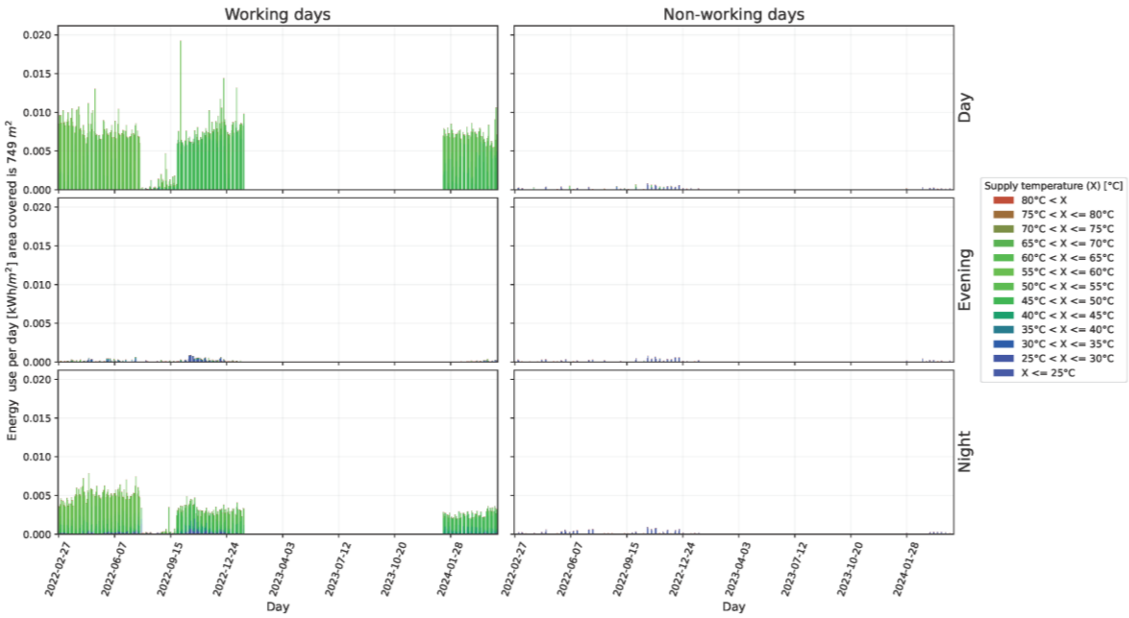


Figure 2.50: Specific heating energy use for the DHW system VVB01_0_east in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for most of 2023.

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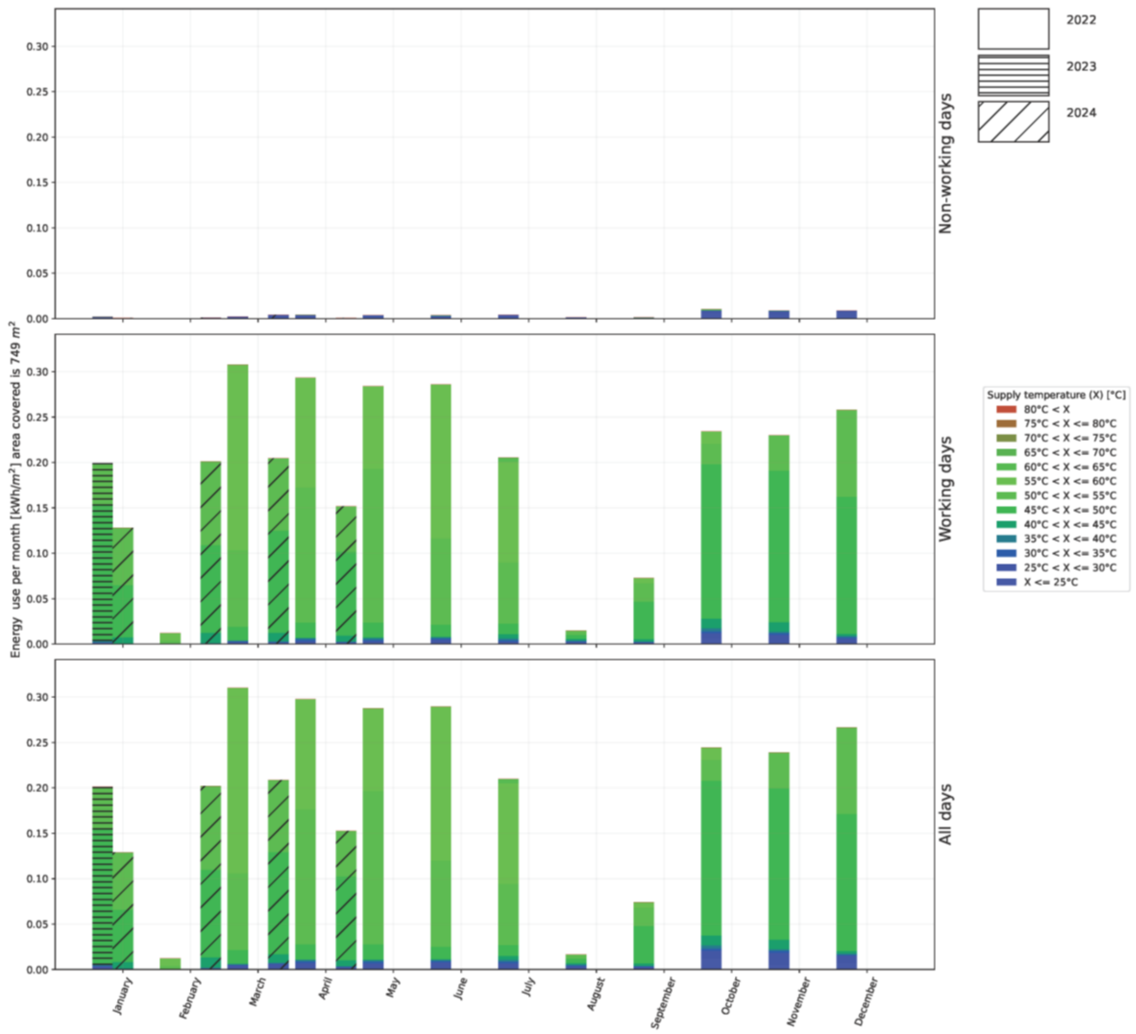

Figure 2.51: Specific monthly energy use for the DHW system VVB01_0_east.

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Heat exchanger – VVB01_1_east

This system covers three toilet sinks. It can be seen from Table 2.23, Figure 2.52, and Figure 2.53 that despite not covering laboratory sinks, the specific energy need in relation to the total building area and the daily and monthly profiles are similar to VVB01_0_east.

Table 2.23: Supply temperature and energy use for VVB01_1_east.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	3.0	0.2

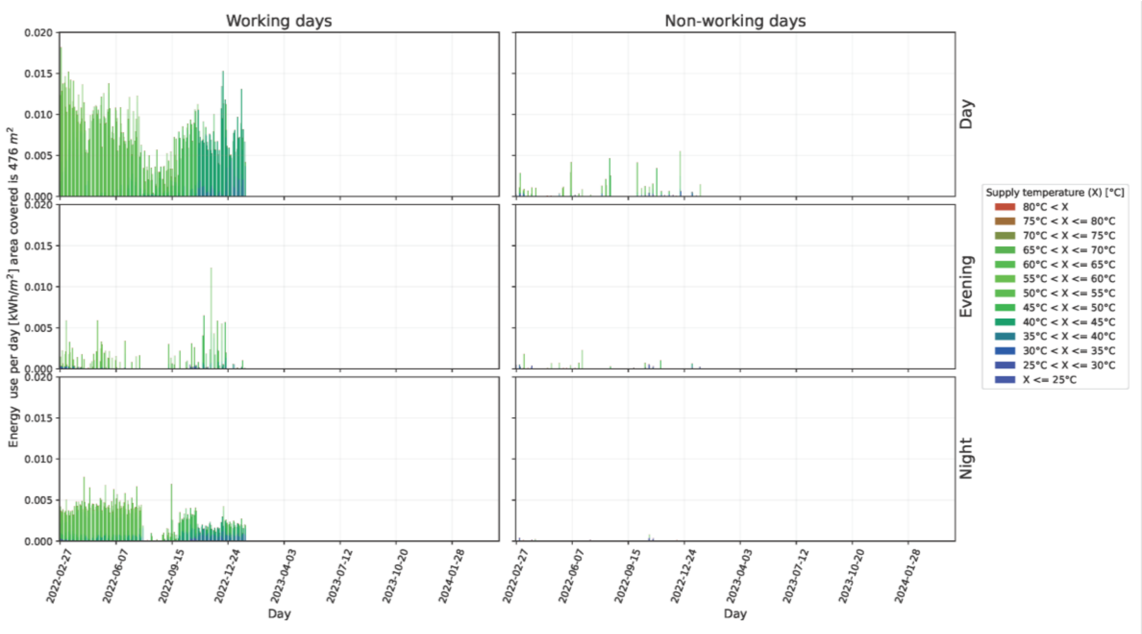

Figure 2.52: Specific heating energy use for the DHW system VVB01_1_east in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for most of 2023 and 2024.

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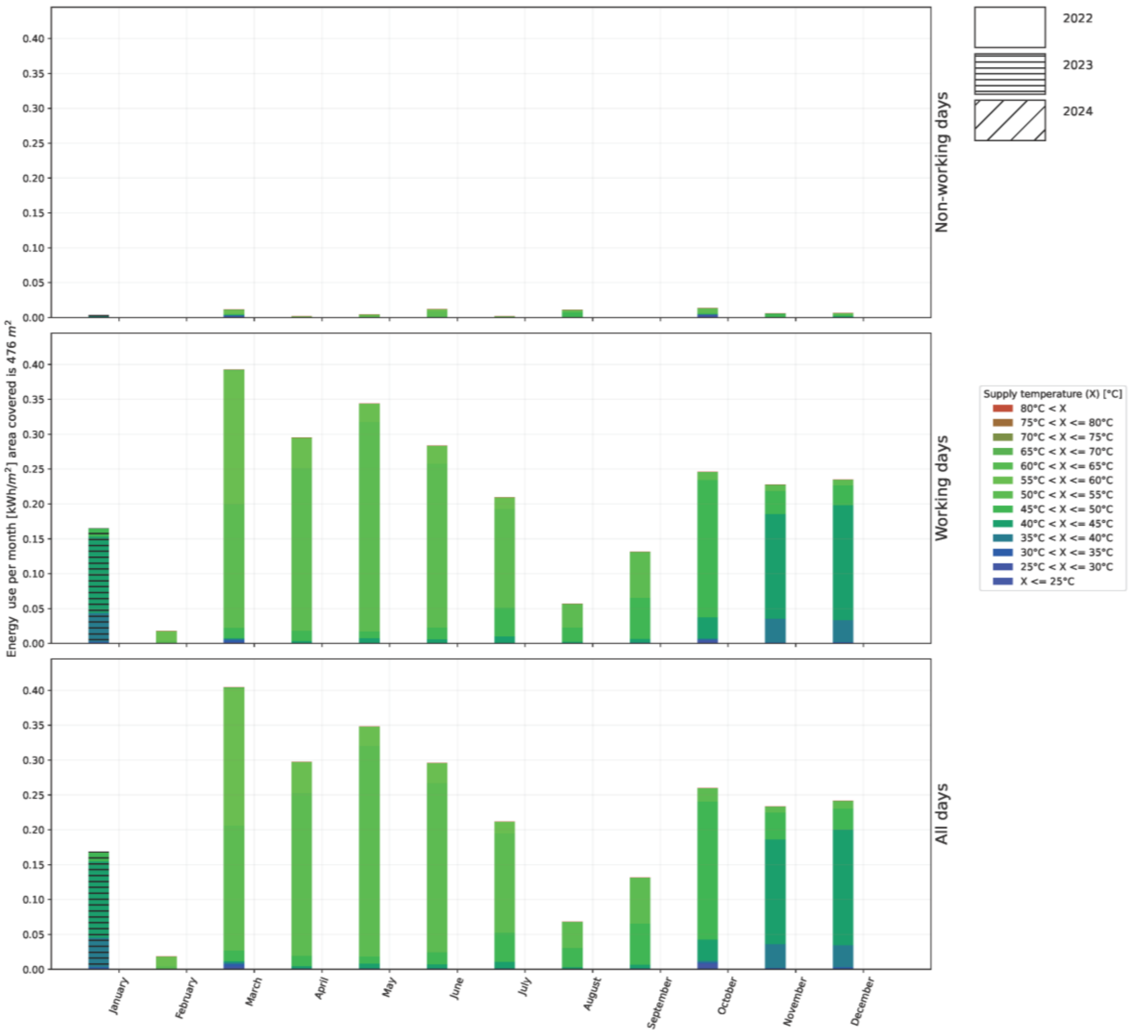

Figure 2.53: Specific monthly energy use for the DHW system VVB01_1_east.

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Heat exchanger – VVB01_2_east

This system covers a kitchen sink and three toilet sinks. In this system, it becomes evident that the energy use, compared to the other DHW systems, is higher. This is likely due to the addition of the kitchen sink, which supplies the main student kitchen. In terms of seasonality, it partly follows the same trend as the other DHW systems, though it has a clearer trend with higher energy use in the colder months, as seen in Figure 2.55.

Table 2.24: Supply temperature and energy use for VVB01_2_east.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	2.5	0.4

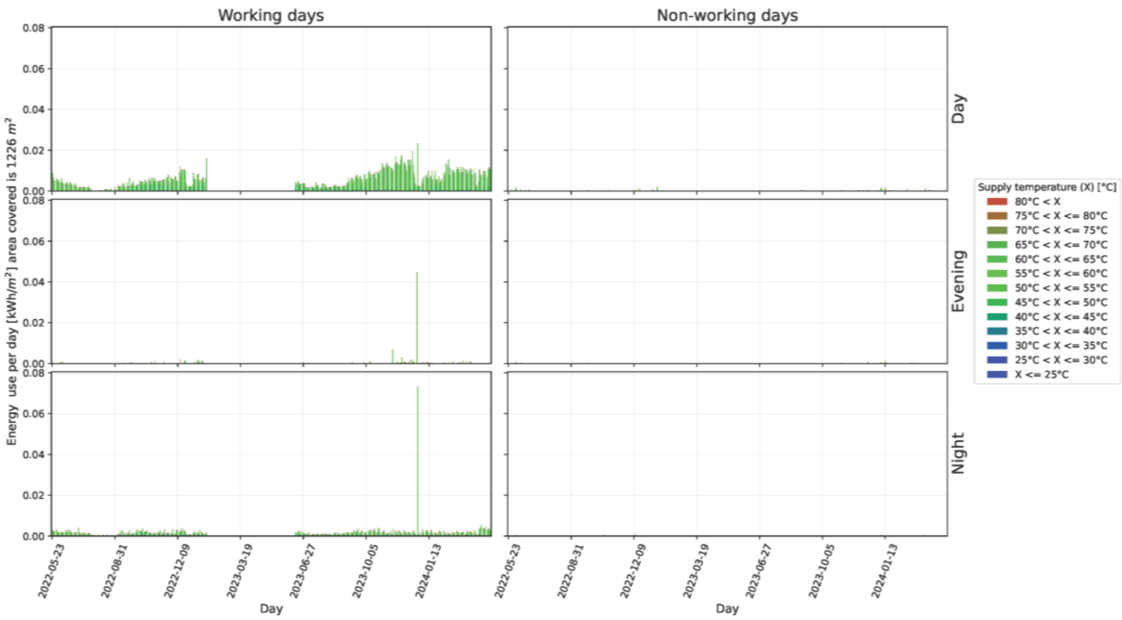

Figure 2.54: Specific heating energy use for the DHW system VVB01_2_east in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for half of 2023.

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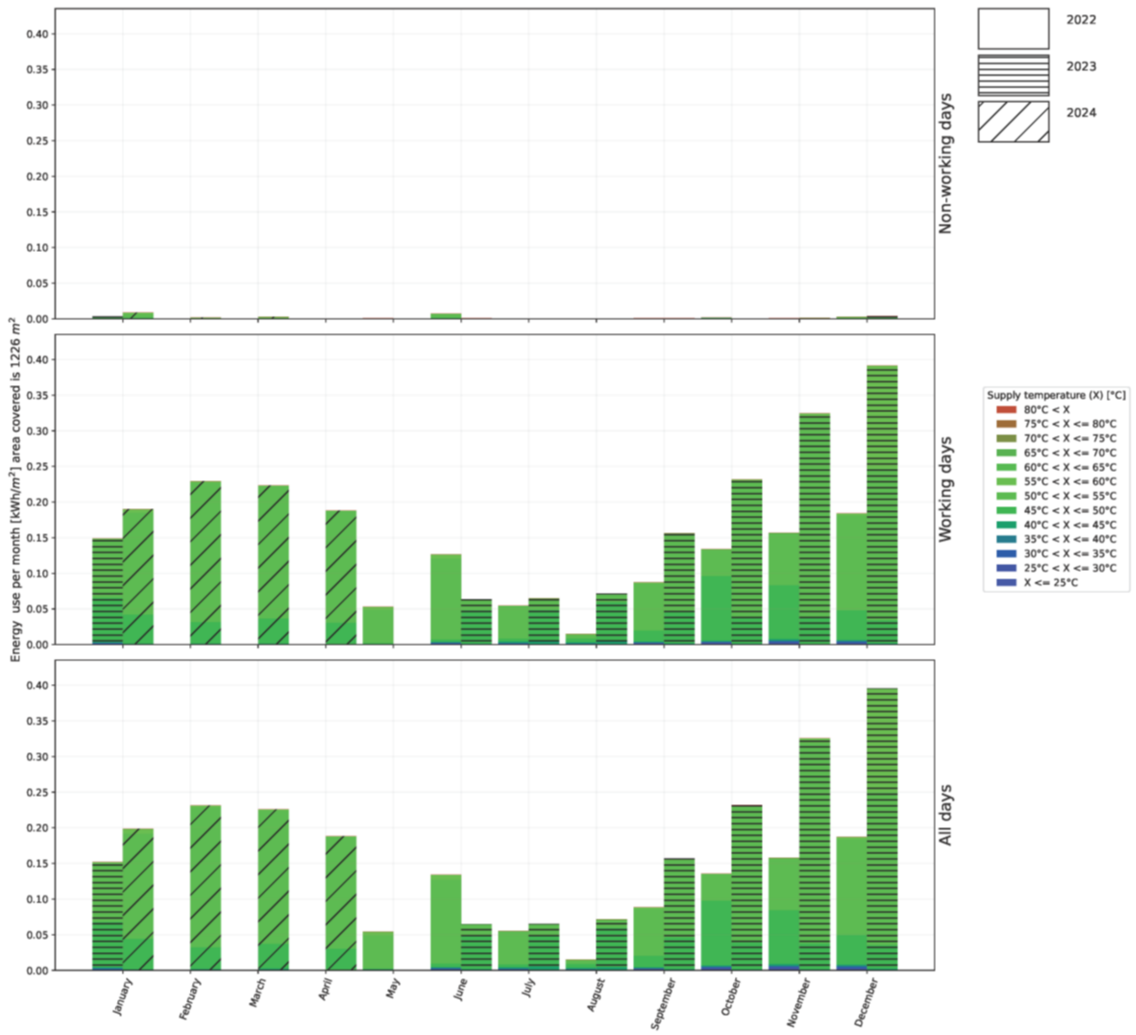

Figure 2.55: Specific monthly energy use for the DHW system VVB01_2_east.

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.

Heat exchanger – VVB01_3_east

This system covers a kitchen sink and three toilet sinks. The same pattern as previous DHW systems applies, with relatively stable daily and monthly energy use, except from July to September, when the energy use is lower. Regarding the max supply temperature seen in Table 2.25, this DHW system did not get above 50°C, which could be an issue in keeping legionella away.

Table 2.25: Supply temperature and energy use for VVB01_3_east.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
50°C	0.7	0.1

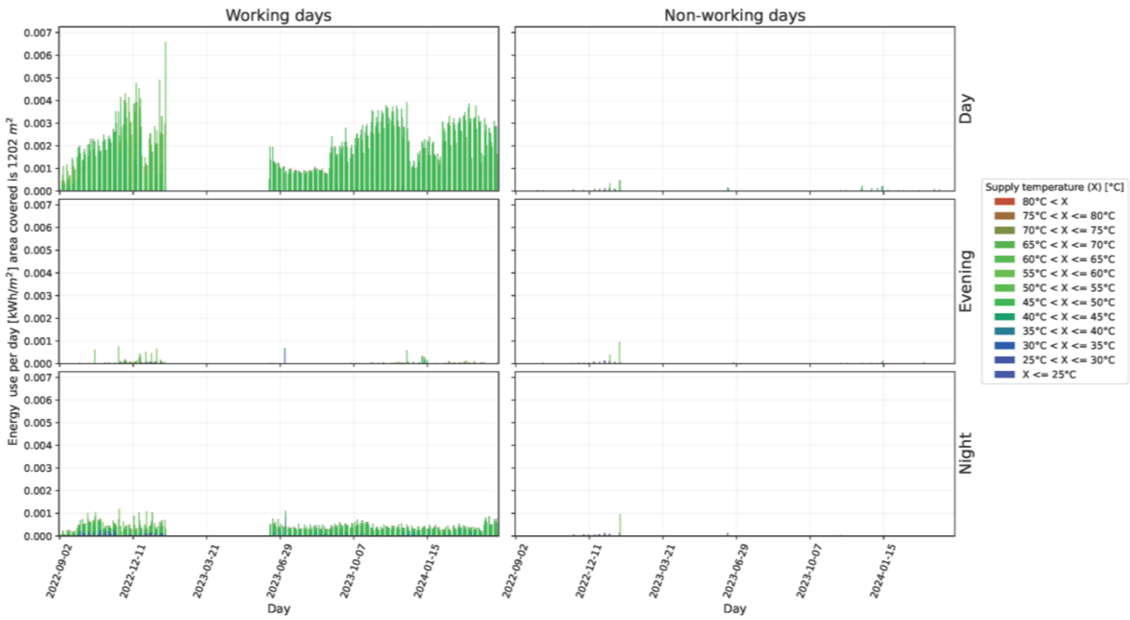

Figure 2.56: Specific heating energy use for the DHW system VVB01_3_east in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for half of 2023.

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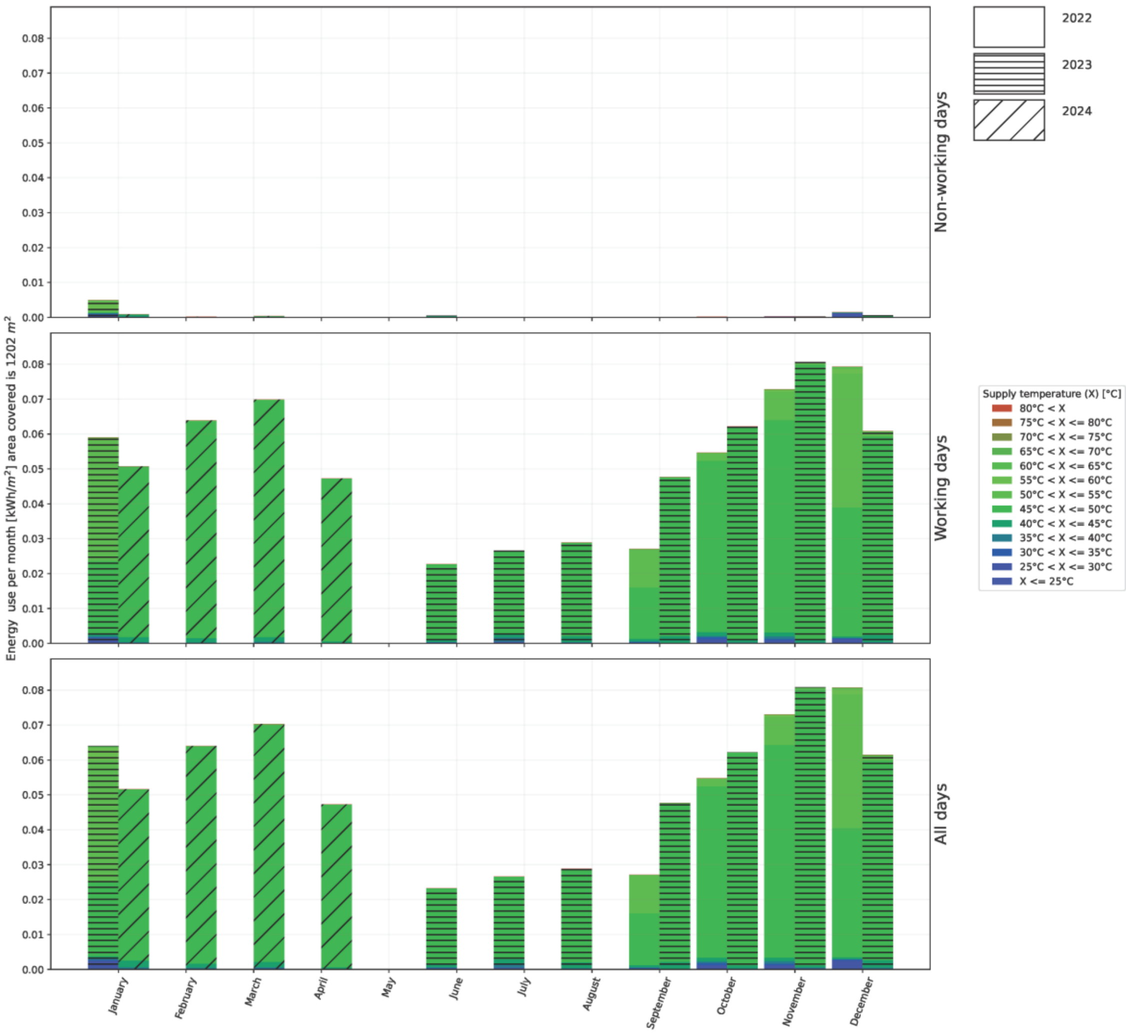

Figure 2.57: Specific monthly energy use for the DHW system VVB01_3_east.

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.

Heat exchanger – VVB02_0_west

This system covers a shower room, two laboratory sinks, and two toilet sinks. It can be seen that the system has similar tendencies to the VVB01_0_east system, which also covers laboratories, with this system having almost no seasonality except for August to September, as seen in Figure 2.59, and a stable daily profile, as seen in Figure 2.58. The clear seasonality matches well with expectations of the area.

Table 2.26: Supply temperature and energy use for VVB02_0_west.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	1.4	0.2

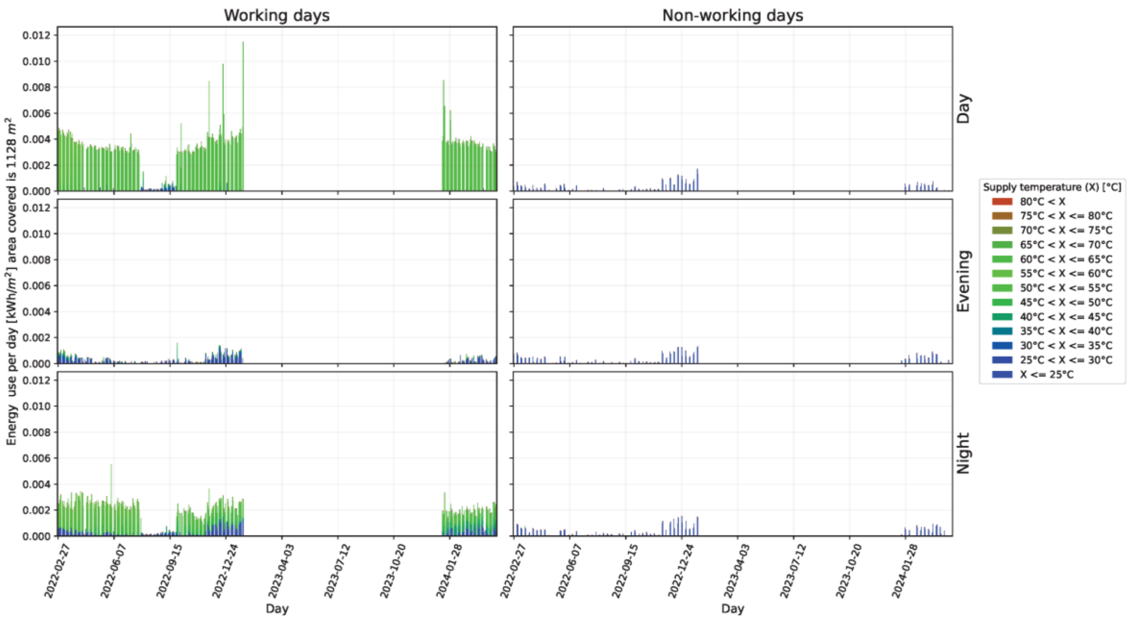

Figure 2.58: Specific heating energy use for the DHW system VVB02_0_west in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for most of 2023.

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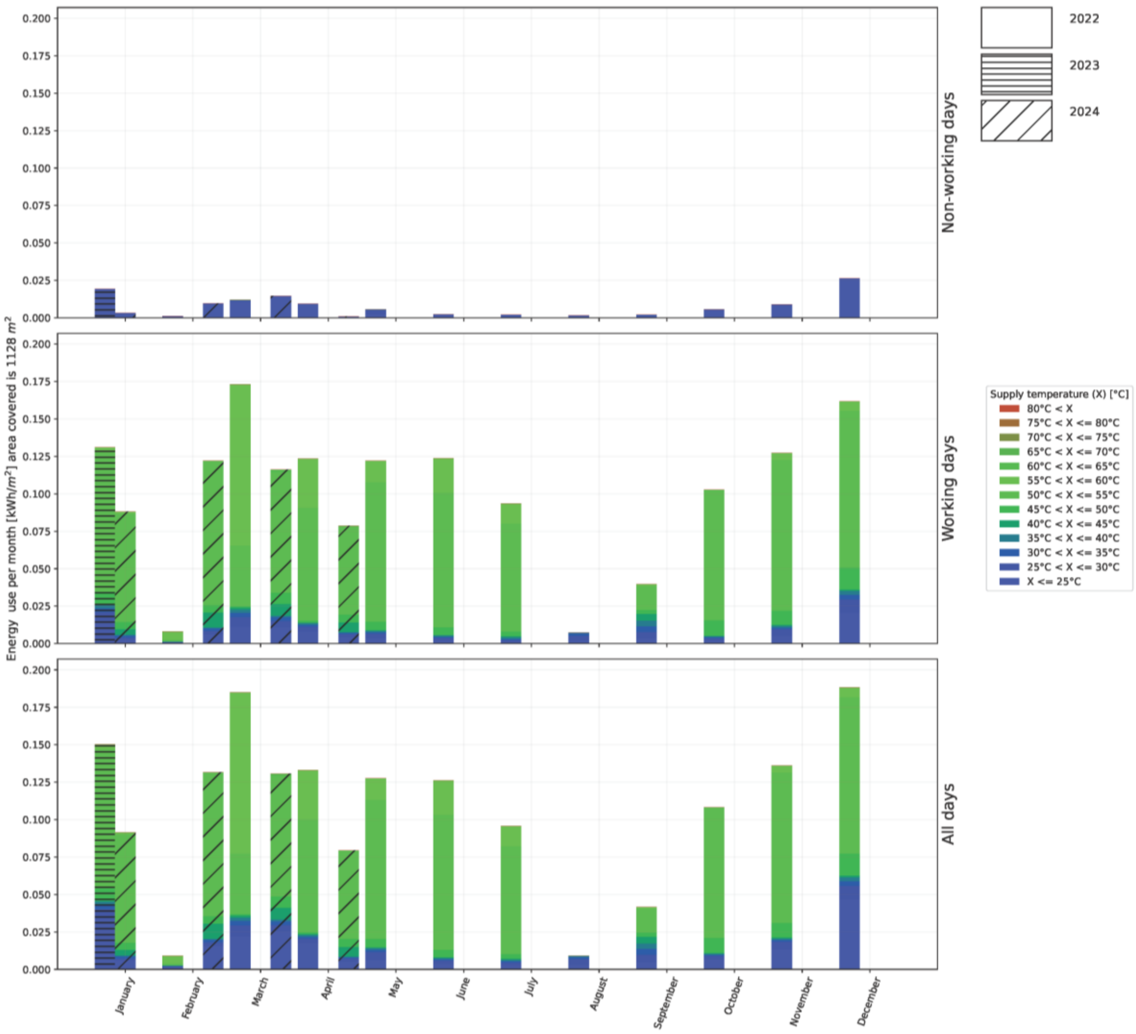

Figure 2.59: Specific monthly energy use for the DHW system VVB02_0_west.

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Heat exchanger – VVB02_1_west

This system covers two toilet sinks. It follows the pattern of no significant daily variation, as seen in Figure 2.60, but has a seasonal variation, with August and September having a lower energy use, as shown in Figure 2.61. This seasonal variation fits well with the known use of the area, as it is mainly occupied by students, who are off in August, while they will tend to have many lectures in September, which are in other areas.

Table 2.27: Supply temperature and energy use for VVB02_1_west.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	3.0	0.2

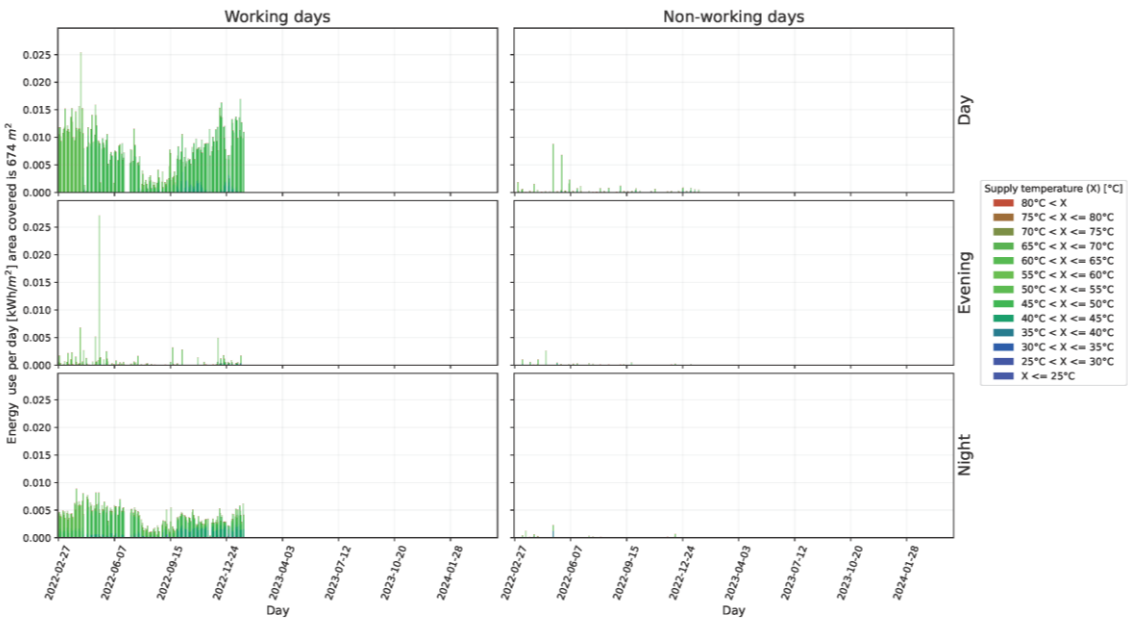

Figure 2.60: Specific heating energy use for the DHW system VVB02_1_west in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for most of 2023 and 2024.

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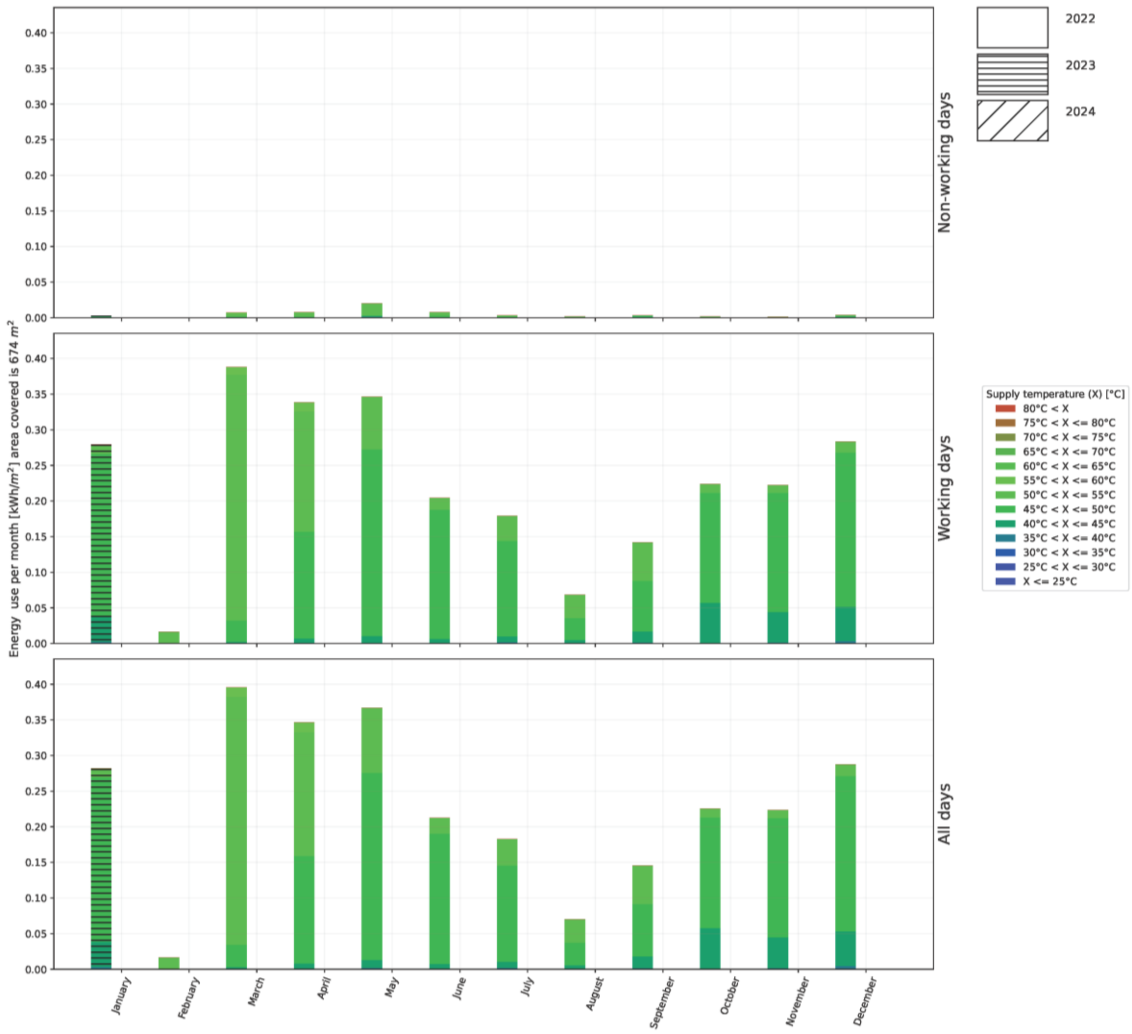

Figure 2.61: Specific monthly energy use for the DHW system VVB02_1_west.

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Heat exchanger – VVB02_2_west

This system covers a kitchen sink and two toilet sinks. It follows the previous DHS system patterns, but only to some degree. The daily variation in energy use is low, as seen in Figure 2.62. However, for the seasonal variation, as seen in Figure 2.63, 2022 has the same pattern seen earlier with low energy use from July to September, but in 2023, it is not the case, indicating some difference between the years.

Table 2.28: Supply temperature and energy use for VVB02_2_west.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	0.6	0.1

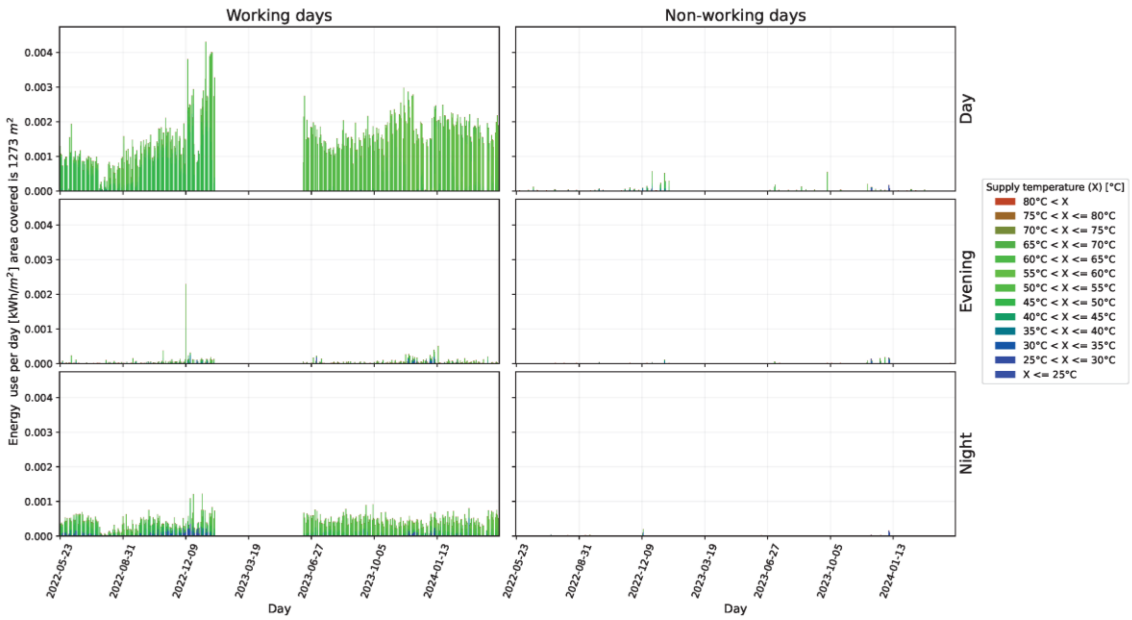

Figure 2.62: Specific heating energy use for the DHW system VVB02_2_west in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for half of 2023.

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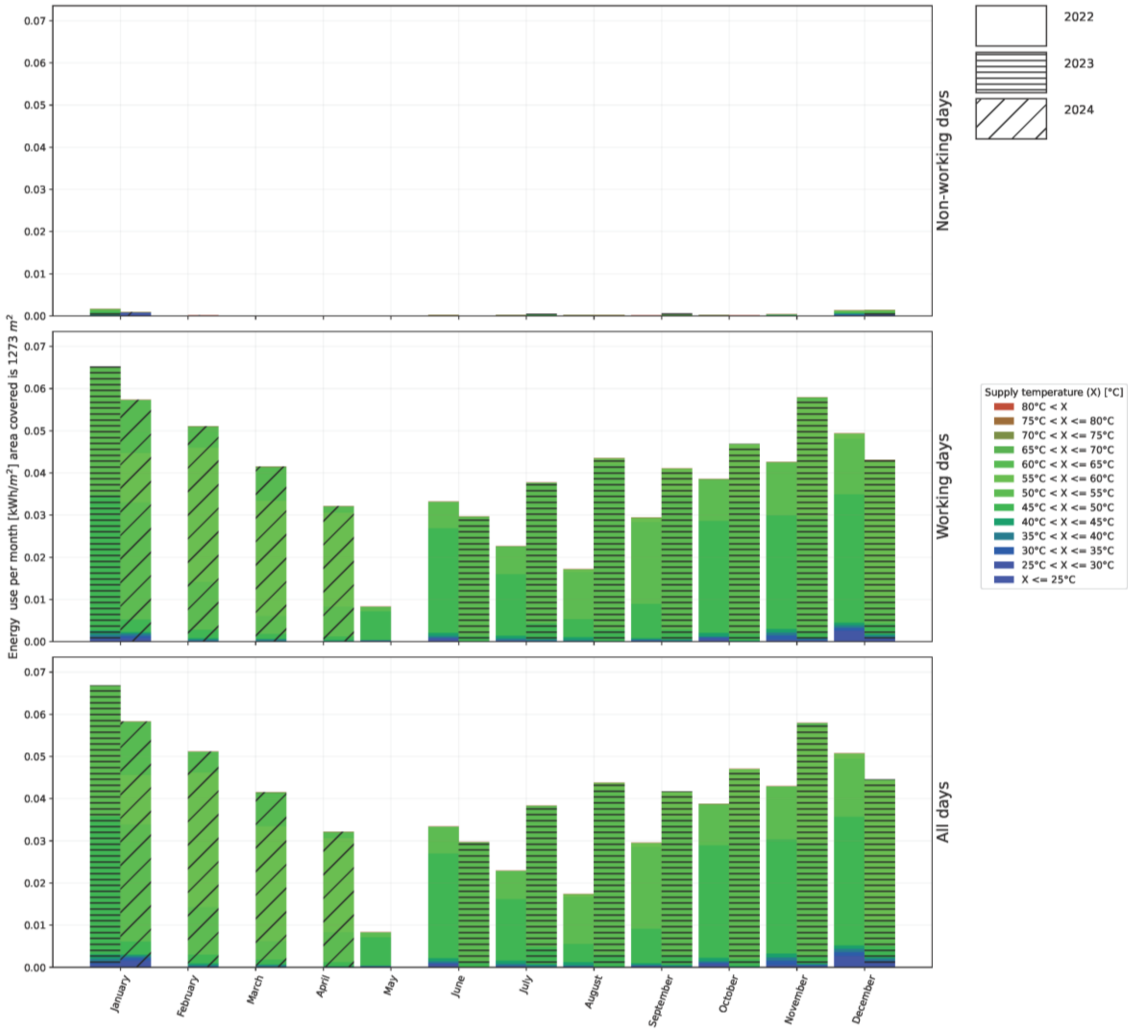

Figure 2.63: Specific monthly energy use for the DHW system VVB02_2_west.

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Heat exchanger – VVB02_3_west

This system covers a cleaning room sink/water supply and two toilet sinks. It appears to have stable daily energy use, as seen in Figure 2.64, but due to missing data, it is impossible to conclude on the seasonality of the system. However, a cautious indication from the data seen in Figure 2.65 shows that, at least for the data available, the monthly variation over the winter period is low.

Table 2.29: Supply temperature and energy use for VVB02_3_west.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
60°C	0.5	0.1

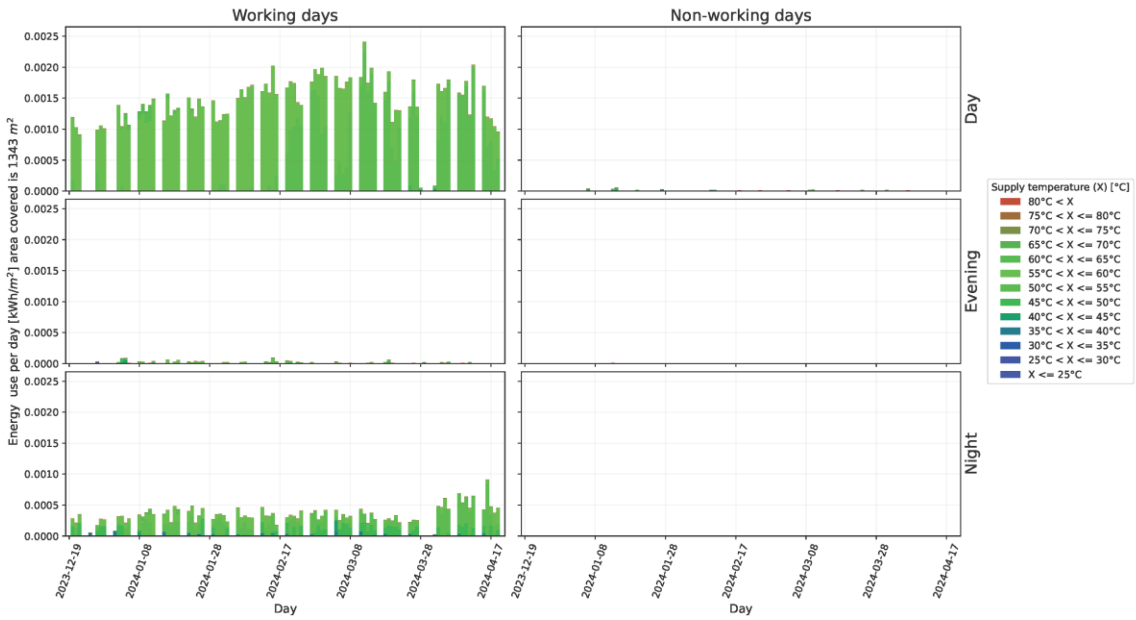

Figure 2.64: Specific heating energy use for the DHW system VVB02_3_west in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night).

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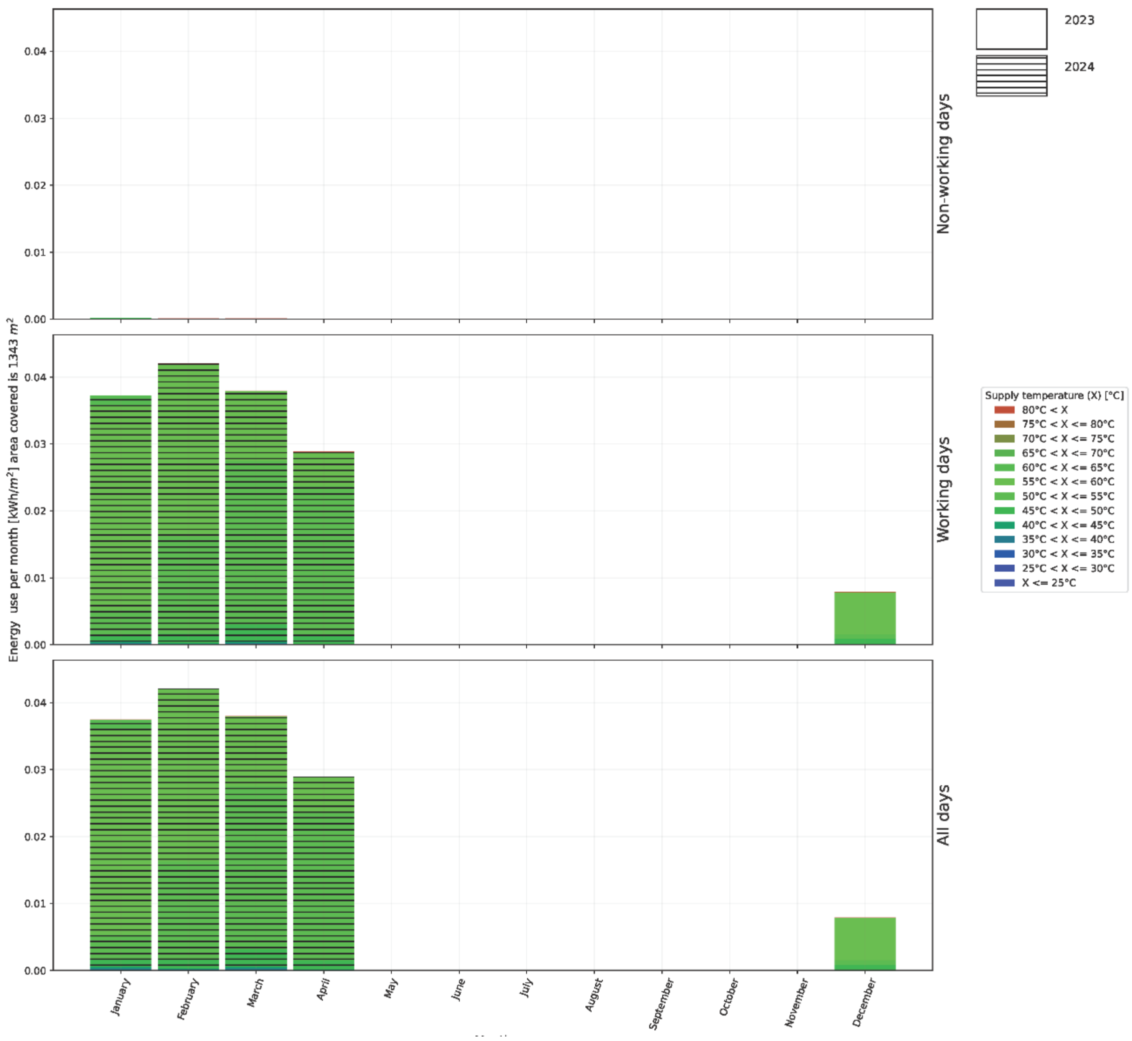

Figure 2.65: Specific monthly energy use for the DHW system VVB02_3_west.

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2.1.2.6 Systems (Miscellaneous)

In this section, the results for the miscellaneous systems are shown along with any individual considerations. Be aware that the specific energy use shown in this section is not equivalent to the one used in previous sections, as it is now only based on the actual gross area covered by the specific system.

Air curtain heating coil - Door01

This system covers the air curtain in the main entrance area. Despite the small area covered by the system, due to the lack of heat recovery for the ventilation air, it has a high specific heating energy use, as seen in Table 2.30. Despite this, due to its limited size, its influence on the total building energy use is low. At the same time, it requires a high supply temperature, which could potentially be kept lower if the system was built with a mixing loop as the supply temperature setpoint of the air was maximally 25°C. In terms of seasonality, there is not enough data to conclude, but because the system relies on the outdoor air as its air source, along with not having a heat recovery system, it is expected to be highly dependent on the outdoor temperature and thus has significant seasonality.

Table 2.30: Supply temperature and energy use for Door01.

Max supply temperature	Specific energy need [kWh/m^2]	
	Actual gross area covered	Full building gross area
75°C	71.5	0.1

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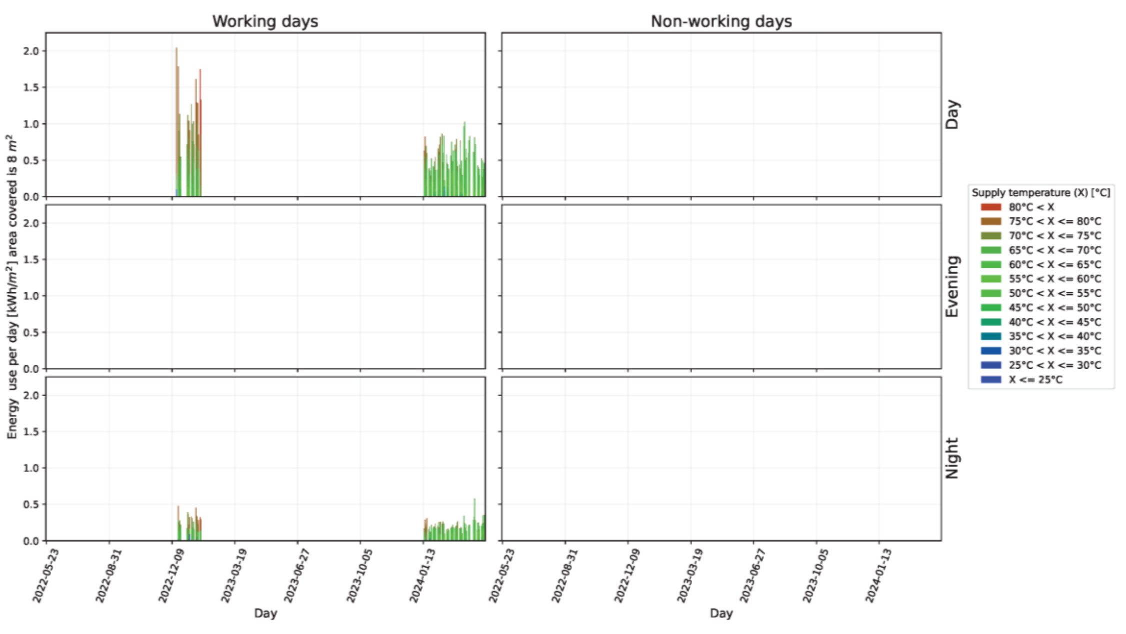

Figure 2.66: Specific heating energy use for the miscellaneous system Door01 in the different periods of each day. The energy use is summed over the hours for each period (day, evening, and night). Values are missing for most of 2022 and 2023.

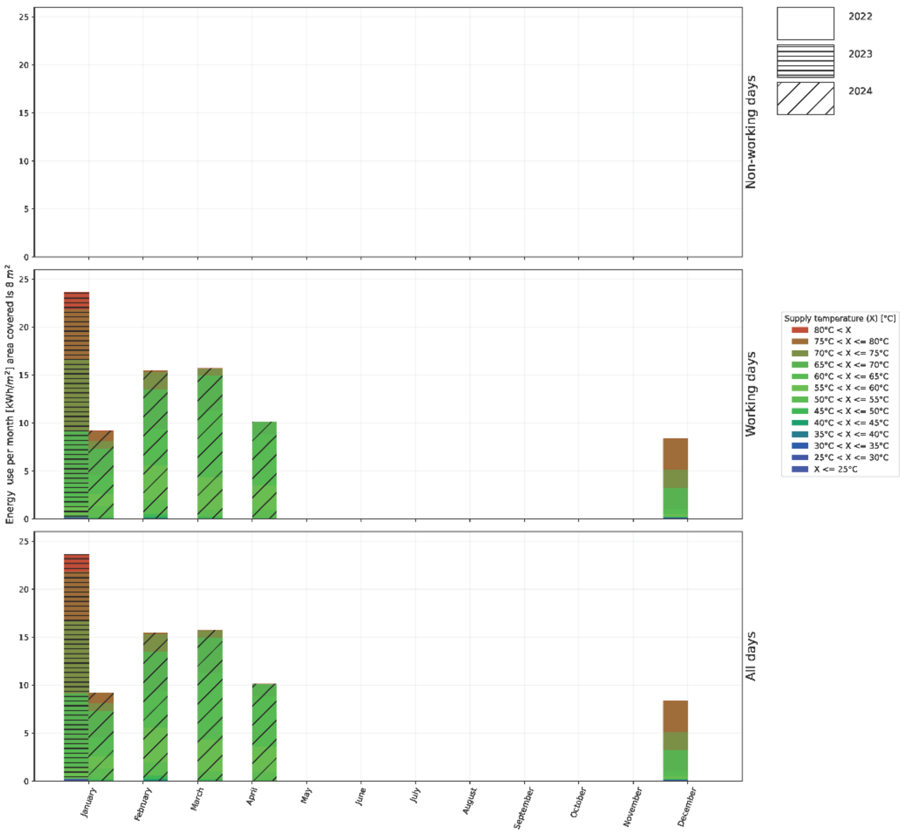

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Figure 2.67: Specific monthly energy use for the miscellaneous system Door01.

2.1.3 Discussion

Through the analysis of the different systems, one of the most important choices that will have to be taken is where heating energy will be supplied in the system. In this case, there could realistically be two locations. The first would be at the supply point for the building, which could result in the simplest setup and the lowest installation costs. However, relatively high supply temperatures would also be required from the waste heat source and could cause issues if low return temperatures are required to be sent back to it. The other location that could be used would be directly at the individual system, where the waste heat exchanger could be mounted directly to the individual system. This would mean significantly lower supply temperatures would be needed depending on the individual systems. The waste heat could be run through multiple systems in a series style connection, meaning that if high supply temperatures are available, it will first run through the systems requiring this, then afterward, if the return temperature from these systems is still adequate, it can be circulated through the systems requiring low supply temperatures. It would thus ensure low return temperatures back into the waste heat source. The issue with this kind of system is that it could be costly to include in an existing building due to high installation costs and the need for a high level of control.

In assessing the different systems properly, it has been seen that having the measurement points in the correct location (as close to the heat exchanger as possible) is essential to get a proper estimate of the actual supply temperature needed. This becomes evident when comparing the supply temperature used by the heat exchangers with either the temperature before the mixing loop or the dimensioned supply temperatures. An example of this for KOMF02 and P-KLIMA can be seen in Figure 2.68, with the different measurement locations shown in Figure 2.69. The temperature before the mixing loop tended to be 20-30°C higher than after it and was generally, as expected, close to the main DH temperature. The dimensioned supply temperature need of 60°C in the two heating coils was generally 10-30°C higher than the actual supply temperature.

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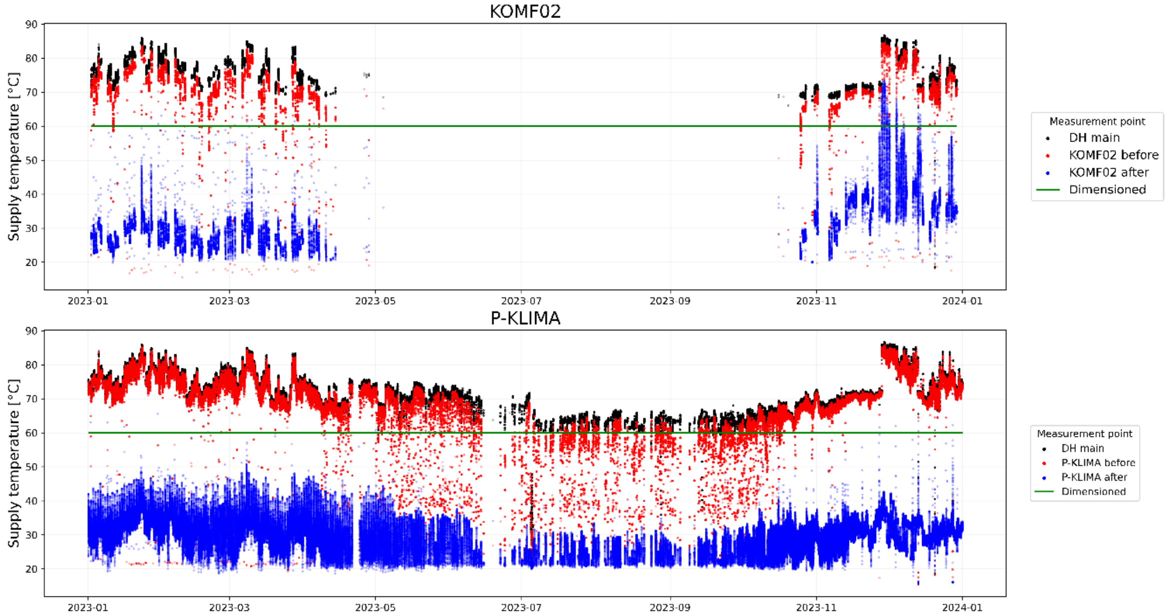

Figure 2.68: Comparison between the different possible locations for measurements. For KOMF02 and P-KLIMA, "before" and "after" refer to measurements before or after the mixing loop.

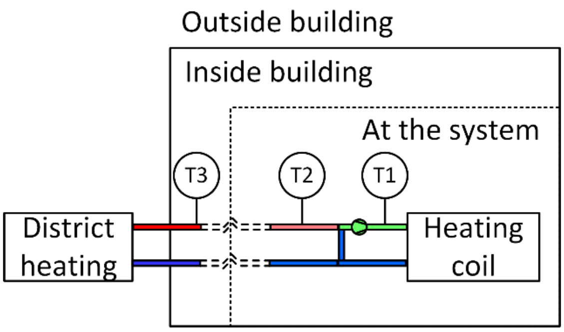

Figure 2.69: Possible supply temperature measurement locations. T1 is the temperature after the mixing loop, T2 is the temperature before the mixing loop, and T3 is the main DH supply temperature. In this case, illustrated for a heating coil but also representative of a heating system, the heating coil is then the entire circuit.

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2.2 EMPA Pilot

2.2.1 General building description

The Empa pilot is located at the campus of Empa & Eawag in Dübendorf, Switzerland. The pilot is part of the NEST (Next Evolution in Sustainable Building Technologies) platform/building. It is a smart living lab with a modular setup, which enables hosting several units as separate entities connected to a backbone. Each of these units can be of a different type, such as residential, offices, or meeting rooms. In this report, we selected multiple units for the analysis: UMAR, Sprint, DFAB, and HiLo. The overview of the NEST building demonstrated in Figure 2.70, and Figure 2.71 shows the energy supply system and key components of the NEST building. The thermal networks have three temperature levels: HTE for the high-temperature network, MTE for the medium-temperature network, and NTE for the low-temperature network. HTE features a high supply temperature range of 65°C to 90°C and a return temperature range of 45°C to 50 °C. MTE temperatures range from a supply temperature of 35°C to 38°C to a return temperature of 25°C to 28 °C. NTE maintains a high temperature (return temperature) of 14°C and a low temperature (supply temperature) of 7 °C. For heating purposes, the MTE is used, and for domestic hot water, the HTE is used. The NTE is used for cooling, but this is not interesting to this project.

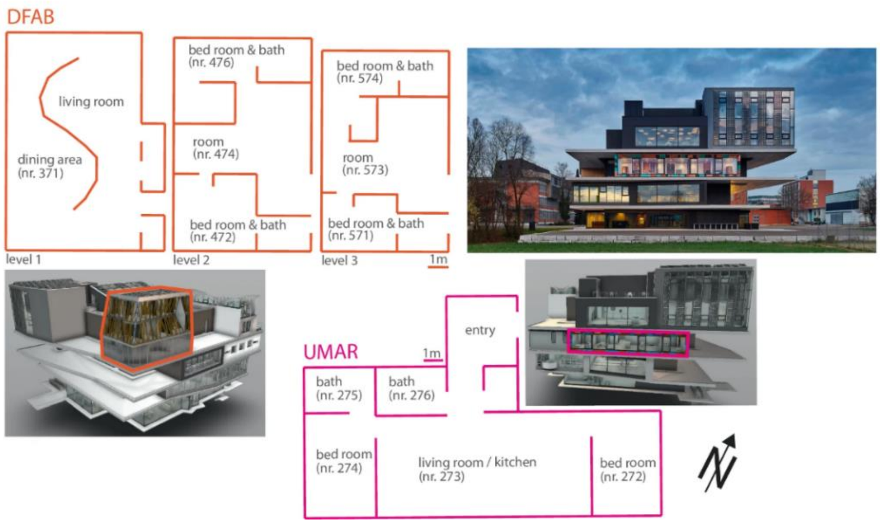

Figure 2.70. An overview of the NEST building and example layouts of two residential units (Heer, et al., 2024).

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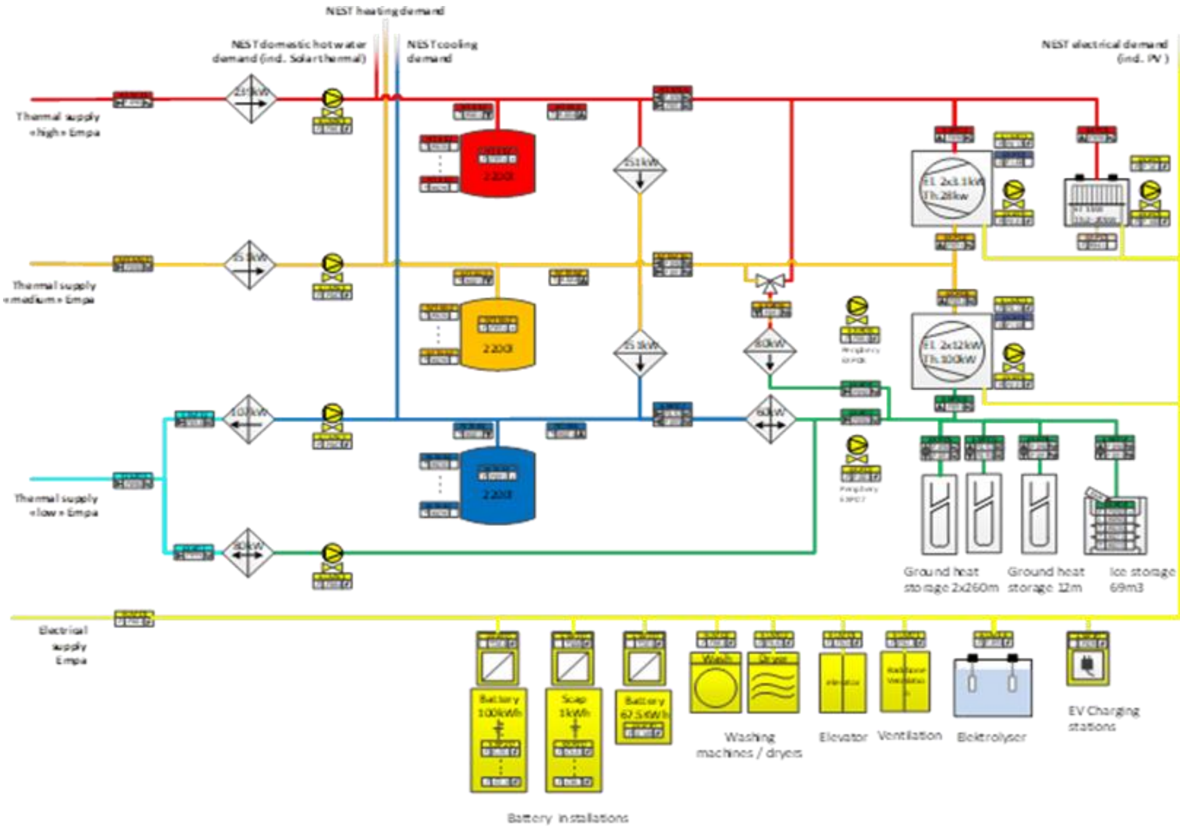

Figure 2.71. Schematic representation of the hybrid storage and conversion facilities at NEST and the Empa mobility demonstrator move. Gas networks are not shown.

2.2.1.1 HiLo

The HiLo Unit (High Performance – Low Emissions) opened at the beginning of 2022, and the measurement started around October 2022. The HiLo Unit is an office space with three different offices Figure 2.72 . The heat is sourced from the medium temperature network MTE. The heating system is hydraulically decoupled from the MTE grid with a heat exchanger. The heat is distributed through the ceiling system and underfloor systems. Office 1 and office 2 have ceiling heating with TABS (Thermally Activated Building Systems) while the gallery and the main space have floor heating. The operation of the system is controlled by switching on/off and setting an adjustable heating/cooling threshold. The thresholds for when to start heating and start cooling can be adjusted with a software. It employs weather-compensated temperature control, with the temperature set point determined by the outdoor temperature through an adjustable heating/cooling curve. Temperature settings can be adjusted individually for each zone. In addition to the

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ceiling and floor system, there is an air conditioning system which is also on the MTE network.

Figure 2.72 Illustration of the HiLo Unit

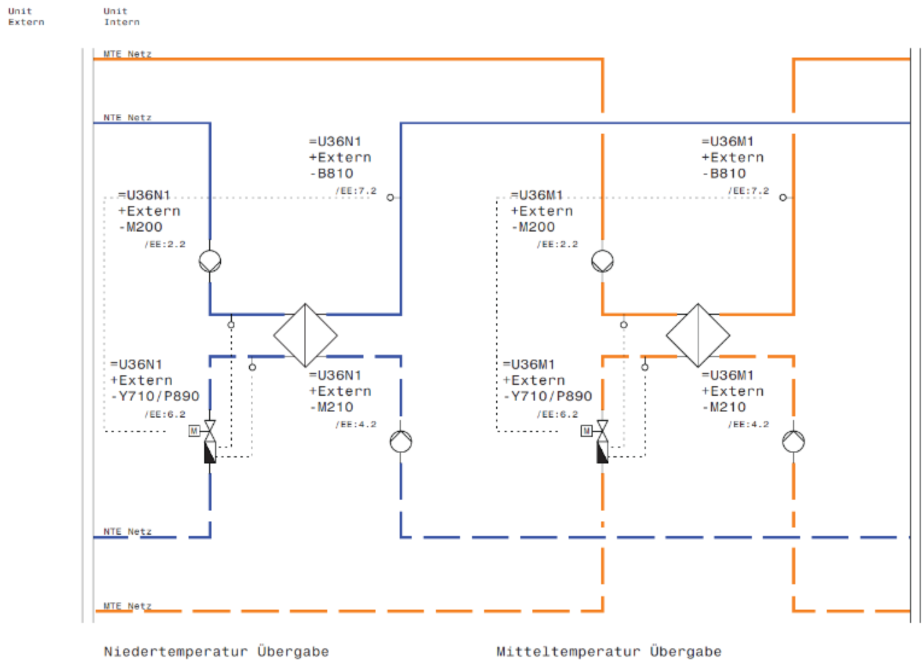

Figure 2.73. Connections between HiLo unit and thermal networks of NEST for space heating.

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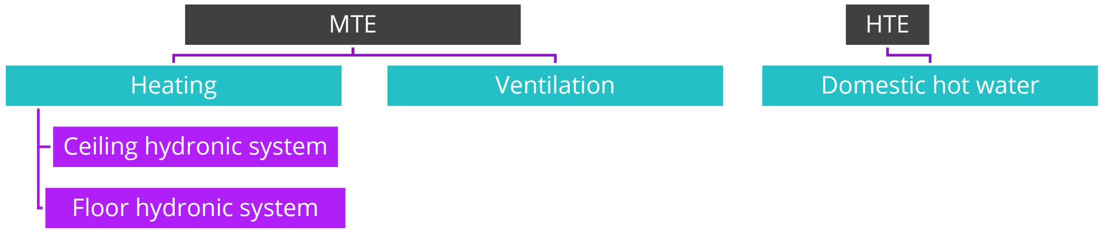

Figure 2.74. System overview for NEST HiLo unit.

2.2.1.2 DFAB

The DFAB unit was opened at the end of February 2019. The DFAB unit is a residential building with three floors and bedrooms. The heating system is designed to provide thermal energy during winter, and there is an additional support air-to-air heat pump during the transition period. The unit is connected to the MTE grid via a heat exchanger. Heat is distributed through a floor heating system, which can be turned on/off and adjusted via a switching threshold to go between heating and cooling mode. It operates with weather-compensated temperature control, where the set point is adjusted based on outdoor temperatures using an adjustable heating curve. Temperature settings for each heating circuit group are individually controlled through room thermostats. In addition, there is a ventilation system not connected to the MTE grid. Domestic hot water is supplied by an onsite heat pump and boiler which are also combined with photovoltaic panels. There is no connection to the HTE grid.

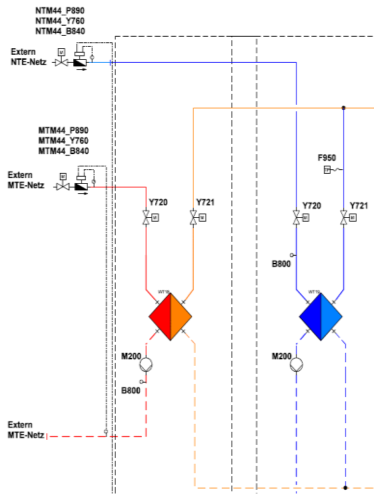

Figure 2.75. Connections between DFAB unit and thermal networks of NEST for space heating and cooling.

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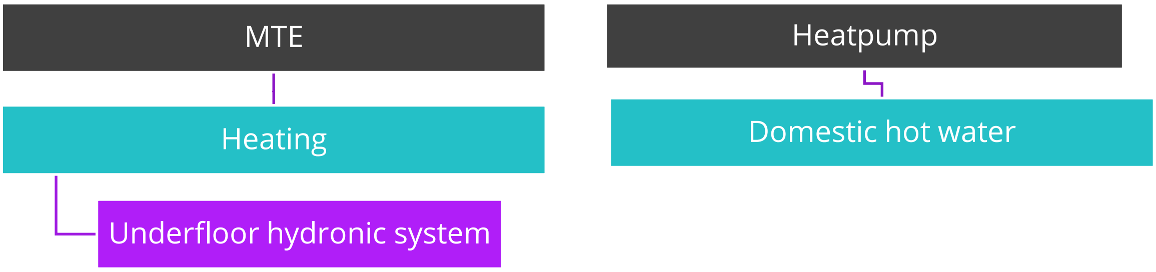

Figure 2.76. System overview for NEST DFAB unit.

2.2.1.3 UMAR

The UMAR opened in February 2018. The UMAR unit is built as a residential building consisting of two bedrooms and one common living room with a kitchen. There are two bathrooms as well. The unit has big windows, leading to high solar irradiance exposure. The purpose of the heating system is to supply thermal energy during the winter, taking heat from the MTE grid via a heat exchanger. Heat is emitted through a ceiling heating system. The system's operation is controlled by an on/off switch and an adjustable heating threshold.

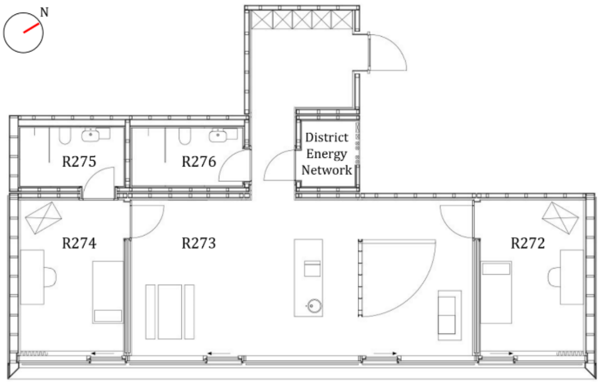

Figure 2.77 An overview of the room layout at Umar with two bedrooms (155m2)

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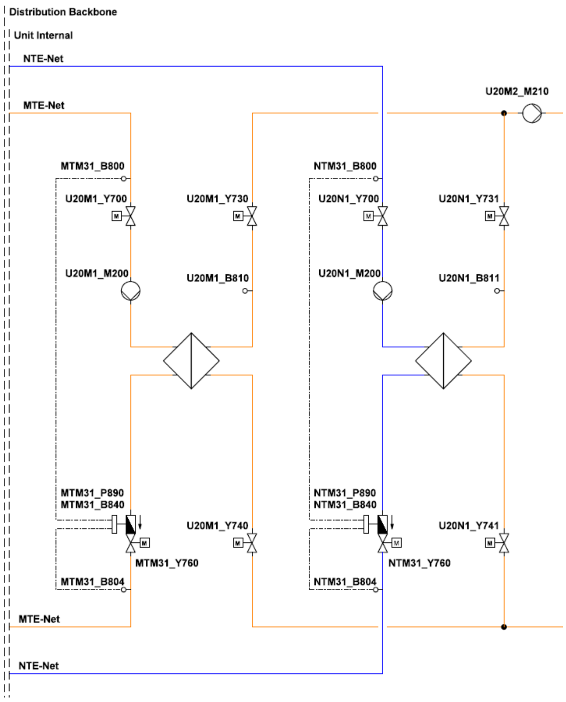

Figure 2.78 Connections between UMAR unit and thermal networks of NEST for space heating and cooling.

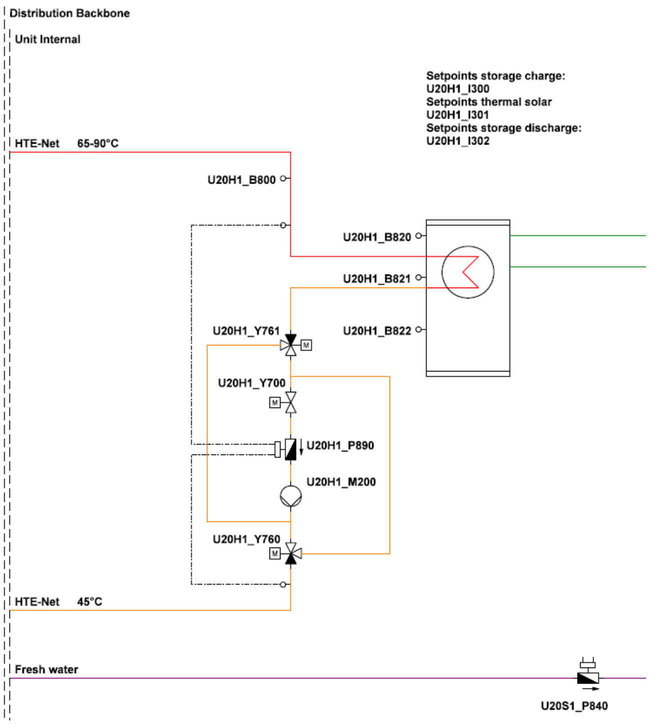

Figure 2.79. Connections between UMAR unit and thermal networks of NEST for DHW.

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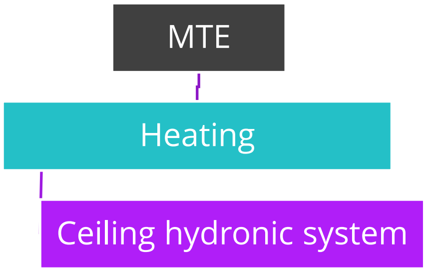

Figure 2.80 Setup for NEST UMAR unit.

2.2.1.4 Sprint

The Sprint unit was opened in August 2021. The heating system is supplied from the MTE grid through a heat exchanger. Heat is emitted through a ceiling heating system. The operation of the system is managed by an on/off switch and an adjustable limit for heating and cooling. It features weather-compensated temperature control, where the set point is adjusted according to the outdoor temperature based on an adjustable heating/cooling curve.

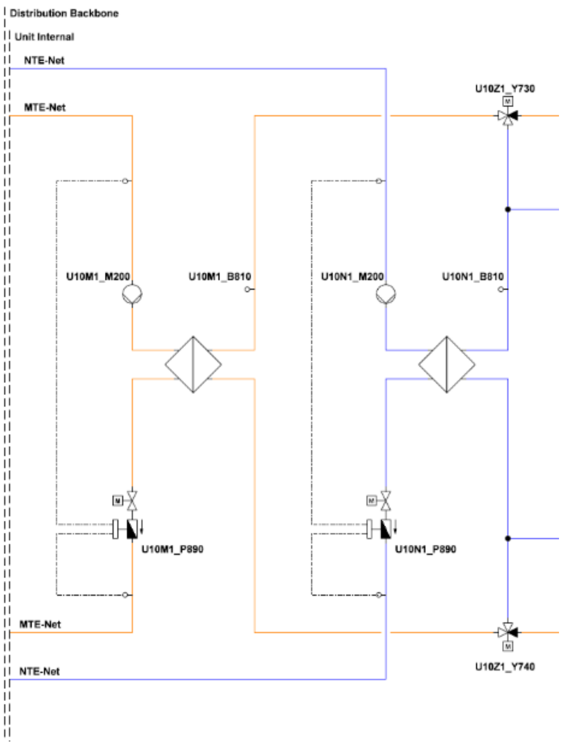

Figure 2.81 Connections between Sprint unit and thermal networks of NEST for space heating and cooling.

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.

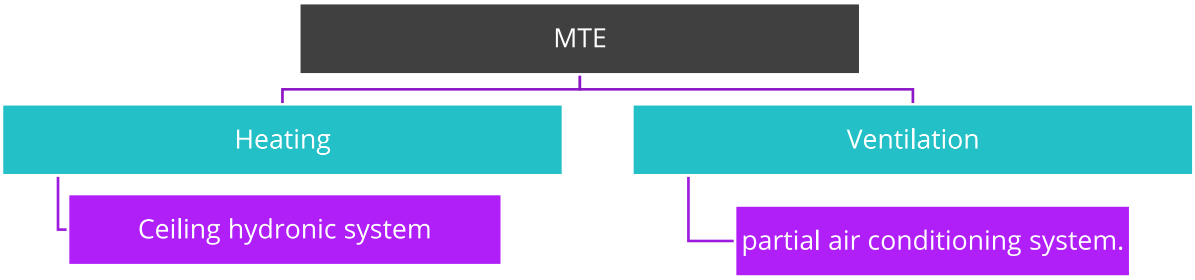

Figure 2.82 Setup for NEST Sprint unit.

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2.2.2 Result

2.2.2.1 Results for UMAR

From Table 2.31 and Figure 2.83, we can observe that the most waste heat potentials are located in the temperature range from 35°C to 40°C. This shows that there is a potential to use waste heat for heating as a data center can provide the necessary level of temperature. For UMAR, only the full-scale measurements are available. There is energy demand across the whole day, but there is energy demand only for the winter and transition months of the year. The seasonality can be best seen in Figure 2.84 with no demand in the summer. From Figure 2.85, there is higher energy demand during working days than non-working days. But there is also energy demand on non-working days. The data from UMAR about domestic hot water (DHW) is deemed untrustworthy and unusable, due to highly irregular spikes in the demand as seen in Figure 2.88.

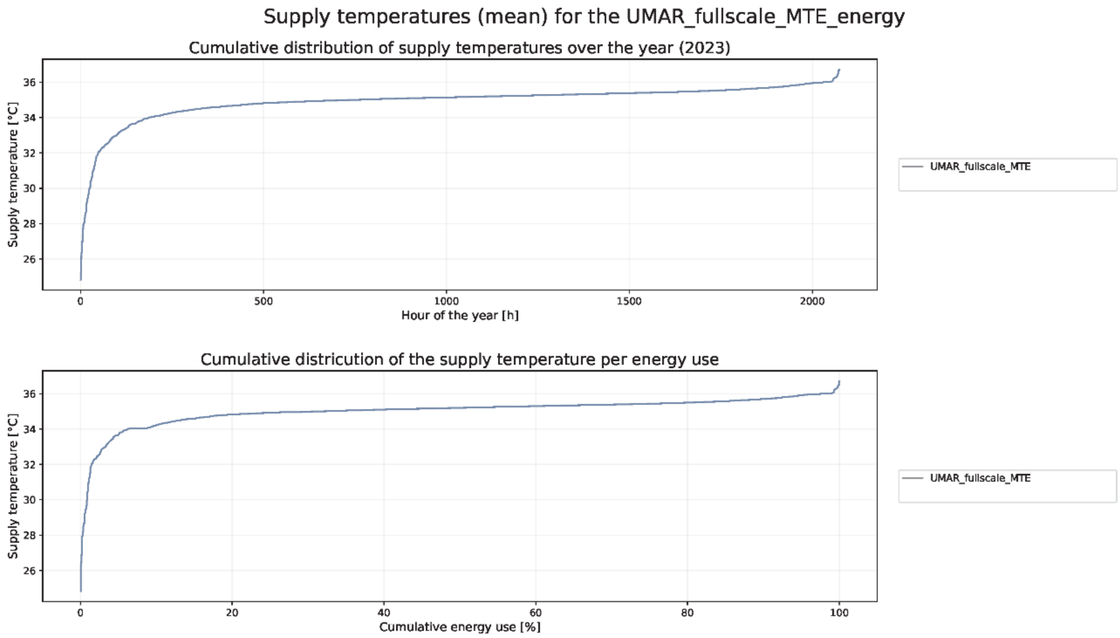

Figure 2.83 Cumulative distribution of the supply temperature 2023 UMAR unit

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Table 2.31. Energy use at the different temperature levels for the MTE supply. The values have the unit kWh/m².

Supply temperature	2022	2023	2024
X <= 25°C	0.00	0.00	0.00
25°C < X <= 30°C	0.02	0.02	0.23
30°C < X <= 35°C	1.71	4.58	5.93
35°C < X <= 40°C	9.59	13.59	2.10
40°C < X <= 45°C	0.01	0.00	0.00
45°C < X <= 50°C	0.00	0.00	0.00
50°C < X <= 55°C	0.00	0.00	0.00
55°C < X <= 60°C	0.00	0.00	0.00
60°C < X <= 65°C	0.00	0.00	0.00
65°C < X <= 70°C	0.00	0.00	0.00
70°C < X <= 75°C	0.00	0.00	0.00
75°C < X <= 80°C	0.00	0.00	0.00
80°C < X	0.00	0.00	0.00

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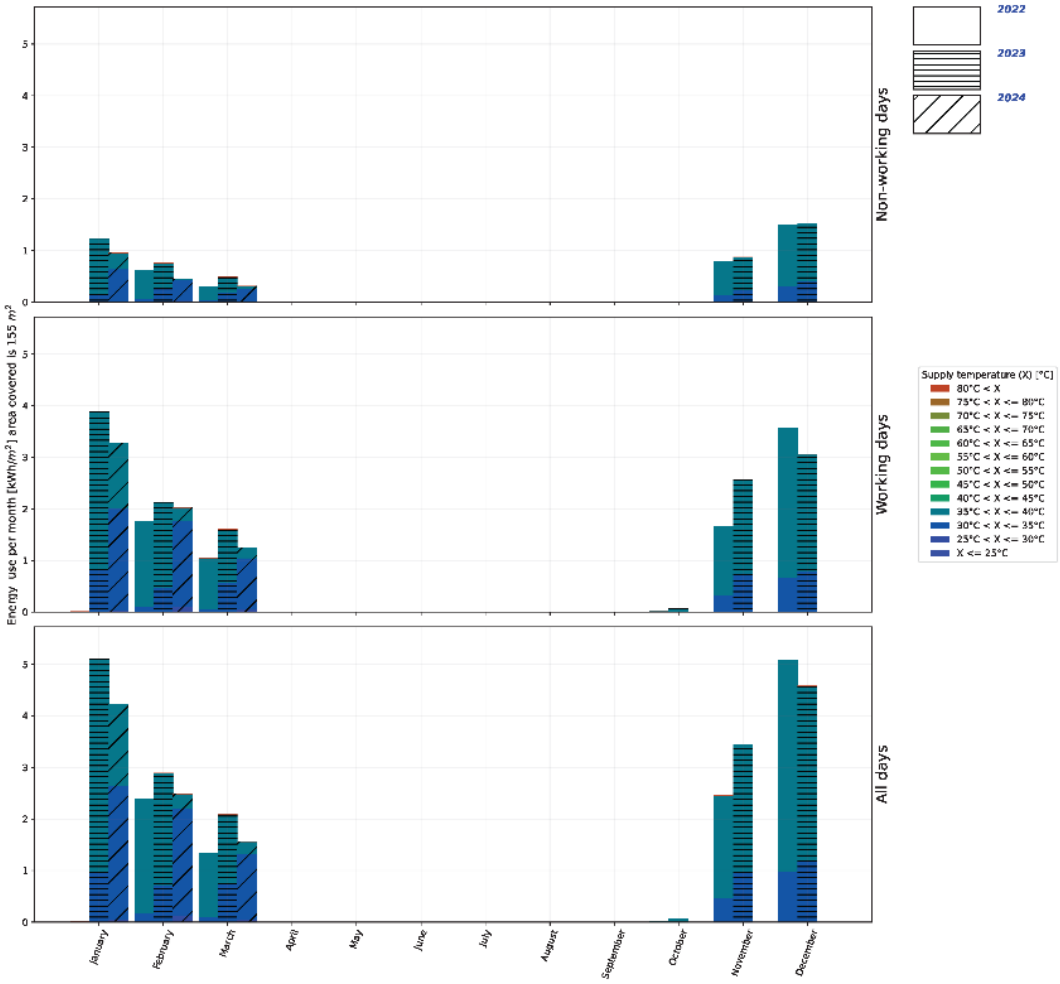

Figure 2.84. Specific monthly energy use for the space heating at the UMAR unit.

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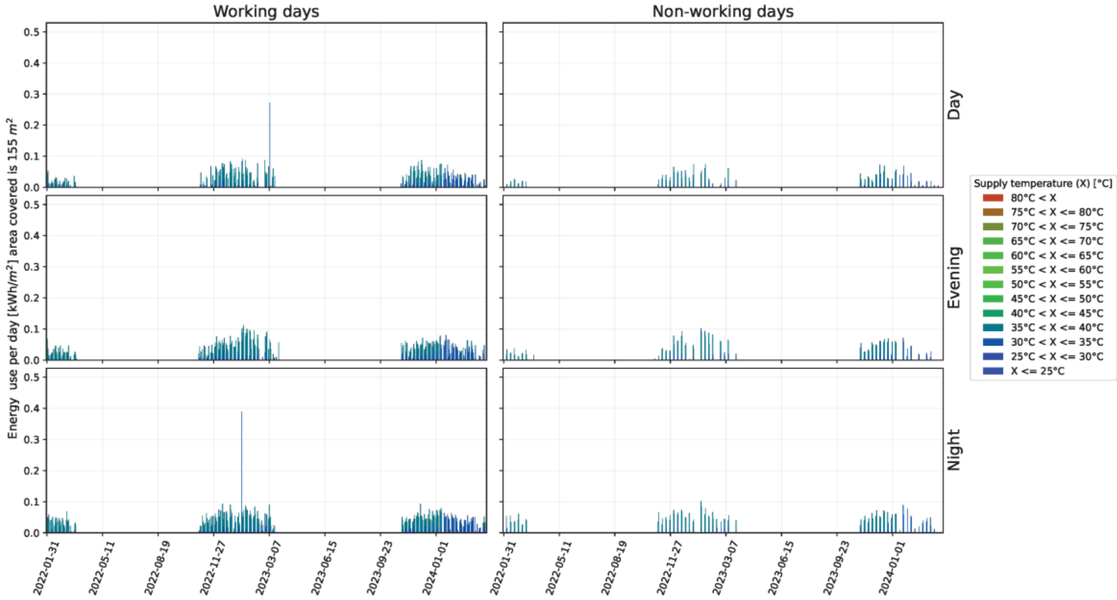

Figure 2.85. Specific heating energy use for the space heating at the UMAR unit in the different timeperiods of each day. For each of the timeperiods (day, evening, and night), the energy use is summed over the hours.

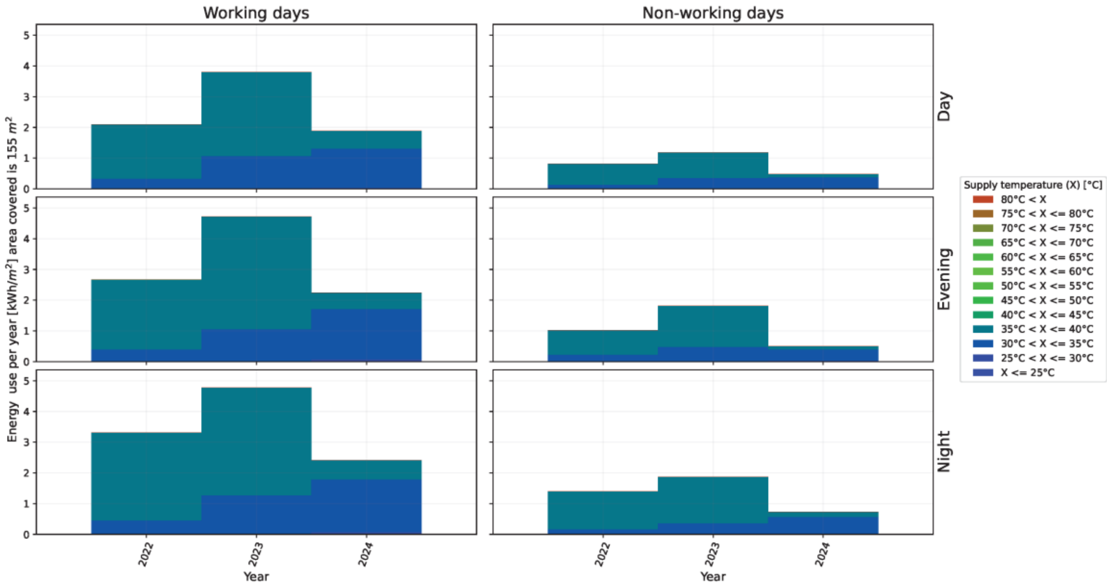

Figure 2.86. Energy use per year UMAR full-scale MTE.

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Table 2.32. Energy use at the different temperature levels for the HTE supply. The values have unit of kWh/m².

Supply temperature	2022	2023	2024
X <= 25°C	0.00	0.00	0.00
25°C < X <= 30°C	0.03	1.50	0.90
30°C < X <= 35°C	0.02	0.00	0.00
35°C < X <= 40°C	0.02	0.02	0.03
40°C < X <= 45°C	0.01	0.02	0.04
45°C < X <= 50°C	0.01	0.02	0.11
50°C < X <= 55°C	0.03	0.06	0.11
55°C < X <= 60°C	0.10	0.22	0.39
60°C < X <= 65°C	0.44	0.37	0.95
65°C < X <= 70°C	0.00	0.00	0.00
70°C < X <= 75°C	0.00	0.00	0.00
75°C < X <= 80°C	0.00	0.00	0.00
80°C < X	0.00	0.00	0.00

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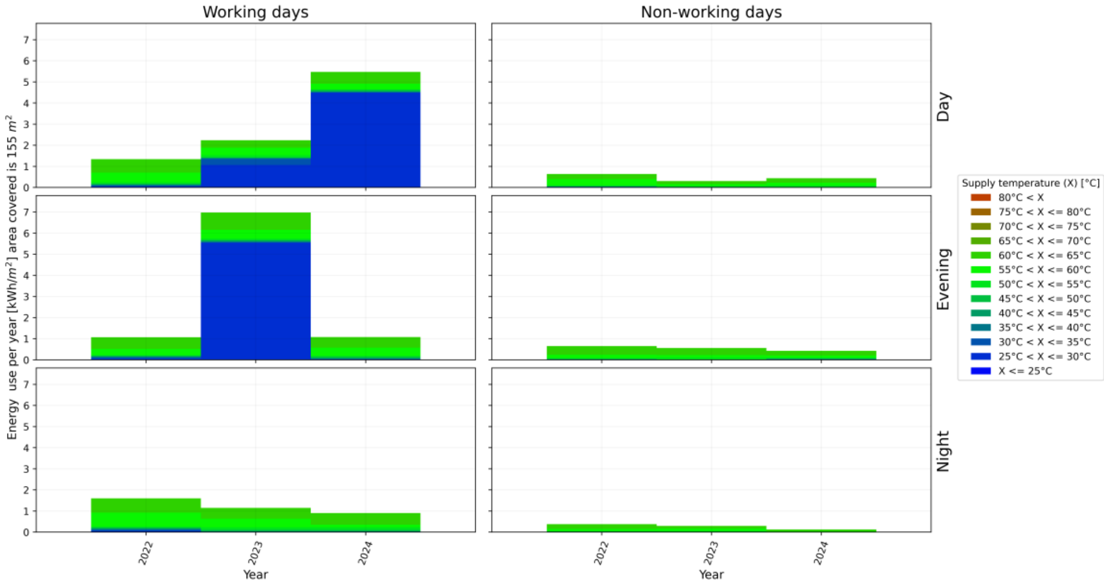

Figure 2.87 Energy use per year UMAR HTE

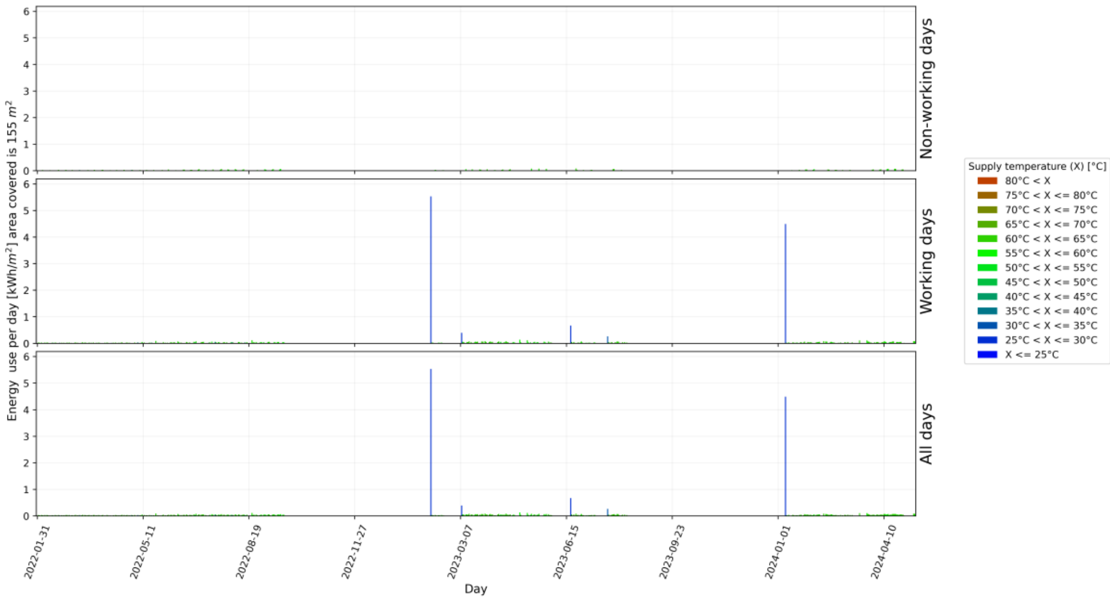

Figure 2.88 Energy use per day UMAR HTE full-scale

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2.2.2.2 Results for Sprint

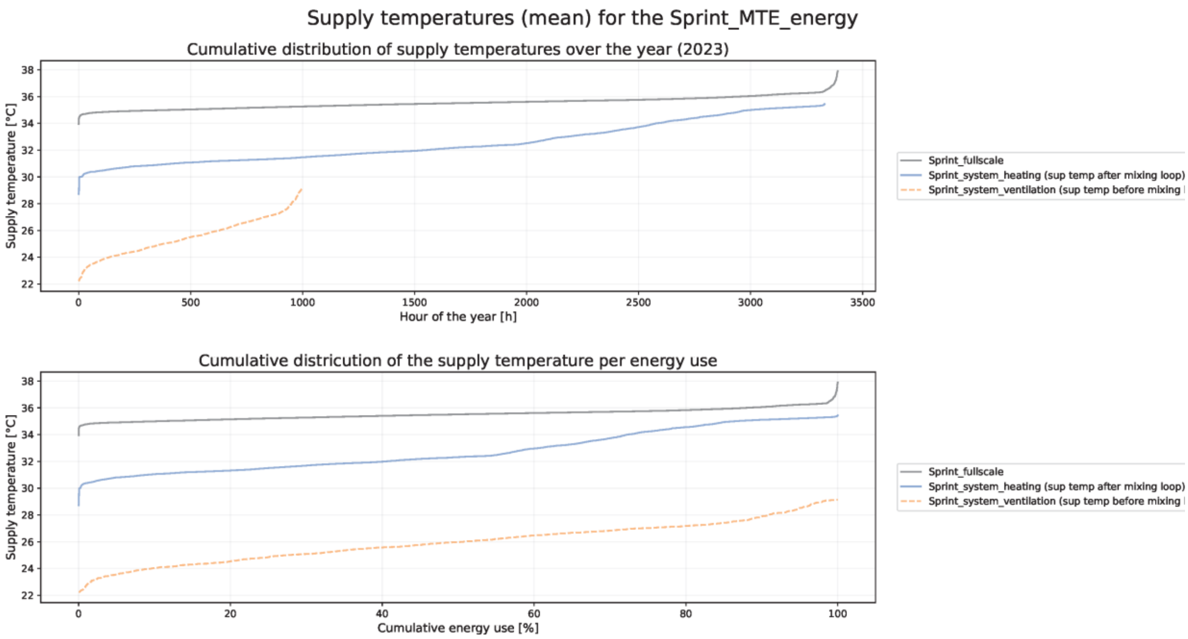

Figure 2.89 cumulative distribution of the supply temperature 2023 Sprint unit.

The maximal supply temperature is around 38°C which enables the use of waste heat and has a good potential. From Figure 2.89 it Figure can be read that the supply temperature needed is mostly between 30°C and 36°C. That temperature can be met by waste heat.

From Table 2.33, we can see that the full-scale shows a difference between the two heating periods 2022/2023 and 2023/2024, more energy is used for the supply temperature interval from 30°C to 35°C than in the previous one. Figure 2.90 and Figure 2.92 show that the energy demand throughout the whole day is ventilation, which does not have a demand every day. There is also here a seasonality no demand in the summer. We can see in the ventilation uses a supply temperature lower than that for the heating.

Table 2.33. Sprint Energy use at the different temperature levels for the MTE supply. The values have unit of kWh/m².

	2022	2023	2024
X <= 25°C	0	0	0.011
25°C < X <= 30°C	0	0	1.027

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30°C < X <= 35°C	1.022	5.726	17.363
35°C < X <= 40°C	32.690	37.381	4.819
40°C < X <= 45°C	0.032	0	0
45°C < X <= 50°C	0	0	0
50°C < X <= 55°C	0	0	0
55°C < X <= 60°C	0	0	0
60°C < X <= 65°C	0	0	0
65°C < X <= 70°C	0	0	0
70°C < X <= 75°C	0	0	0
75°C < X <= 80°C	0	0	0

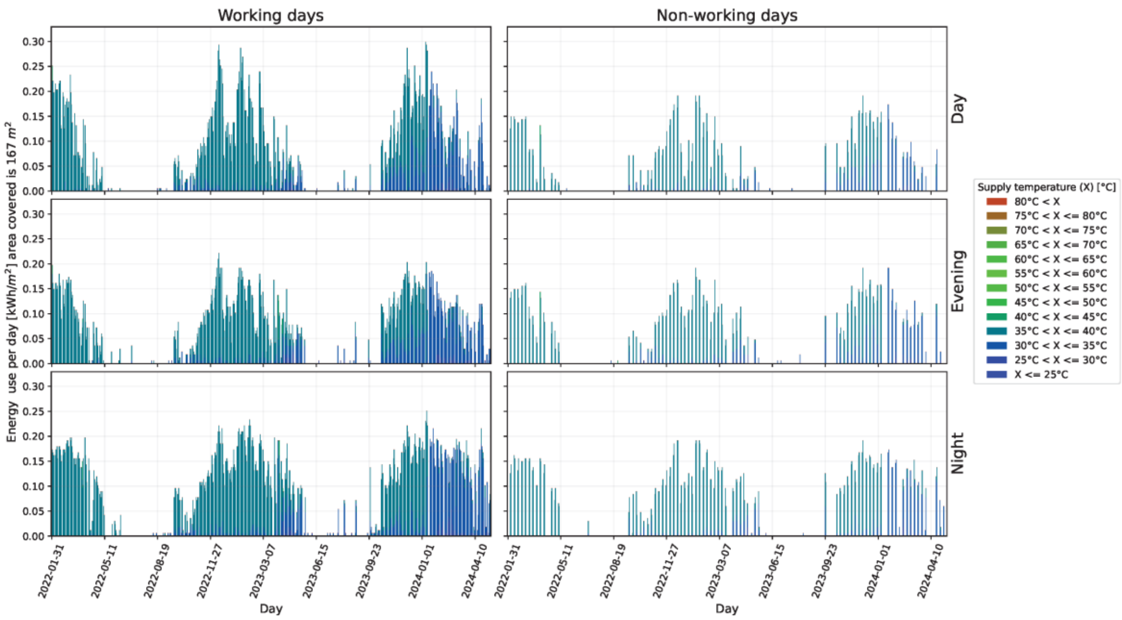

Figure 2.90 Energy use per day for full-scale Sprint.

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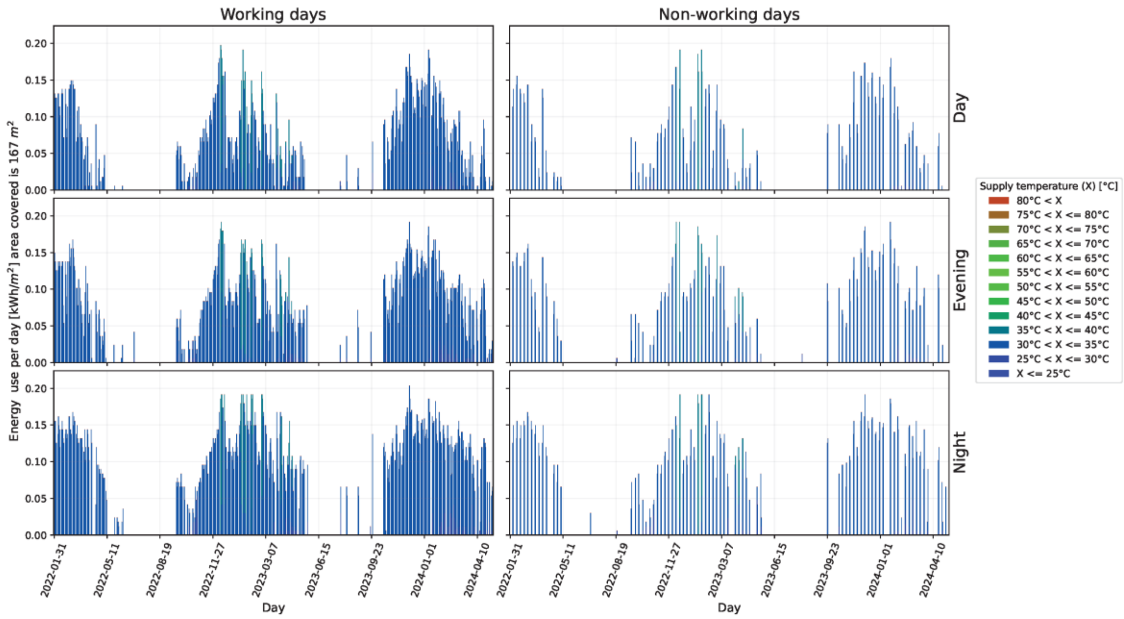

Figure 2.91 Energy use per day for heating in Sprint.

There is a noticeable difference in the energy for the ventilation in the Sprint unit as seen in Figure 2.92. From Figure 2.90 and before can be seen that there is no energy use on the non-working days and less in the evening and at night. While the first one is the full-scale and the second one is the heating system.

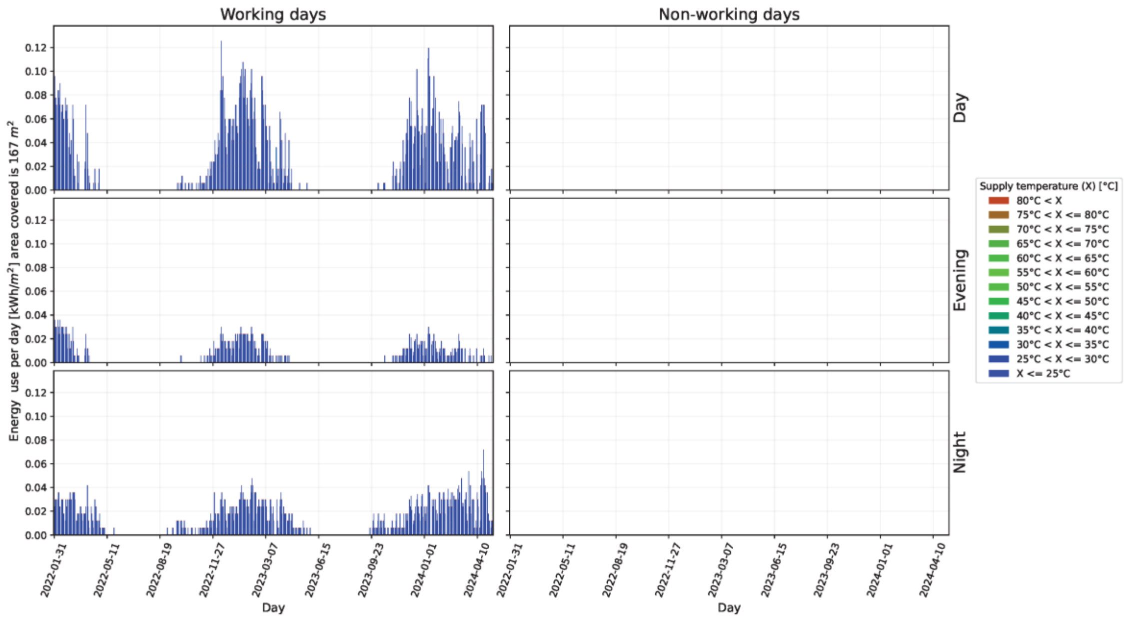

Figure 2.92 Energy per day for ventilation in Sprint

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2.2.2.3 Result DFAB

The Figure 2.94 below shows the daily time of the day distribution of the supply temperature and energy for the full-scale unit DFAB. The same can be read from Figure 2.96 the system level of the heating system of DFAB. As DFAB is a residential unit there is heating demand in the heating period through the whole day. There is no noticeable change in the energy across the day. There is mostly demand for lower supply temperatures, which are suitable to be coupled with waste heat from a source such as a data center. The energy demand is seasonal as there is no demand for heating in the summer and part of spring, which can be seen in Figure 2.95 and Figure 2.96. The demand driver for the heating is the outdoor temperature. From Table 2.34 we can see that the most energy demand is for a supply temperature between 35 and 40 degrees Celsius. Followed by 30°C to 35 °C.

Table 2.34 Energy use at the different temperature levels for the MTE supply. The values have unit of kWh/m².

Supply temperature	2022	2023	2024
X <= 25°C	0.00	0.00	0.00
25°C < X <= 30°C	0.00	0.01	0.19
30°C < X <= 35°C	1.19	3.06	4.06
35°C < X <= 40°C	8.37	12.79	1.90
40°C < X <= 45°C	0.00	0.00	0.00
45°C < X <= 50°C	0.00	0.00	0.00
50°C < X <= 55°C	0.00	0.00	0.00
55°C < X <= 60°C	0.00	0.00	0.00
60°C < X <= 65°C	0.00	0.00	0.00
65°C < X <= 70°C	0.00	0.00	0.00
70°C < X <= 75°C	0.00	0.00	0.00

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75°C < X <= 80°C	0.00	0.00	0.00
80°C < X	0.00	0.00	0.00

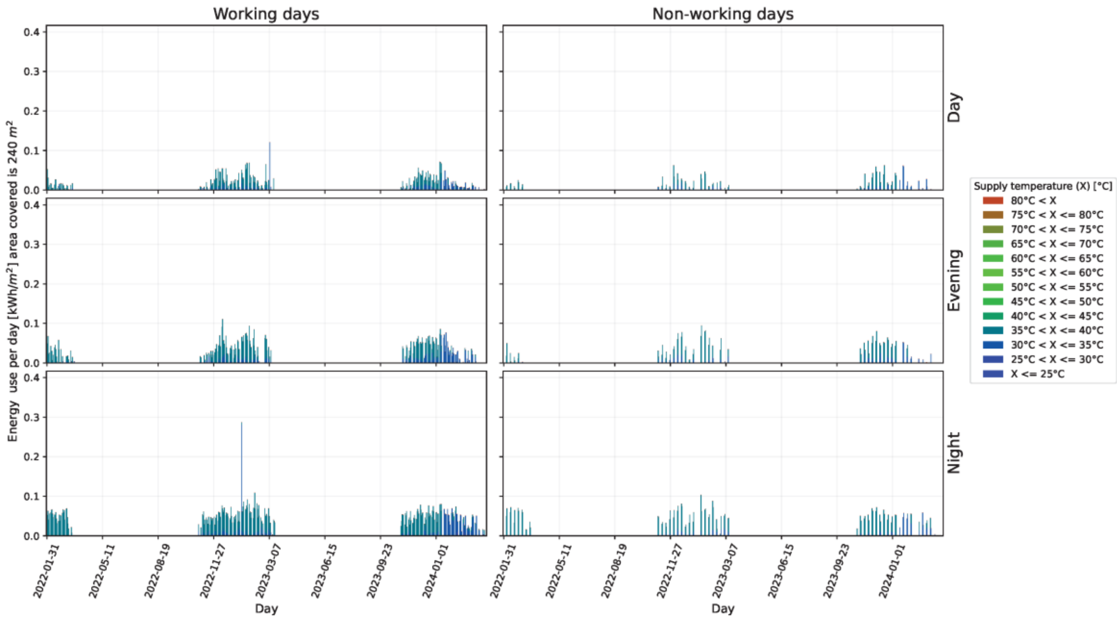

Figure 2.93 Energy use per day for full-scale in DFAB.

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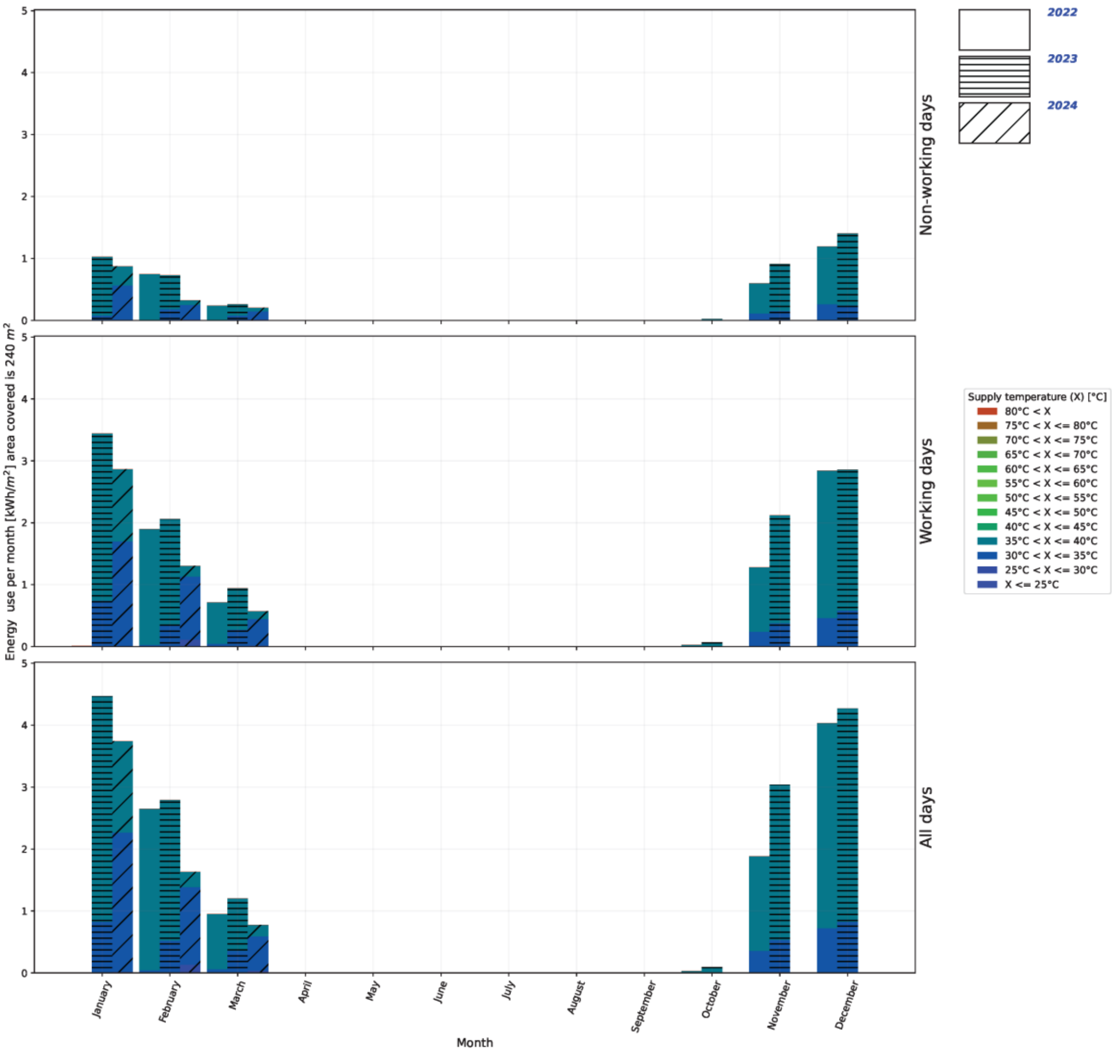

Figure 2.94 Energy use per month at full-scale in DFAB

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.

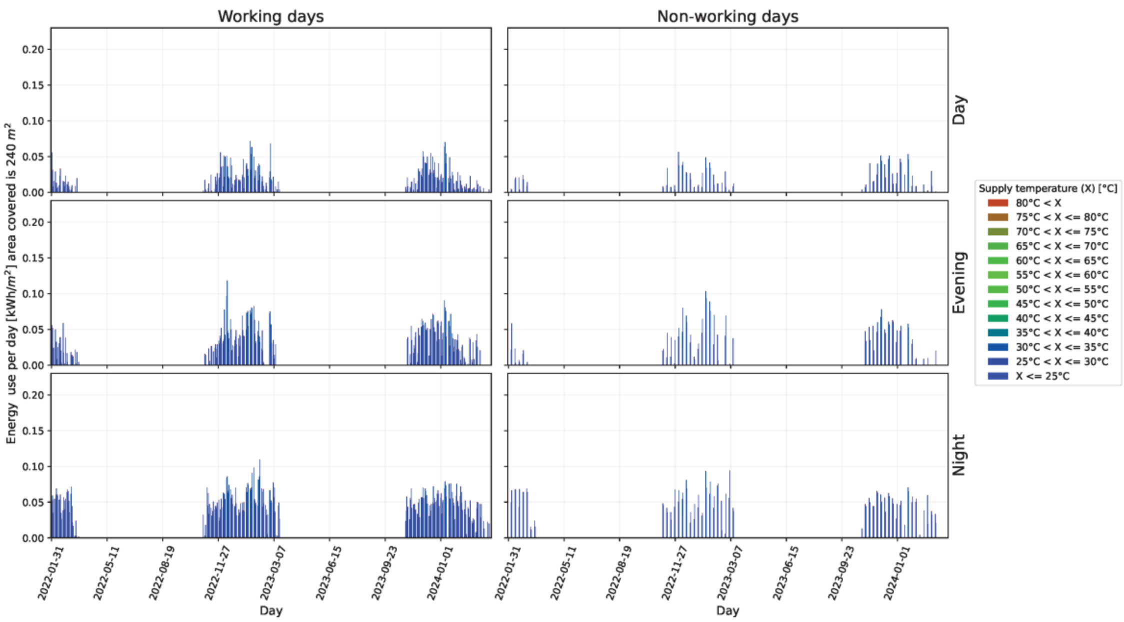

Figure 2.95 Energy use per day for the heating system in DFAB.

As seen in Figure 2.93 and in Figure 2.95 there is more energy usage during working days than during non-working days.

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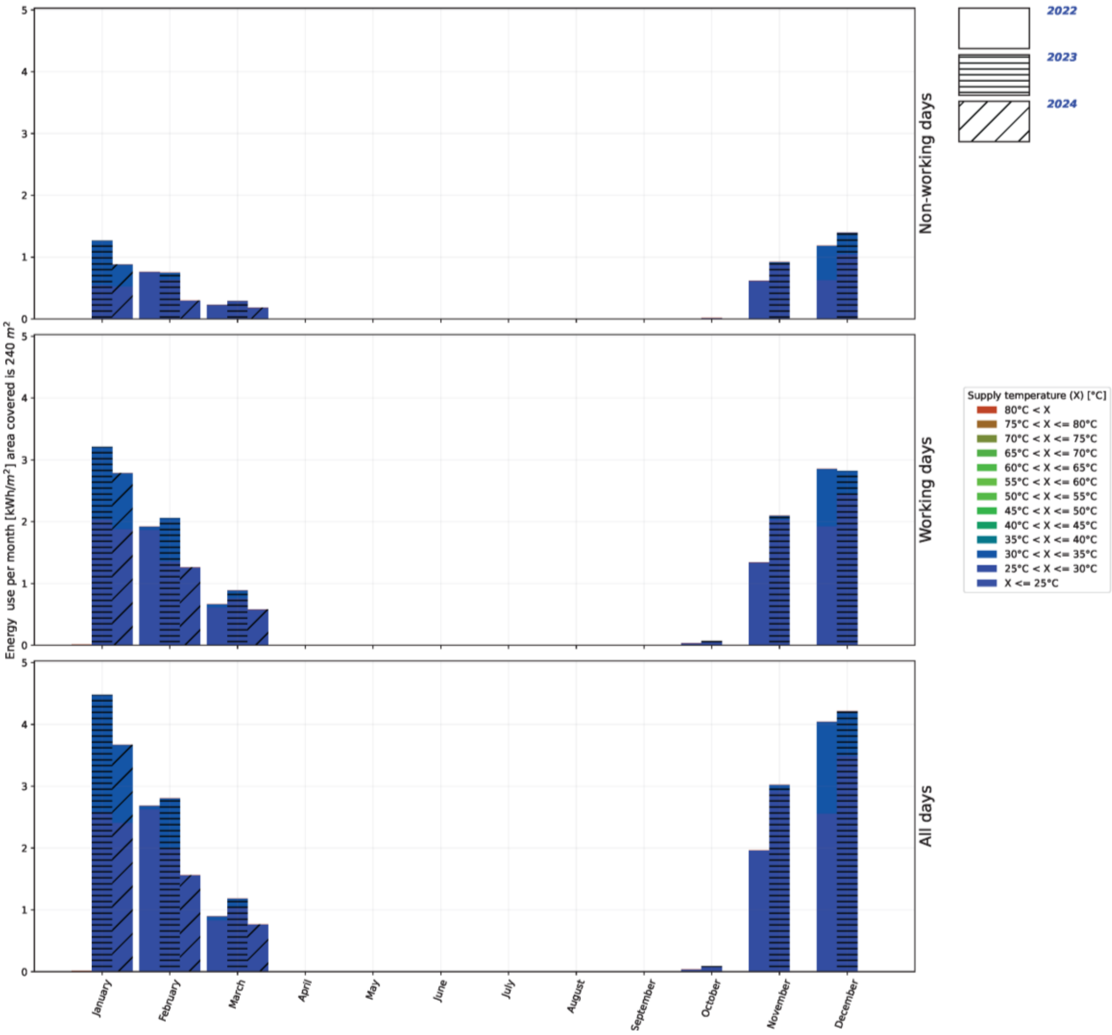

Figure 2.96 Energy use per month for the heating system in DFAB.

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.

2.2.2.4 Result HiLo

The full-scale plots in Figure 2.97 and Figure 2.98 show that there is energy demand for lower supply temperatures around 30°C to 40°C which makes them suitable to waste heat. Table 2.35 also supports this. As with the other units, we can observe seasonality because there is not much demand for heating in the summer. This can be seen in there is a clear seasonality. Figure 2.100 shows that for the year 2023 the supply temperature is constant for a long time. From Figure 2.97 we can read that the energy consumption is higher on working days vs on non-working days, in addition to that we can see that the energy consumption is lowest during the night.

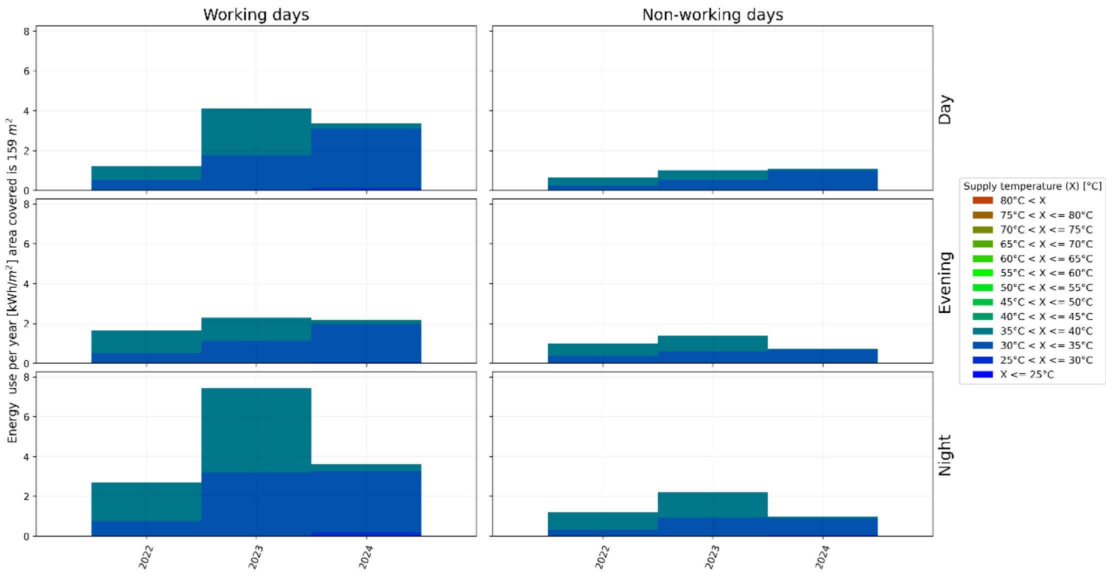

Figure 2.97 yearly energy use per year in HiLo.

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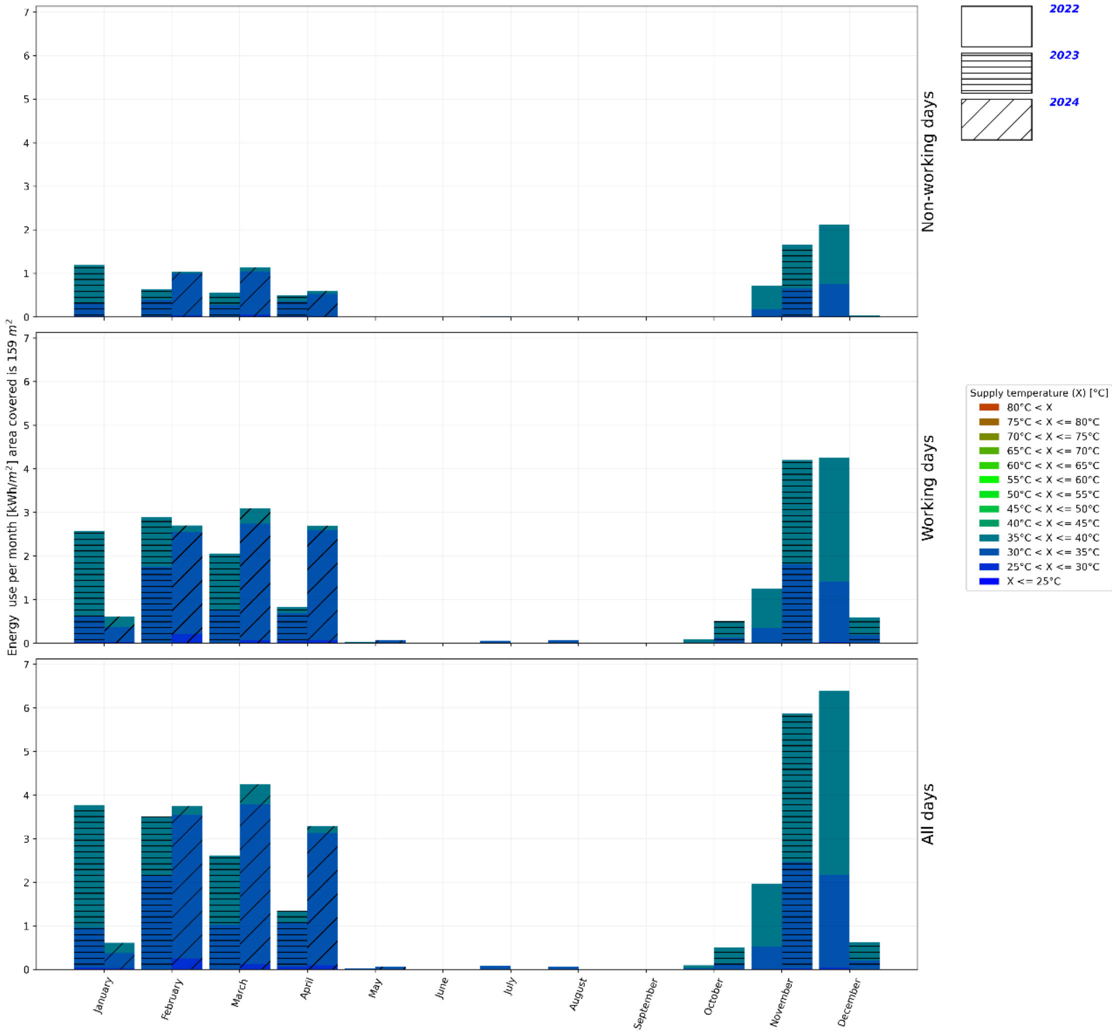

Figure 2.98 Specific monthly energy use for the space heating at the HiLo unit.

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.

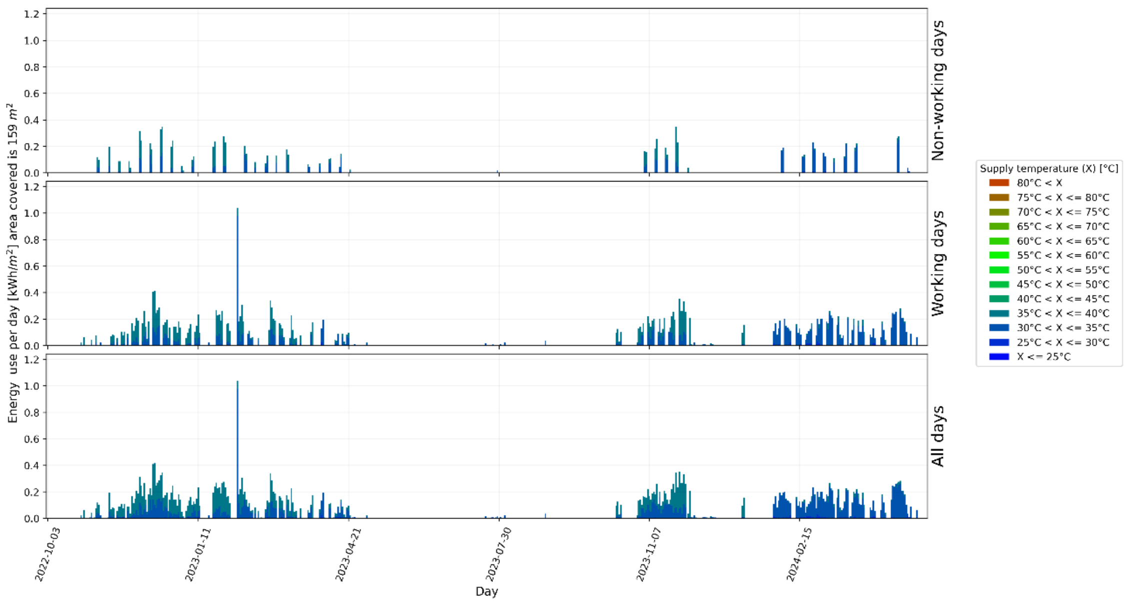

Figure 2.99 MTE HiLo energy use for the full-scale at the HiLo unit in the different time periods of each day. For each of the time periods (day, evening, and night), the energy use is summed over the hours.

Table 2.35. HiLo Energy use at the different temperature levels for the MTE supply. The values have unit of kWh/m².

Supply temperature (X)	2022	2023	2024
X <= 25°C	0.006	0.013	0
25°C < X <= 30°C	0.044	0.157	0.503
30°C < X <= 35°C	2.667	7.981	10.393
35°C < X <= 40°C	5.736	10.258	1.054
40°C < X <= 45°C	0	0	0
45°C < X <= 50°C	0	0	0
50°C < X <= 55°C	0	0	0

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55°C < X <= 60°C	0	0	0
60°C < X <= 65°C	0	0	0
65°C < X <= 70°C	0	0	0
70°C < X <= 75°C	0	0	0
75°C < X <= 80°C	0	0	0
80°C < X	0	0	0

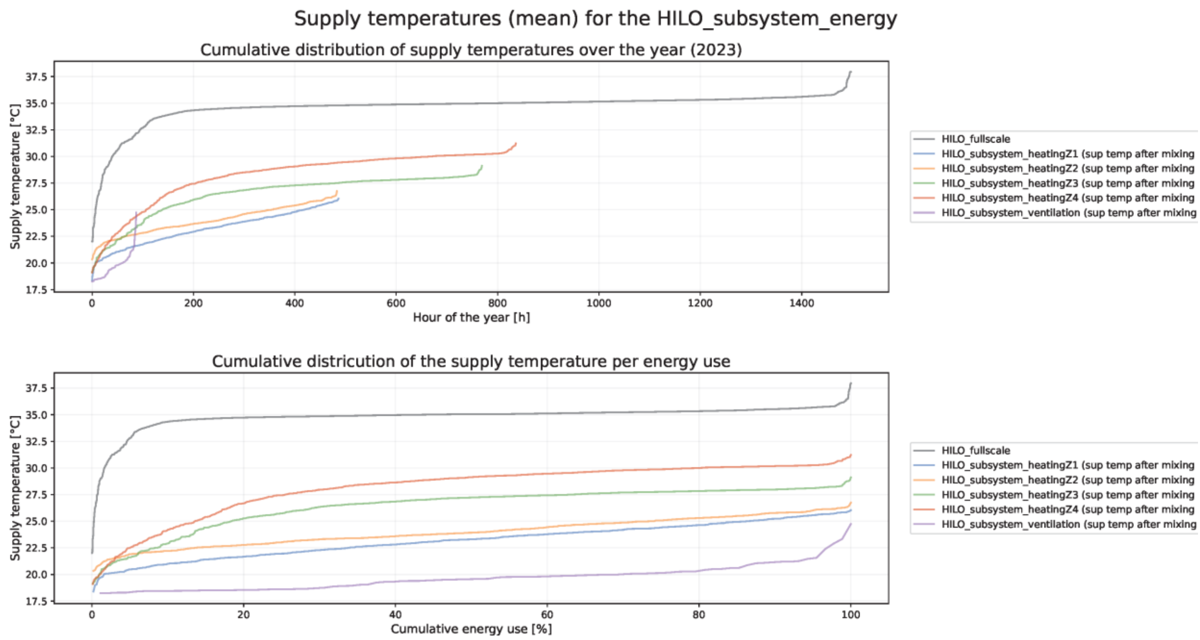

Figure 2.100 cumulative distribution of supply temperature 2023 HiLo Unit MTE

In the following subsection we have a look at the different subsystems of HiLo.

2.2.2.4.1 Zone 1-Z1

Zone 1 is small and therefore does not have a big impact, its area is 22.93 m². Also here can be seen that there is more energy consumption on working days.

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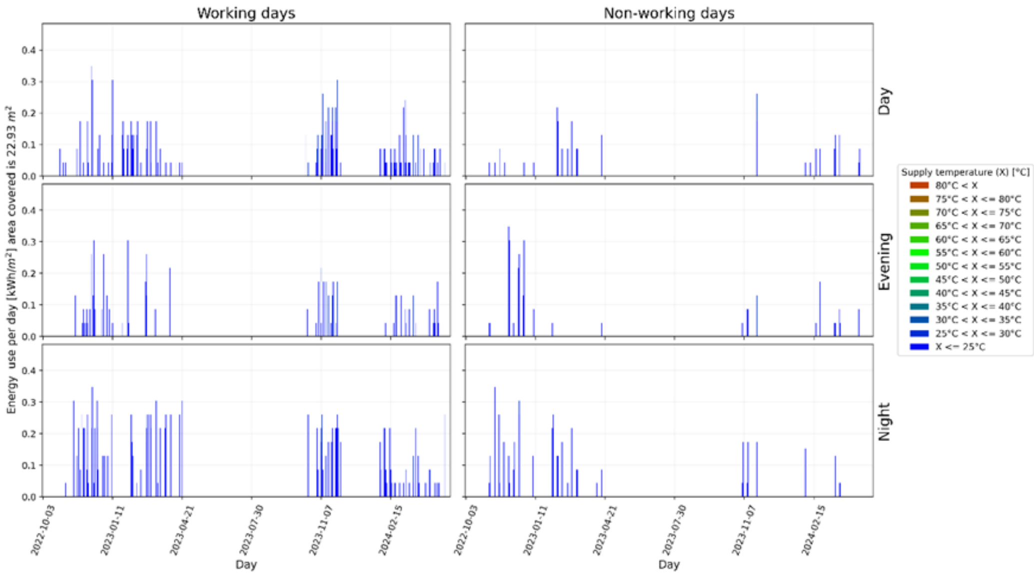

Figure 2.101 energy use per day Zone 1 HiLo

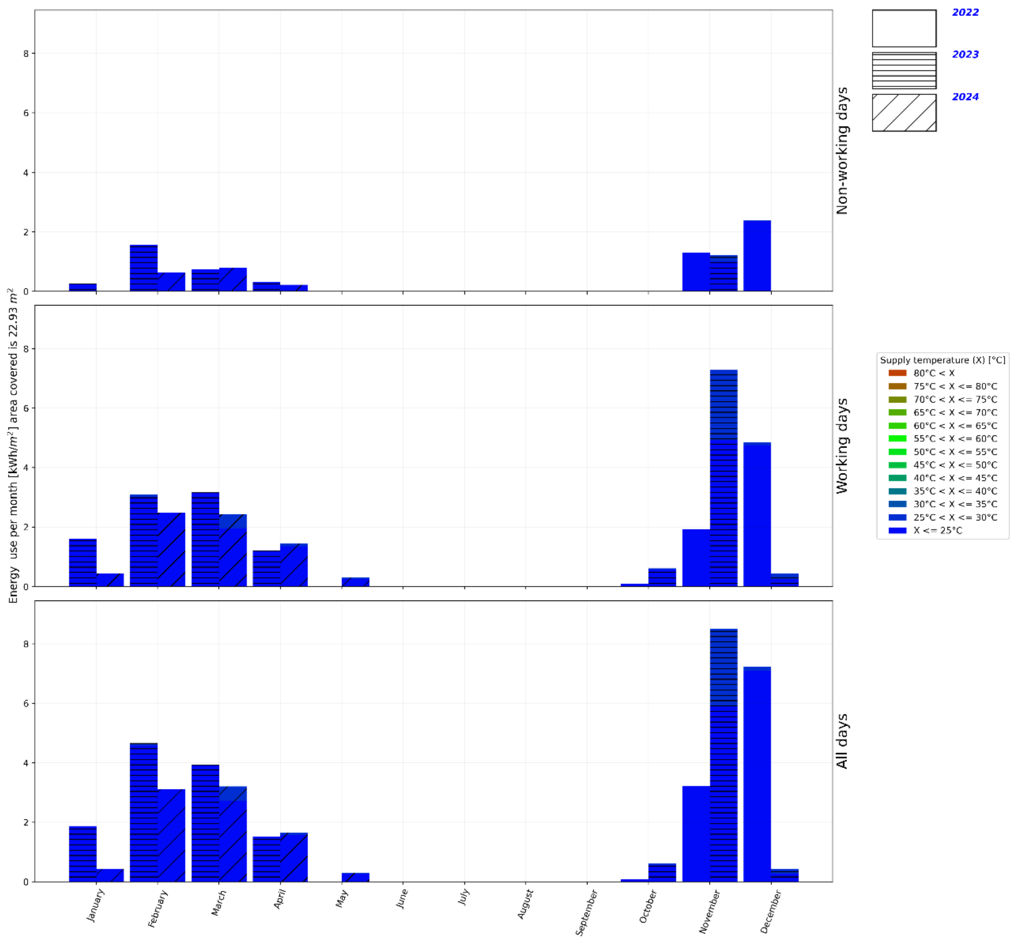

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Figure 2.102 energy per month Zone 1 HiLo

2.2.2.4.2 Zone 2-Z2

As for the other systems energy use is significantly higher in colder months, indicating natural outdoor driven heating demand. And seasonal pattern which will allow to use more waste heat in the winter with no demand in the summer. Zone 2 is also a small room.

There is clearly a monthly change from season to season in the energy demand as seen in Figure 2.104.

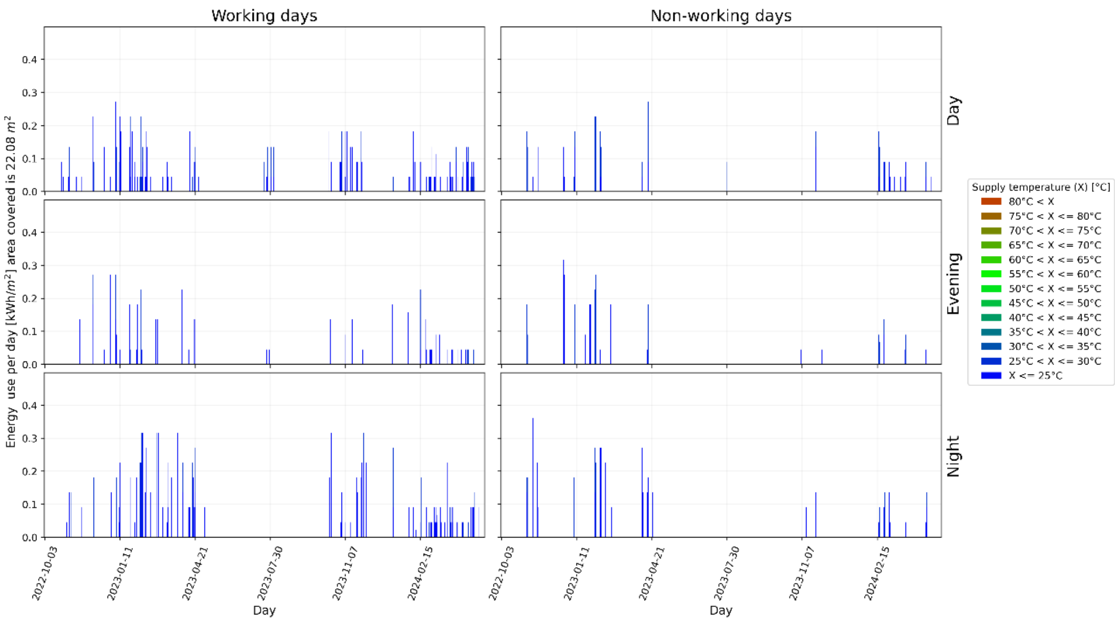

Figure 2.103 energy use per day HiLo zone 2 heating

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.

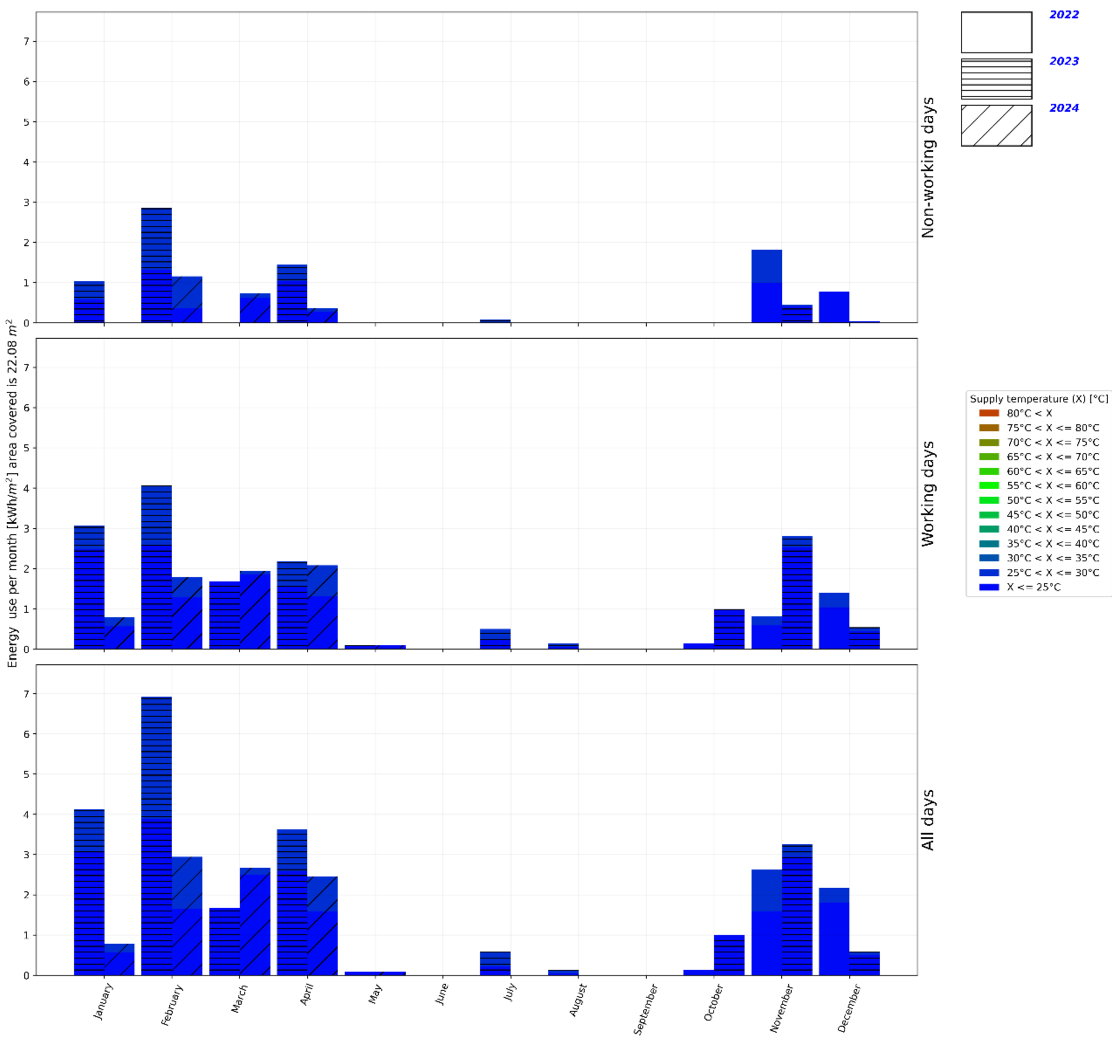

Figure 2.104 Energy use per month HiLo heating zone 2

2.2.2.4.3 Zone 3-Z3

Zone 3 is much bigger the Zone 1 and Zone 2 and is 93.98 m². Zone 3 consists of more than one area but is an open space. As for the other systems energy use is significantly higher in colder months, indicating natural outdoor driven heating demand. Seasonal pattern which will allow to use more waste heat in the winter with no demand in the summer. The energy demand is seasonal as seen in Figure 2.105 and Figure 2.106

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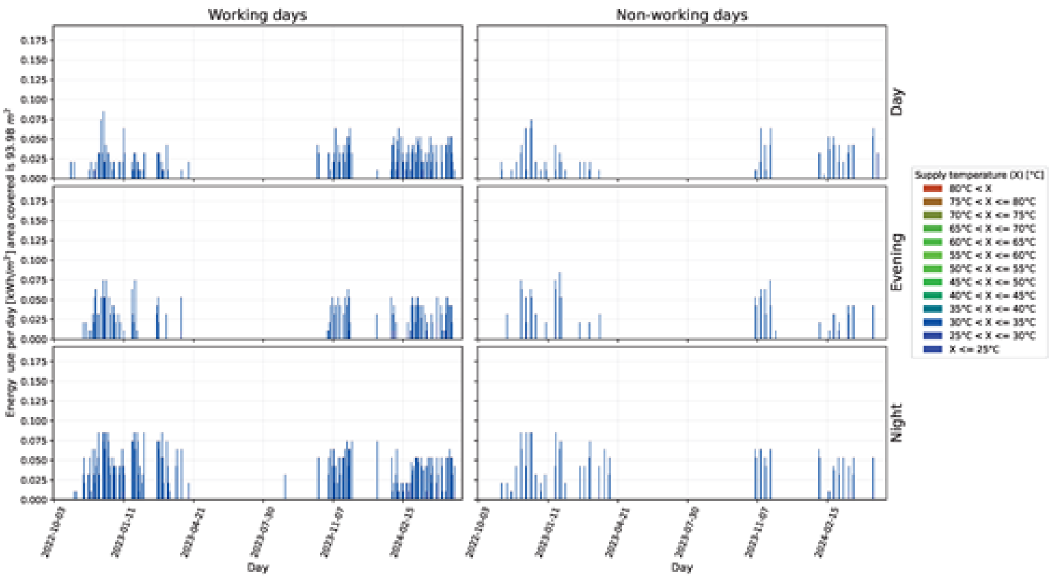

Figure 2.105 Energy per day Zone 3 HiLo

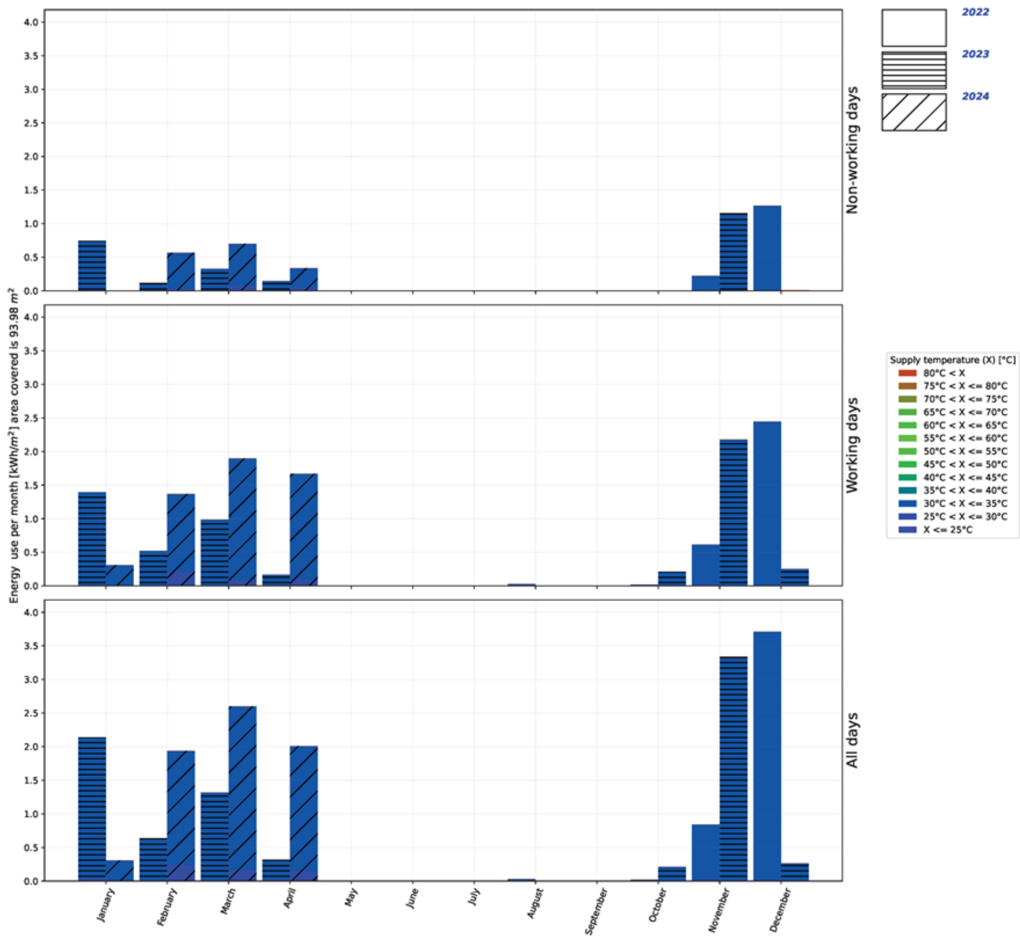

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Figure 2.106 Energy per month Zone 3 HiLo kWh/m²

2.2.2.4.4 Zone 4-Z4

Zone 4 is the smallest of the entire zones its size is only 6 m². Not relevant. The energy demand is seasonal as seen by the two figures Figure 2.107 and Figure 2.108. Zone 4 is only a room for technical stuff.

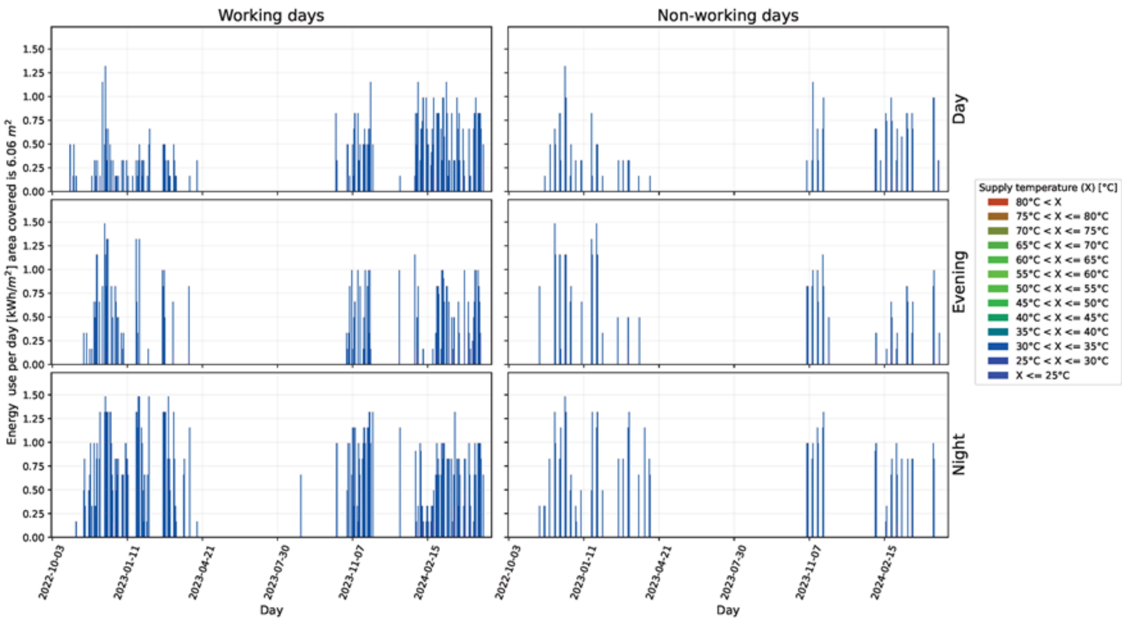

Figure 2.107 Energy use per day Zone 4 HiLo

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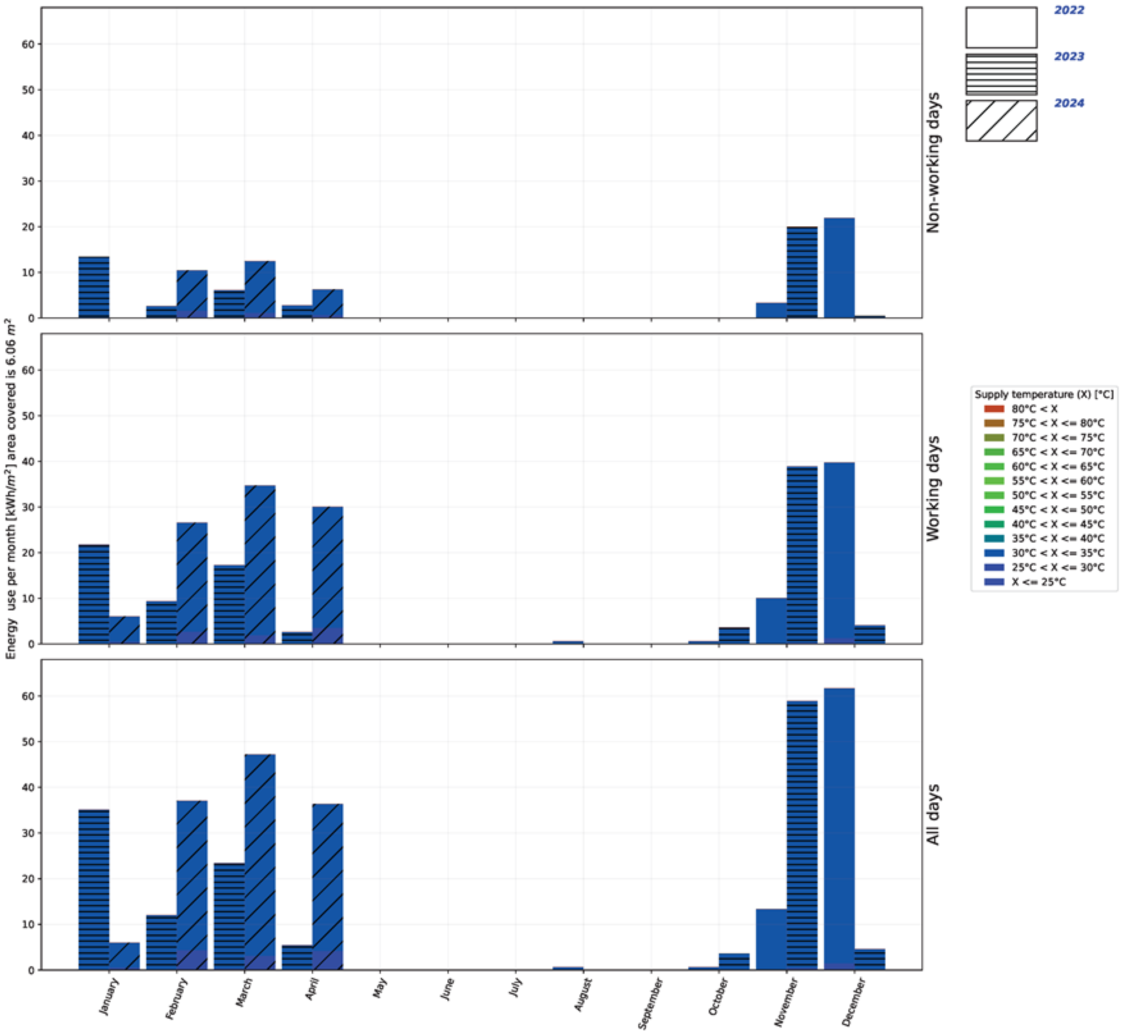

Figure 2.108 Energy per month Zone 4 HiLo

2.2.2.4.5 Ventilation

The ventilation system is only needed for working days and not active on non-working days. This can be seen in Figure 2.109. Figure 2.110Figure shows that the demand for energy for the ventilation system in the summer.

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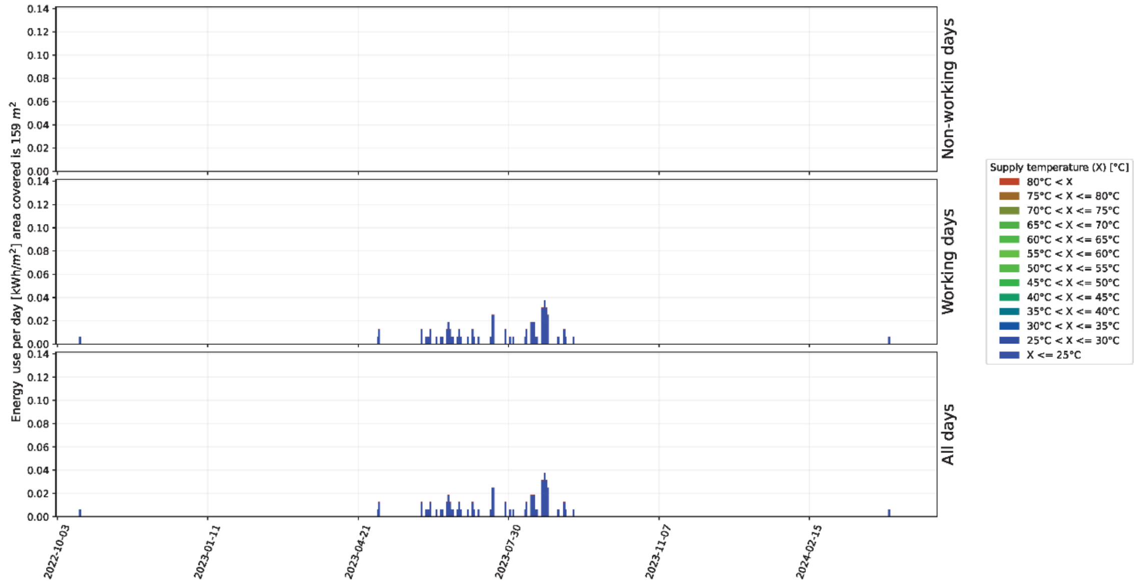

Figure 2.109 energy per day Hilo subsystem ventilation HiLo

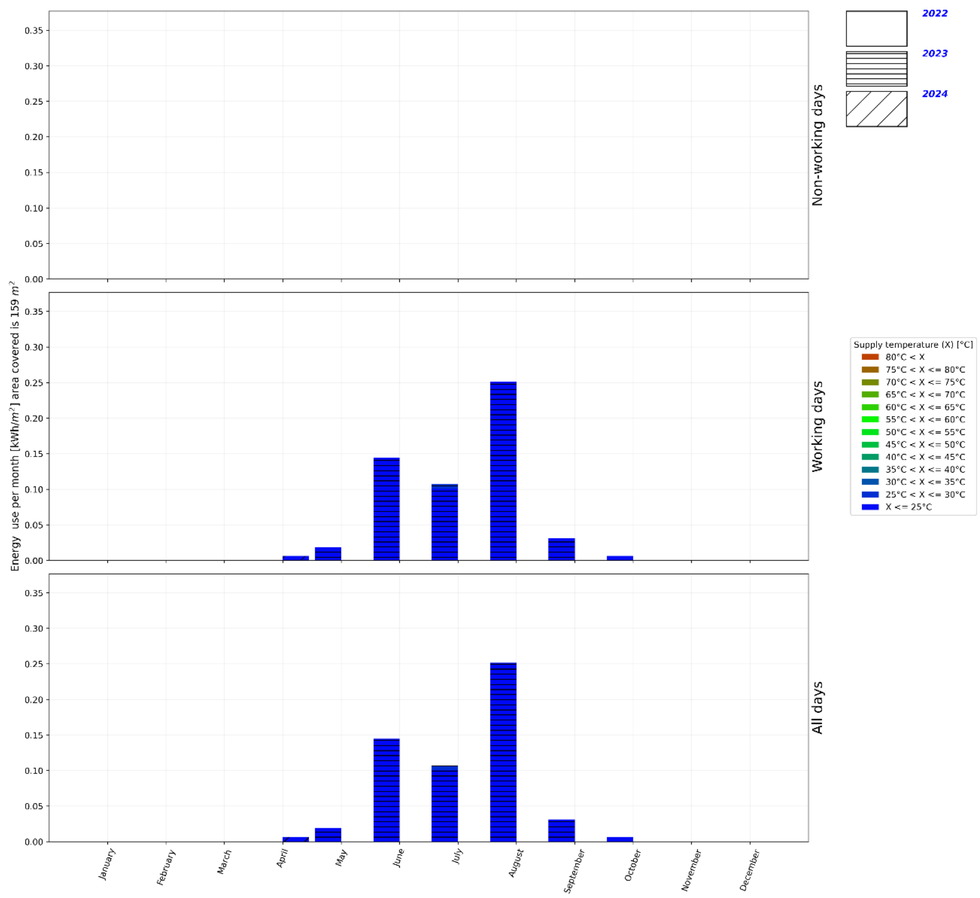

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Figure 2.110 Energy demand for ventilation HiLo

2.2.3 Discussion

As shown in the result section the units in NEST show great potential for using waste heat for heating. Even if the demand is only seasonal due to the heating system being of the 4th generation, they need a much lower supply temperature. Also, the ventilation system does not need a high supply temperature as well. The low supply temperature needs are suitable to be used with waste heat recovery. A drawback is that the demand for waste heat is seasonal as there is no demand for heat in the summer. What really is suitable, is that the waste heat can be supplied directly to the MTE grid which makes it very scalable and easier to deploy. Moreover, through HEATWISE, switching from the current air-cooled to a newly developed on-chip liquid cooling system from project partner ZutaCore enables the waste heat to reach higher temperatures. This system is designed for optimum heat recovery. The recovered heat reaches temperatures of up to 70°C. The heat could be thus used partially and in conjunction with a heat pump (to boost to the HTE) for the high-temperature network of NEST and used to power the residents' showers, for example.

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2.3 TOFAS Pilot

Figure 2.111: Bursa TOFAS car factory facility with the location of the IT office marked.

TOFAŞ manufactures both passenger cars and light commercial vehicles. Headquartered in İstanbul, TOFAŞ carries out its production activities in its factory in Bursa, established in 1968 on an area of approximately 1 million m², of which 350,000 m² is closed. It is one of the biggest automakers in the sector with its 7,000 employees and 450,000 vehicles annual production capacity. TOFAŞ manufactures for the Fiat, Citroën, Peugeot, Opel, Vauxhall, and RAM brands in Bursa (Production has been diversified in different time periods), which has achieved for it the "Gold Level" within the scope of the WCM-World Class Manufacturing Program that is implemented in the 175 plants within the framework of **Stellantis**. TOFAŞ plays a leading role in Turkish automotive sector; it conducts sales and after sales operations for the Fiat, Alfa Romeo, Lancia, Jeep, Ferrari, and Maserati brands in Türkiye. It has presented world-famous examples of its pioneering "Fiat Yol Arkadasim" and R&D studies to both the European and World market.

TOFAŞ, a leader in the Turkish automotive industry, is part of the HEATWISE consortium within the scope of the pilot region. Performance tests on cooling will be carried out thanks to the ZutaCore heat cooling solution, which is planned to be located in TOFAŞ datacenter. With the HEATWISE project, which will last for 3 years, studies on the reuse of idle energy will also be carried out.

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2.3.1 Pilot description

2.3.1.1 General building description

Figure 2.112: Main building of the TOFAS car factory, the image shows the IT office part in the ground floor (see Figure 2.111 for location details).

The IT office part, which will be the focus point of this investigation contains a combination of open-office with cubicles, along with some individual offices, several meeting rooms, and some toilet facilities. The layout can be seen in Figure 2.113. This part of the building is 980 m².

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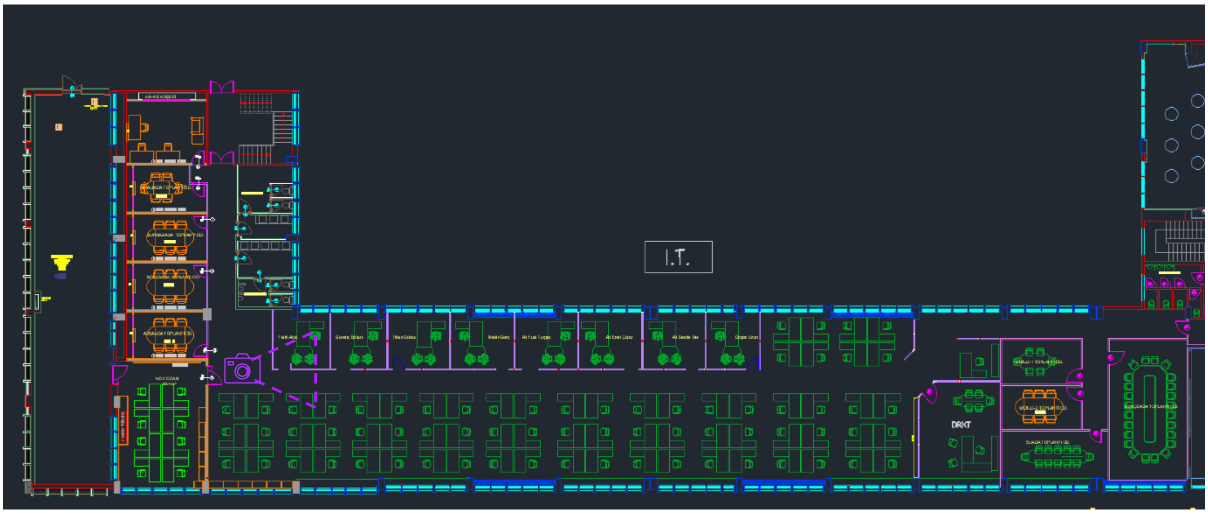

Figure 2.113: Floor plan of the IT office (the picture location of Figure 2.114 is marked with the purple camera and view cone).

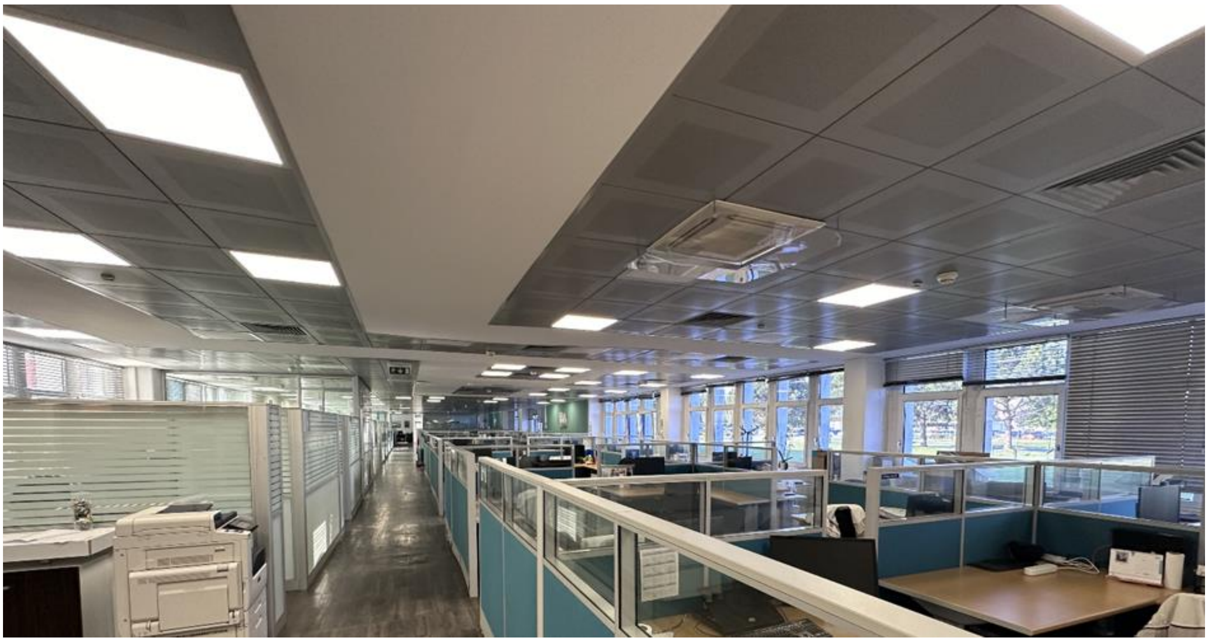

Figure 2.114: Main hall of the IT office (see Figure 2.113 for the image location).

2.3.1.2 System description

The main heat source for the IT office is a centrally located boiler. The boiler heats the water up to a supply temperature of 90°C to be able to supply many different systems with different requirements.

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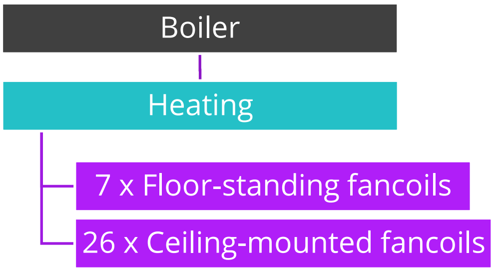

Figure 2.115: System overview of the TOFAS pilot systems using hot water.

The technical systems in the TOFAŞ IT office contains an air heating-based circuit using fan coils. The fan coil circuit is comprised of several floor-standing and ceiling-mounted fan coil units, the ceiling-mounted fan coils cover the majority of the open office (right side of the office), illustrated in Figure 2.116, while the floor-standing fan coils cover the other part of the open-office and many of the meeting rooms (left side of the office), illustrated in Figure 2.117. The fan coils are used for both heating and cooling, but in this case, only the heating part is discussed.

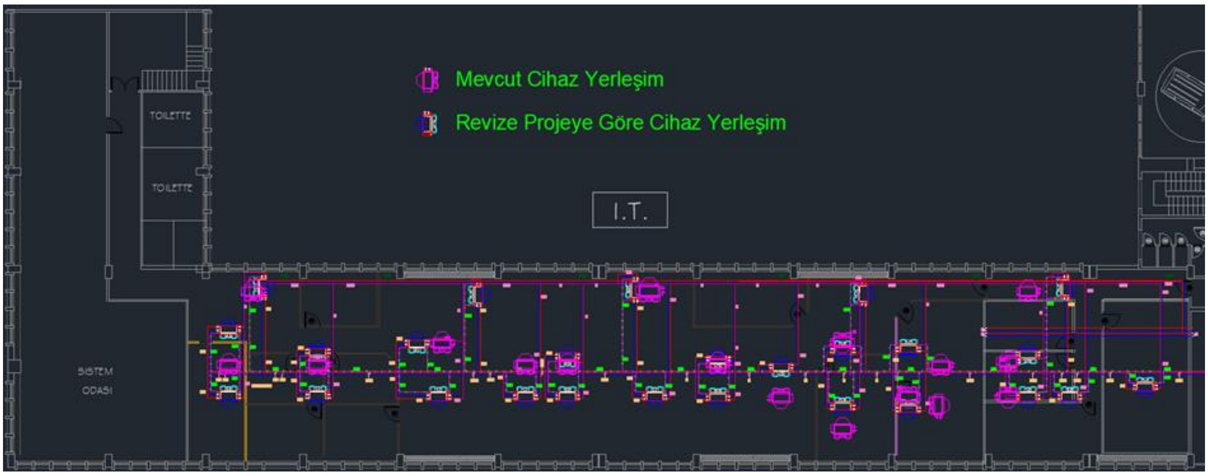

Figure 2.116: Old part of the IT office (with the ceiling-mounted fan coil system).

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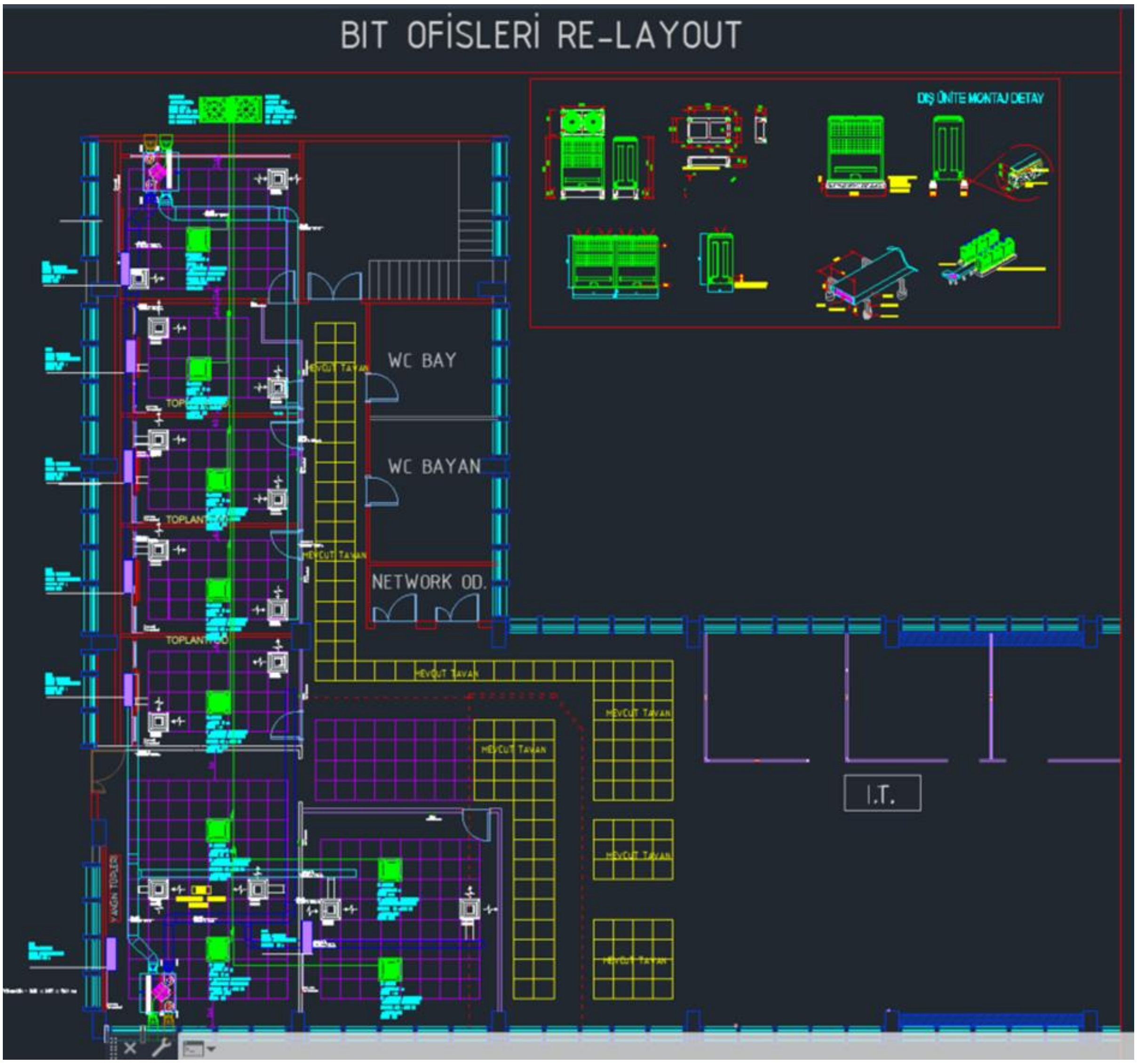

Figure 2.117: New part of the IT office (with the floor-standing fan coil system, in bright purple, and AC system, in green).

The fan coil circuit (both floor-standing and ceiling-mounted) is supplied with hot water from the central boiler, where the supply temperature, when reaching the IT office, has been lowered to 50°C for safety reasons, and has an expected return temperature after the fan coil circuit of 30°C. The hot water is supplied to a heating coil located inside the fan coil unit, as illustrated for the ceiling-mounted fan coil in Figure 2.118. The fan coils are controlled to reach a setpoint temperature in the rooms 22-24°C throughout the year. They are normally only available during the working hours, unless adjusted by the operational personnel.

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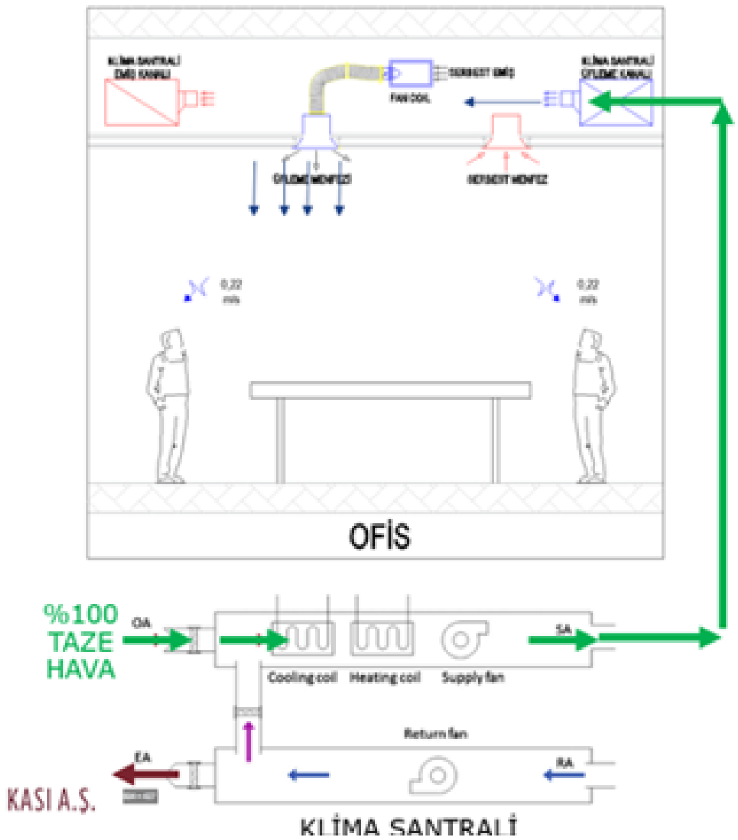

Figure 2.118: Illustration of the fan coil principle applied in the IT office.

For ventilation in the new part of the IT office, several AC units are installed. These are mainly used for ventilation and cooling. They are therefore not of interest in this case.

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2.3.2 Results

In this pilot, only data on the total heating use for the fan coils was available, it is shown in Figure 2.119. There is a relatively stable energy use over the heating period (December to March), a decline in the use during the transitions period (April and November), and no energy use during the cooling period (May to October). This means that there is a significant need during the heating season, but also that it is only half the year where there is a need. Coupled with the knowledge that the system has an expected supply temperature of 50°C, means that there is a potential for utilizing the waste heat in parts of the year.

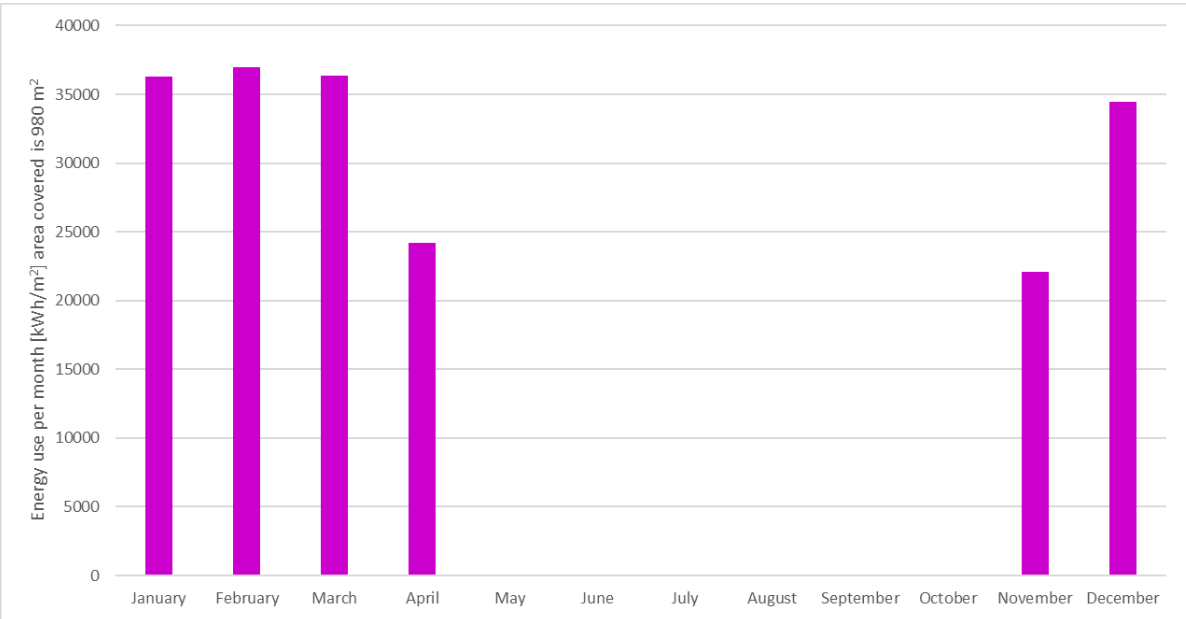

Figure 2.119: Monthly energy use in 2023 for the IT office.

2.3.3 Discussion

The result fit well with the knowledge from the AAU pilot in section 2.1, as the waste heat temperature potential between using the main supply point (the boiler) and the actual system temperature (the fan coil system) has a large difference. It should also be noted that even though the actual supply temperature is not measured, it was found in section 2.1 that using a design value means underestimating the potential, thus in this case, the potential is expected to be as stated or better.

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2.4 PSNC Pilot

PSNC provides computing and networking infrastructure for science and industry. It operates a supercomputing data center, which applies the Direct Liquid Cooling technology for its largest HPC systems. The waste heat from the data center is currently re-used in the heating system of offices for more than 500 people located in the main building presented in Figure 2.120.

Figure 2.120: Picture of the PSNC pilot building.

The front part contains offices and laboratories. There are two renewable energy source installations: 20kWp offgrid and 50kWp ongrid PV system located on the roof. Among the laboratories there is a micro data center with air-based cooling and a smaller testbed that consists of around 20 heterogeneous nodes. Its maximum power exceeds 10kW and has an average energy use of 65 MWh. This testbed is directly connected to the offgrid PV system. It is used for development and validation of project results. The main data center is located in the building without windows at the back of the main office building. The total power usage of the building exceeds 2MW. The building is located nearby a larger campus of Poznań University of Technology. Apart from the main building, PSNC also have buildings in other locations, including a building in Poznań with a secondary data center that uses air cooling. The goal of the pilot is to study further development of waste heat re-use strategies, including a recovery of the excess heat from the main data center in external buildings and an analysis of the heat re-use potential in other PSNC data centers.

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Another goal is to analyse dynamic management of the data center and building based on the heat and electricity demand and costs.

2.4.1 System description

The heat source for the office part of the building is heat pumps in a VRF system with a glycol loop, which can be seen in Figure 2.121. The glycol loop has a minimum temperature of 10°C in winter and a maximum temperature of 40°C in summer. In heating mode, the temperature of the medium in the glycol loop is raised through a heat exchanger between it and the waste heat from the cooling of the servers in the adjacent server room. In the summer cooling mode, the heat is dissipated via a glycol system to dry-coolers equipped with an adiabatic system located on the roof. A 45% glycol solution circulates as the working fluid in the glycol loop supplying the external units. A heat exchanger with parameters of 12/9°C on the primary side (waste heat) and 10/7°C on the secondary side (VRF main loop) is used between the glycol loop and the waste heat system. Three-way valves are installed on the glycol loop supplying the compressor units to direct the flow to the waste heat exchanger when heating of the VRF system is required or to bypass it when cooling is needed.

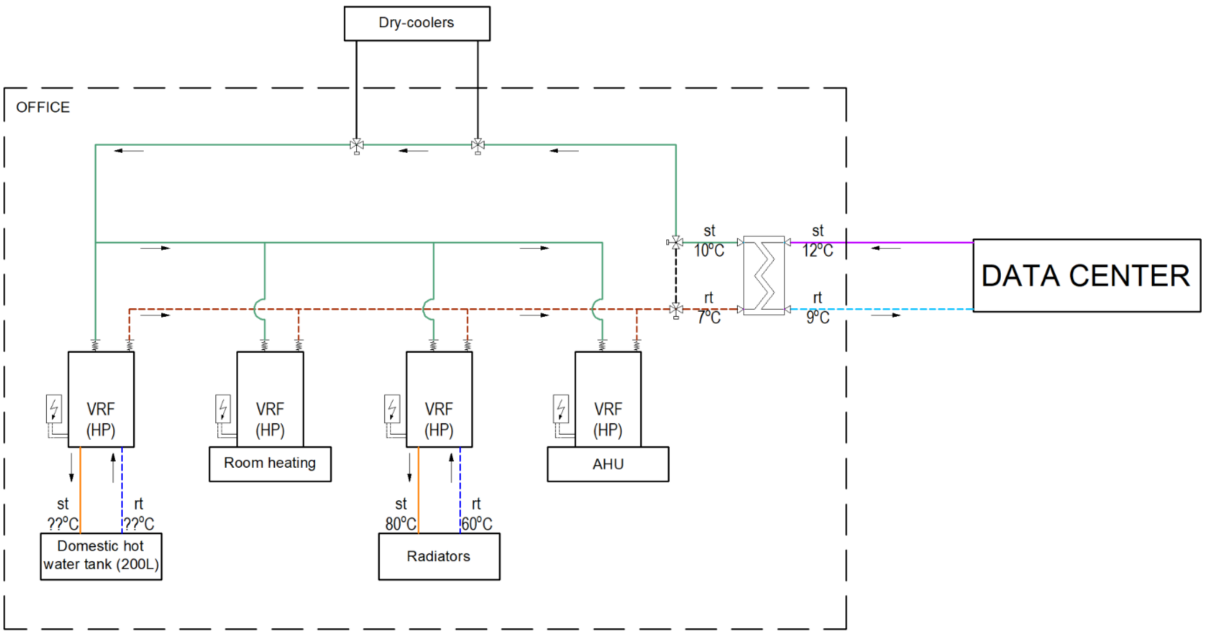

Figure 2.121: Schematic of heat recovery including the glycol loop feeding the VRF system's compressor units – heating mode. (brown/green lines – glycol, orange/navy blue lines- water, purple/blue line – waste heat)

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The total heat load, according to the project documentation, is 412 kW (at -18°C). The total electrical power of the installed VRF system compressors is 288 kW for the heating period.

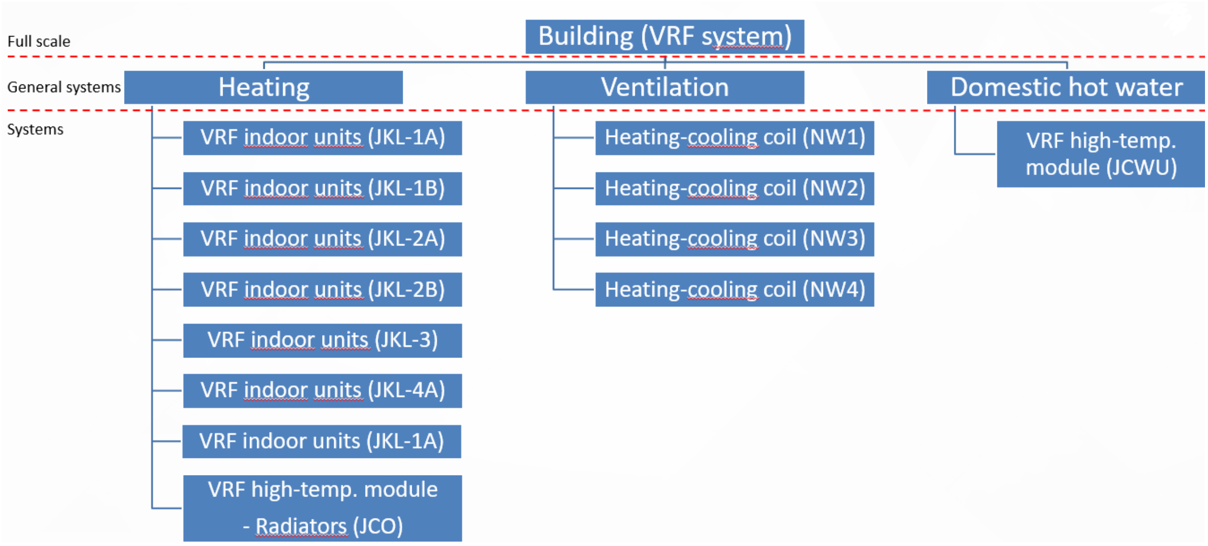

Figure 2.122: System overview for the PSNC pilot of the technical systems using hot water.

2.4.1.1 Heating Systems

Rooms equipped with VRF systems are heated using ducted or cassette indoor units ("Room heating" in Figure 2.122). These indoor units are connected to compressor units located in the technical room on level -1 through a refrigerant piping system. The connection is facilitated by intermediate heat recovery units, allowing the simultaneous heating and cooling of different groups of rooms within the same system.

In a VRF system, the refrigerant condensing temperature in the condenser of the unit located in the room is approximately 40-60°C. This parameter is an internal setting of the device and cannot be adjusted from the Building Management System (BMS). To improve the efficiency (COP) of this system, efforts should be focused on raising the temperature in the glycol loop.

Rooms not directly equipped with VRF indoor units, such as restrooms, changing rooms, showers, and technical rooms, are heated using a water radiator system ("Radiators" in Figure 2.122). The heating medium in this system, with supply and return temperatures of 80/60°C, is prepared by three dedicated external VRF units. Plate radiators equipped with valves and thermostatic heads are used as heat emitters in these rooms. The same

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heating water also supplies an air curtain that protects the main entrance of the building from the courtyard side.

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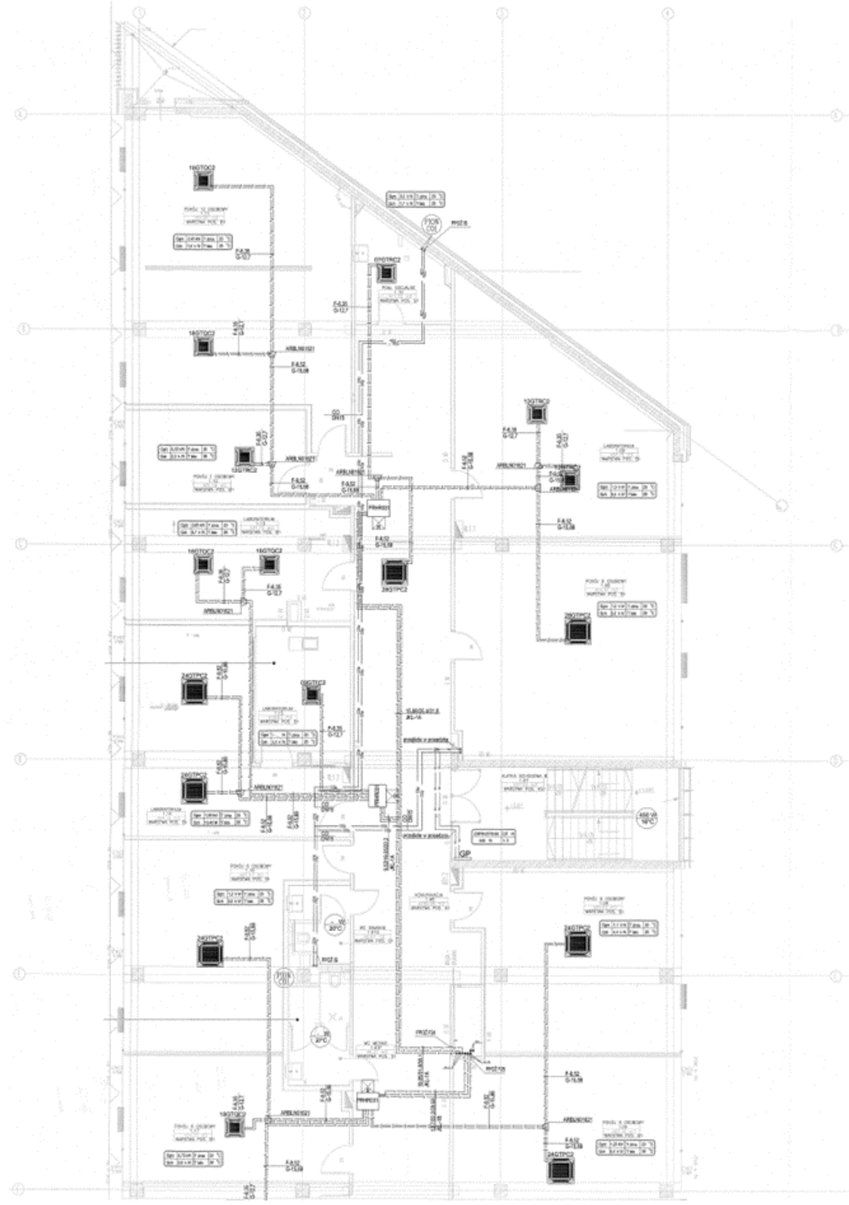

Figure 2.123: Sectional floorplan of an example of the heating system for the office part of the building.

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2.4.1.2 Ventilation System

The heating of ventilation air in the air handling units is achieved using dedicated external VRF units. Heat exchangers (heating-cooling coils) directly connected to the compressor units in the VRF system are used for this purpose. The building is equipped with a mechanical supply and exhaust ventilation system for office, seminar, and social rooms. The system is divided into four zones, each served by separate air handling units.

In addition, sanitary and technical rooms are equipped with roof exhaust ventilation lines.

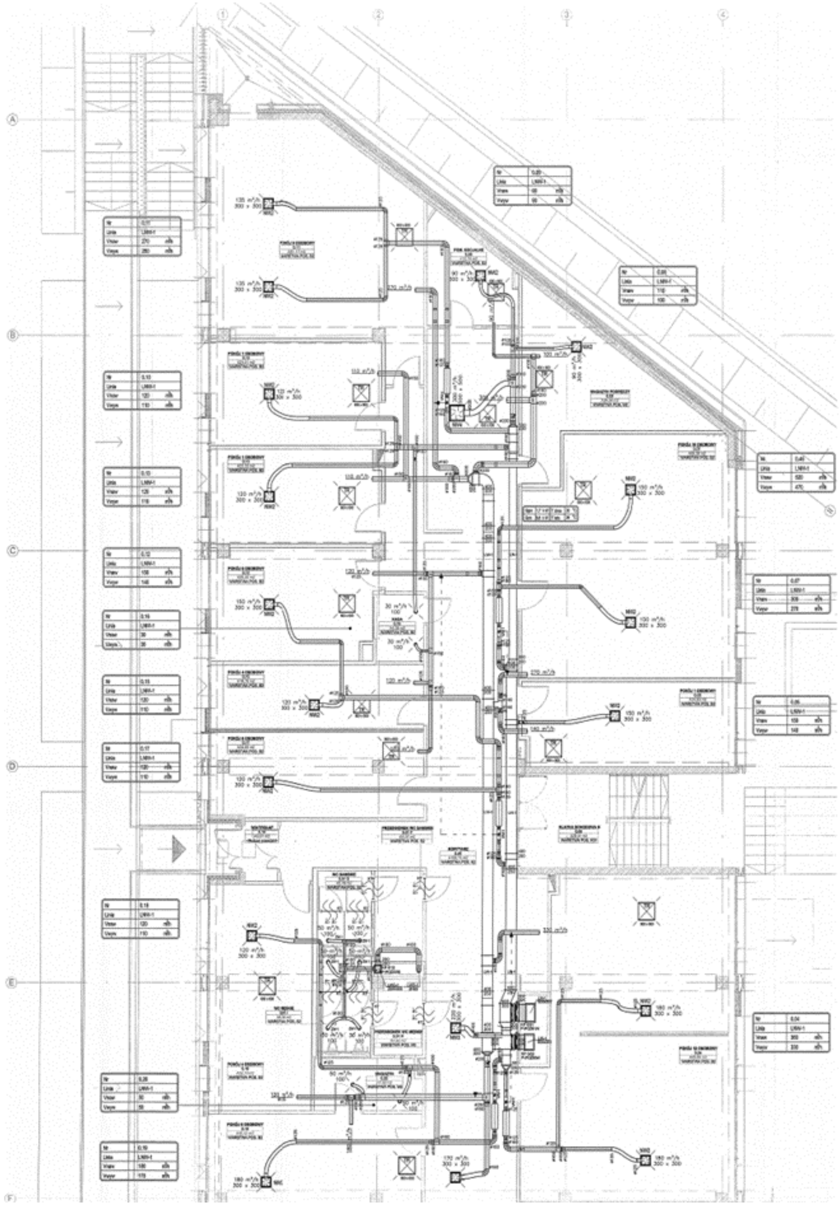

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Figure 2.124: Sectional floorplan of an example of the mechanical ventilation system for the office part of the building.

2.4.1.3 Domestic hot water system

Domestic hot water is prepared in a 200-liter storage tank, which is fed by a heating medium obtained from a dedicated VRF outdoor unit.

2.4.2 Results

For the energy use of the systems, only the total electric energy for all the systems was available, this means that it is difficult to evaluate the potential for using waste heat directly (not “upgraded” in temperature as is currently done). This is because it is not possible to separate which energy use is for low / medium / high supply temperatures supply systems, and during the cooling period, which energy is for cooling and which is for DHW.

For the heating systems, it is possible to speculate that the “room heating” VRF systems have some potential for using waste heat due to their necessary supply temperature of 40-60°C.Rhe radiators, on the other hand, will have more difficulty in using it, as they were seen to need 60-80°C supply temperatures.

For the ventilation systems, there is not an available design supply temperature, but taking offset in the measured temperatures form the AAU pilot, it is possible to speculate that they could have a high potential, as they were found to not need more than 50°C, and generally use their energy at around 30-40°C, as seen in section 2.1.2.3.

For the DHW system, there is a water tank, which acts as a buffer, this means that the supply temperature should be a bit higher than the expected temperature of the DHW out of the tank. An assumption could be that the supply temperature should be 5°C higher than the desired temperature of the DHW, and using the higher temperatures measured for the AAU pilot of 60°C, as seen in Figure 2.18, this would give necessary supply temperatures of 65°C, meaning that there would be some limited potential for using waste heat.

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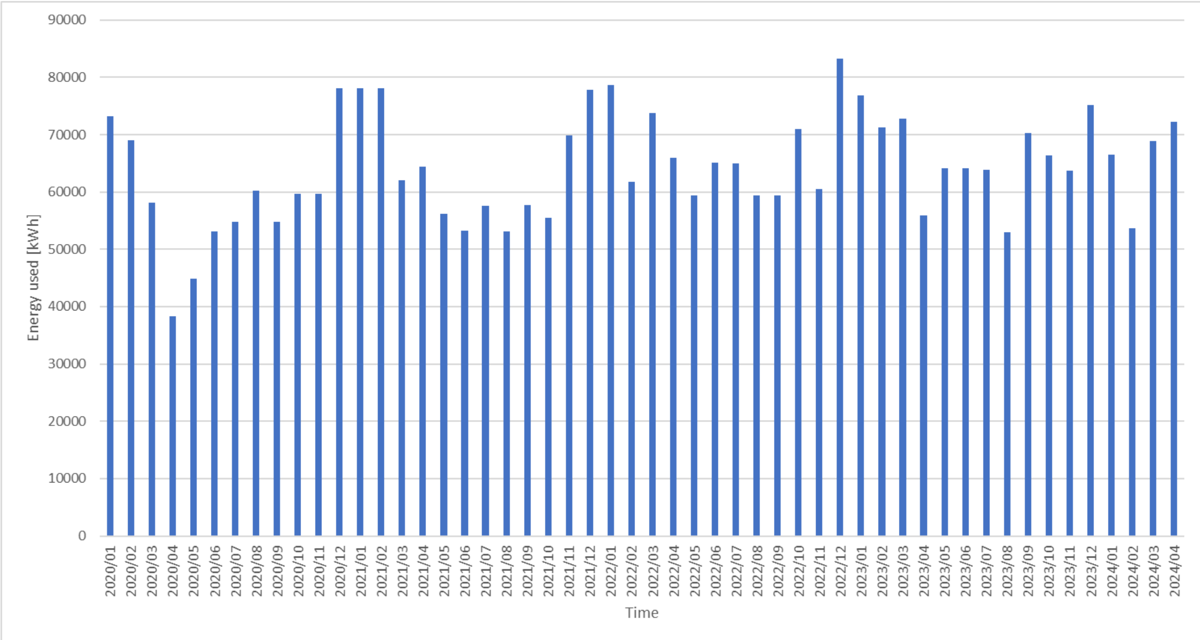

Figure 2.125: Energy (electricity) used by all systems in each month.

2.4.3 Discussion

In this pilot, despite being a highly modern and advanced building, with a highly advanced heating system already using waste heat "upgraded" by a heat pump, it does not contain the specific measurements of individual energy per system along with the supply temperatures. But as there are design or operational set values available for the system, it is possible to speculate on the potential. If the energy use had been available per system or per system type, it may have been possible to give a better estimate of the actual potential.

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3 Upscaling from building level to local area level

In the case that the waste heat recovered from the Data Centre exceeds the demand from the building, it is crucial to have an alternative application for such heat to avoid dumping it into the environment. However, selecting the optimal external application will be heavily dependent on the particularities of each data centre and its surroundings. Two of the main aspects to be considered when evaluating the feasibility of an external waste heat application are the amount of heat available after its internal use, in both quantity and quality (referring to its supply temperature), and the location and measured heat demand of the nearby buildings. This information could open the panorama and facilitate the selection of a feasible solution for the problem.

3.1 Background and Considerations

When defining the optimal application for excess waste heat, it would mostly depend on the temperature range at which the heat can be recovered and utilized. As shown in Table 3.1, different case scenarios around the globe have found a particular application according to the temperature at which the heat was recovered. It is noticeable that in most of the application for cases when the heat comes at around 70°C or below, the selected application is to couple it with a district heating network.

Table 3.1 Examples of applications for recovered waste heat from Data Centres

Temperature range	Type/media of cooling	End-use	Reference
~90°C	Direct free air cooling	Generation of electricity	Sweden (Wahlroos, Pärssinen, Rinne, Syri, & Manner, 2018)
	Air-cooled condenser	Desalination process	Moss Landing, California (Miller, Data Centers That Recycle Waste Heat, 2010)
~70°C	CRAH cooling	District Heating	Helsinki, Finland (Wahlroos, Pärssinen, Rinne, Syri, & Manner, 2018)

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	Two-Phase cooling	Primary system coolant	Stockholm Data Parks (Stockholm exergi; Stockholms stad; ELLEVIO; STOKAB, 2020)
~25-50°C	Direct air cooling	District heating with Heat pumps	Northern Europe (Wahlroos, Pärssinen, Rinne, Syri, & Manner, 2018)
	Water with heat exchanger	District heating, greenhouse, pool	Equinix in Saint-Denis, France (Récupération de la chaleur fatale du data center Equinix par la Ville de Saint-Denis, n.d.)
	Air with heat exchanger	District heating	Bahnhof Thule in Stockholm, Sweden (Miller, Telehouse to Heat Homes at Docklands, 2009)

3.2 Methodology

To precisely assess the economic feasibility of utilizing the surplus of waste heat recovered on nearby applications will require a detailed case-by-case evaluation of the application. Hence, for the purposes of this report, a simplified methodology has been developed to obtain an initial estimation of the heat that would be necessary to reasonably implement the recovered heat into a district heating network.

3.2.1 Feasibility analysis

The estimation of the amount of heat that would be needed to make economically feasible the integration of the waste heat from the data center will be dependent on different factors, some of which are going to be considered as parameters to be user-defined and other are fixed form the data that has been gathered.

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Firstly, the Return on Investment, a user-defined parameter, will determine the payback period that is expected to have for the integration. It is defined by the equation:

$$ROI = \frac{CAPEX}{SAVINGS}$$

The ROI accounts for the capital cost, or CAPEX, which is the necessary investment for the equipment and connection materials. This value is heavily dependent on the pilot since the associated costs encompass the piping necessary to connect the waste heat to the selected district heating application and the additional equipment, mainly heat pumps, to match the temperature supplied by the network. Therefore, for the purpose of this simplified calculation, the CAPEX is expected as another user-defined parameter.

$$CAPEX = Piping + HeatPump$$

On the other hand, to compute the financial savings that the integration could bring, the total analysis period (the same as the ROI) and the specific cost of fuel (accounting for the region and the end-use tariffs) in net present value are what determine the total amount.

$$SAVINGS = \ Q_{WH}\ (ROI)(Cost\ of\ fuel)(1 + Inflation\ rate)^{ROI}$$

Moreover, it is important to also account for the transmission losses associated with the distance between the data center and the integration point to the DH network. Since this value is strongly dependent on the temperatures in the pipe, the ground temperature, and the pipe's insulation, it can vary significantly from case to case. Therefore, for this calculation, these losses are estimated at 219 kWh/m per year, based on a previous calculation from the Central Agricultural Raw Materials Marketing and Energy Network (*Centrale Agrar-Rohstoff Marketing- und Energie-Netzwerk [German]*) in Bavaria, Germany (C.A.R.M.E.N. Merkblatt, 2009).

$$Q_{WH} = Q_{recovered} - Q_{losses}$$

$$Q_{losses} = (distance)(q_{loss})$$

After considering all the pertinent information, it is possible to obtain a simplified equation to estimate the amount of heat to be recovered to achieve an economically feasible integration of the excess waste heat to a DH application.

$$Q_{recovered} = \frac{CAPEX}{ROI^2(Cost\ of\ fuel)(1 + Inflation\ rate)^{ROI}} + (distance)(q_{loss})$$

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3.2.2 Information and assumptions

For the calculation of the feasibility analysis, annual-averaged energy prices for natural gas and electricity under different domestic and industrial consumption tariffs were retrieved from Eurostat for Denmark, Poland and Türkiye (Eurostat A, 2024) (Eurostat B, 2024) (Eurostat C, 2024) (Eurostat D, 2024). For Switzerland, the cost of natural gas and electricity according to the tariff was obtained from the official website of the Swiss Federal Administration (Eidgenössisches Departement für Wirtschaft, Bildung und Forschung WBF A, 2017) (Eidgenössisches Departement für Wirtschaft, Bildung und Forschung WBF B, 2017). The fuel prices per country are available in **Error! Reference source not found.** and **Error! Reference source not found.** in the Annex. The 5-year average inflation rate for the four countries where the pilots are located, extracted from Eurostat, can also be found in the Annex in **Error! Reference source not found.**.

For the calculation of the feasibility analysis, annual-averaged energy prices for natural gas and electricity under different domestic and industrial consumption tariffs were retrieved from Eurostat for Denmark, Poland and Türkiye (Eurostat A, 2024) (Eurostat B, 2024) (Eurostat C, 2024) (Eurostat D, 2024). For Switzerland, the cost of natural gas and electricity according to the tariff was obtained from the official website of the Swiss Federal Administration (Eidgenössisches Departement für Wirtschaft, Bildung und Forschung WBF A, 2017) (Eidgenössisches Departement für Wirtschaft, Bildung und Forschung WBF B, 2017). The fuel prices per country are available in **Error! Reference source not found.** and **Error! Reference source not found.** in the Annex. The 5-year average inflation rate for the four countries where the pilots are located, extracted from Eurostat, can also be found in the Annex in **Error! Reference source not found.**. The parameters to be determined by the user include the ROI, CAPEX, and distance. The ROI should be defined according to the investor's requirements. The CAPEX and distance depend on the future location of the heat delivery. The CAPEX, as previously stated, will account for the investment cost of the pipes as well as any equipment needed to increase the output temperature from the data center to meet the building's requirements. This parameter is influenced by the difference in temperature and the distance between the data center and the connection point.

3.2.3 Calculation tool

A calculation tool is developed to provide a quick estimation of the heat to be recovered, based on the methodology previously defined. As an illustrative example, a comparative

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analysis of heat to recovery between the four countries, for two case scenarios is carried out and presented in Figure 3.1. The first scenario has higher heat to recover to reach the specified ROI of 5 years replacing Natural Gas, in comparison to the longer ROI of 10 years from the second scenario replacing Electricity. Moreover, the considered capital costs and the connection distance are also larger in the first scenario than in the second. This tool could be useful in evaluating the feasibility of the connection between a DC and a future heating grid.

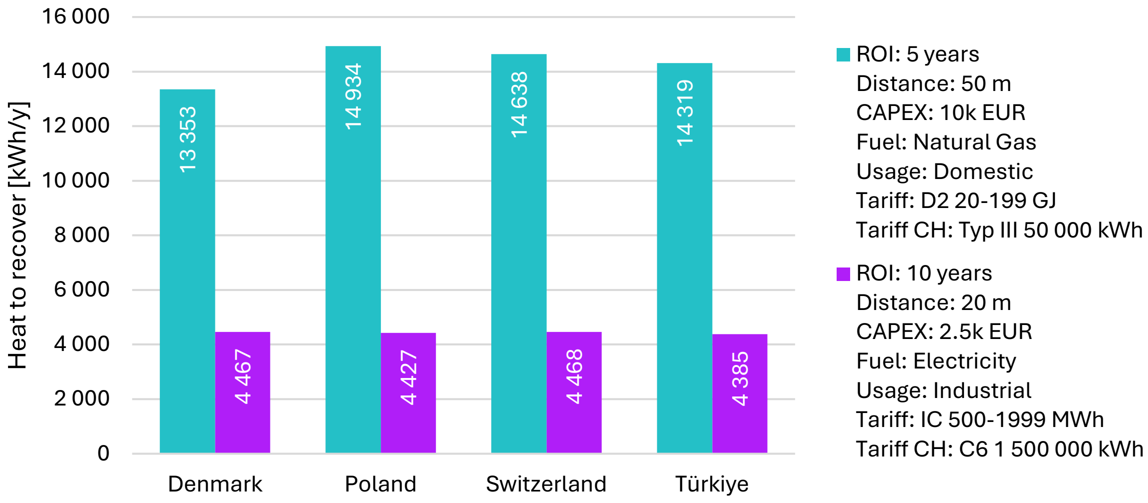

Figure 3.1 Comparative analysis on the necessary recovered waste heat from the different pilots under the same integration conditions to the District Heating network for it to fulfill the chosen requirements.

3.3 Pilot-specific potential applications

Potential beneficiaries for the excess waste heat have been identified for each pilot. However, in most cases, district heating systems are the primary beneficiaries due to their fixed heat demand in terms of both quantity and temperature, making them a simpler and more reliable option. Nevertheless, a thorough evaluation of the potential applications for each of the pilots is conducted and presented in this report.

3.3.1 EMPA, Switzerland

The recently installed micro data center (mDC) in the NEST research building at EMPA is part of the ECO-Qube project. This international EU research project investigates the integration of data centers into building systems for energy-efficient operation. NEST is a

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sustainable modular demonstrator building with various subsystems, including batteries, heat pumps, and PV installations.

As part of the ECO-Qube project, and as shown in Figure 3.2, a prototype cooling system with zonal cooling and waste heat valorization capabilities has been designed and deployed in EMPA's pilot data center. The cooling system is directly integrated into EMPA/NEST's cooling and heating systems.

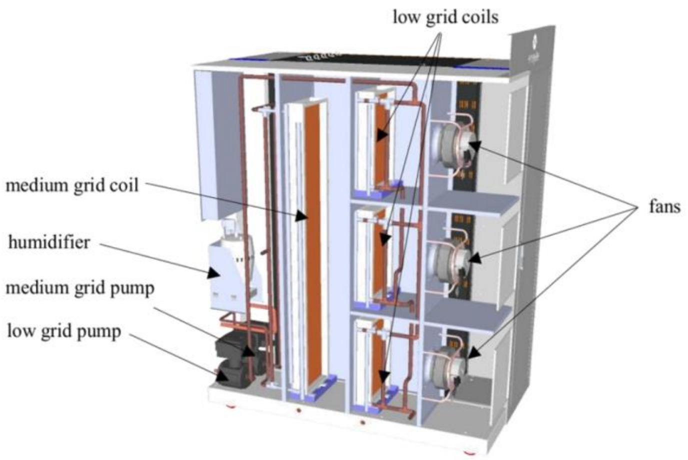

Figure 3.2 Zonal Cooling Concept of the ECO-Qube Data Center at EMPA

The energy supplier in Dübendorf is the company Glattwerk. Glattwerk has initiated a project to develop a low-energy neighborhood with houses and offices at Giessenarea (Glattwerk, n.d.), located 400 meters from the NEST building. For this neighborhood, Glattwerk has created a heating concept involving the extraction of heat from the smooth and brought to the corresponding temperature level by means of heat exchangers and heat pumps and distributed. Gas heating is also provided for peak load coverage and redundancy. Due to its proximity to the NEST building, the extra waste heat from the micro data center (mDC) could potentially be sold to this small district heating system. Although specific temperature information is not available, it can be assumed that the district heating system operates at a low temperature, given the neighborhood's focus on low-energy buildings.

Moreover, through HEATWISE, the cooling system will be switched from the current air-cooled to a newly developed on-chip liquid cooling system from Israeli project partner ZutaCore. This cooling system is designed for optimum heat recovery. The recovered heat reaches temperatures of up to 70°C. The heat could thus be used partially and in conjunction with a heat pump (to boost to the HTE) for the high-temperature network of

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NEST and used to power the residents' showers, for example, or be supplied directly for the medium temperature network, supplying the space heating and heating coils in ventilation.

3.3.2 TOFAS, Turkey

The pilot at TOFAS utilizes Huawei FusionCube racks for database storage. The current cooling system of the racks is air-based but will be switched to ZutaCore's hybrid cooling solution. This type of cooling system will allow for higher output temperatures that can be utilized within the car factory. Currently, the energy consumption of natural gas is 463,607 GJ (TOFAS, 2022). By integrating heat recovery from the server room, energy consumption could be reduced.

At the factory, waste heat recovery projects have already been implemented within the paint workshop. Therefore, it can be assumed that some infrastructure needed for heat recovery already exists in the factory, which can help reduce the cost of heat recovery from the racks.

Alternatively, if the pilot prefers to sell the waste heat, partnering with the city could be a viable solution. The Bursa Sustainable Energy and Climate Change Adaptation Plan (BUSECAP) of 2017 proposed a district heating project aimed at heating 100,000 dwellings between 2020 and 2030 (BURSA METROPOLITAN MUNICIPALITY, 2017). Therefore, the waste heat could be sold to the Metropolitan Municipalities responsible for district heating. However, this plan may be more costly due to the need to construct pipelines between TOFA and the district heating network.

3.3.3 PSNC, Poland

The data center in Poznań is using Direct Liquid Cooling (DLC) to remove heat directly from components like the CPU, GPU, and memory, eliminating the need for air as a heat transmission medium. This method allows the cooling liquid to operate at relatively high temperatures, up to 35-45°C. For now, the heat waste is directly used to heat the PSNC main building.

The PSNC main building, where over 400 employees work, is located near the data center and includes conference rooms, research infrastructure, laboratories, and offices. The PSNC office building is not connected to the district heating system (DHS) due to its self-sufficiency in domestic hot water and central heating, achieved through waste heat from

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the data center. The waste heat could also largely cover the consumption of the Poznań University of Technology (PUT) campus, with any surplus potentially transferred to Veolia's DHS.

Near the campus is located a district heating network. The owner and the operator of the district heating system is Veolia Energia Poznań S.A operating within the Veolia group. The district heating provides heating water between 125°C / 60°C in the heating season and between 70°C / 46°C in the summer season. The district heating system is primarily supplied by the EC-II Karolin heat and power plant, which has an available heat capacity of 835 MW. This plant is supported by three gas-fired boiler houses with a total capacity of 23.6 MW for peak demands.

Figure 3.3 Veolia's district heating network

A previous project financed by Horizon 2020 named RENergetic explored different scenarios to use waste heat more widely. Two scenarios were evaluated: a direct linkage PSNC to Veolia's district heating network and a linkage from PSNC through PUT to Veolia (Górzeński, 2022).

The direct linkage assumes the sale of waste heat directly to the Veolia district heating network. Depending on the coolant temperature, this process can be seasonal or year-round. This scenario requires increasing the supply water temperature using heat pumps (the municipal heat network averages 48°C in the return pipeline and 85°C in the supply pipeline during the heating season) and constructing a 75-meter connection to the municipal heat network. The linkage from PSNC through PUT to Veolia offers lower temperatures in winter (55-60°C for most buildings on campus). The campus buildings

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could be supplied directly from the heat pump at 60°C or from a water loop (20-30°C) acting as a lower heat source for individual building heat pumps. In the summertime, the large heat pump would supply heat directly to the DHS supply pipe at 70°C. This scenario assumes the sale of recovered heat to the PUT heat network, with any surplus going to the Veolia district heating network, enabling year-round heat reuse.

Finally, none of these two scenarios were implemented due to a lack of funding. However, through HEATWISE, PSNC will evaluate the possibility of switching their current Direct Cooling System to a mixed two-phase liquid cooling and air immersion setup under development by ZutaCore. This solution will increase the waste heat recovery potential, with output temperatures up to 70°C. The higher temperatures will reduce the need to upgrade output temperatures and could lower the investment costs of the previous scenarios.

3.3.4 AAU, Denmark

Today, 80% of the heat demand in the municipality of Aalborg is covered by district heating, sourced from a variety of providers, including a central power plant, a cement factory, a waste incineration plant, and waste heat from various industries and decentralized CHP (Hotmaps project, n.d.). Integrating waste heat recovery from the database racks of Aalborg University can further support Aalborg's district heating network, enhancing its efficiency and sustainability.

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4 Conclusions

In this report two main areas for the waste heat potential of a building were investigated, the potential for using it inside the building itself, and the potential for using it outside of the building.

When looking at the potential for using the waste heat inside the building, it was found that one of the most important things to be aware of when the potential is based on measurements is the measurement location of the supply temperature. In general, three different locations are possible. This is either at the building's main supply point, on the system before any mixing loop, or on the system after all mixing loops. It was found that using anything other than the supply temperature after the mixing loop means that the potential at the system level may be severely underestimated. This is because the temperature before the mixing loop will always be equal to or higher than the temperature the system needs.

If the potential is not evaluated based on measurements, which would happen either for new buildings or buildings with no measurements, it would typically need to be evaluated based on the design values of the different systems. This was found to be an unreliable method, as the design values are normally a singular value under certain conditions. This could cause the system's potential to be severely under- or overestimated, depending on how the system is operated and the conditions it was designed for. It is also worth noting that the measurement points needed for making a detailed system level analysis are rarely available in most normal buildings, as they are not necessarily needed to control the building. This issue was found in the PSNC pilot, as even though it is a modern and highly monitored building, the necessary measurement points needed were not available. It was though found that having at least the design values can indicate if the system will be a candidate for using waste heat. But to give a proper estimate, measurements of at least the energy use of the individual systems or system types is necessary, as seen in the TOFAS pilot, where this meant that at least the amount of energy that could potentially be covered could be estimated conservatively.

When considering the potential of the building, it was found that there are significant differences between looking to supply at the full-scale level and the system level. This difference is mainly caused by the full-scale level needing higher supply temperatures than the system level, and is thus more dependent on the waste heat temperature delivered from the source. In this project, the waste heat source is data centers using a

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ZutaCore heat recovery solution, which has been reported to have the ability to supply a maximum water temperature of 70°C from the data center. For the AAU pilot, the difference between supplying at the building and system level was seen to be 56%-point at the supply temperature of 70°C, which changes to 72%-points at a supply temperature of 60°C, as the change for the system level is small, while the building level loses all its potential. This means that when supplying at the full-scale level, the waste heat recovery system is highly sensitive to changes in the supply temperature.

Besides the total energy amount usable, at the different levels, it is also important to understand the temporal aspect of the energy use, where some systems (DHW, ventilation) mainly or only have energy use in the occupied hours of the building, while other systems (space heating, ventilation) use energy during all hours of the day. The same occurs in terms of seasonal variations, where some systems (space heating, ventilation) only use energy during the heating and transition season, while others (DHW) use energy year-round.

Lastly, this report evaluates the possibility that, after self-consumption of the heat in the building, there is still waste heat to dispose of. A thorough literature review on alternative applications for waste heat revealed that the primary aspect to be considered is the output temperature of the waste heat, which helps determine the most suitable solution for its use. Consequently, given the output temperature of the heat recovered from the pilots analyzed in the project, the excess waste heat would be mostly utilized for district heating.

The methodology envisions a tool designed to analyze the profitability of connecting a building to a data center for waste heat reuse. The tool calculates the necessary amount of heat recovery to achieve profitability based on a specified ROI. Other key parameters include the distance between the data center and the potential heat consumer, the capital cost for installation, the current energy tariff and the type of fuel being replaced. This tool can serve as a business case for potential future buildings considering a connection to the data center, providing an estimation of the cost savings from purchasing heat from the data center compared to traditional heating methods. Further analysis should evaluate the feasibility of connecting the data center to the nearest district heating network, considering the potential revenue from selling excess waste heat to the district heating operator.

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Annexes

Fuel prices per country

Annual-averaged energy prices for natural gas and electricity under different domestic and industrial consumption tariffs for Denmark, Poland and Türkiye. Eurostat

Fuel type	Usage	Tariff	Denmark	Poland	Türkiye
Natural Gas	Domestic (Eurostat A, 2024)	D1 < 20 GJ	€ 0.1519	€ 0.0777	€ 0.0175
		D2 20 - 199 GJ	€ 0.1438	€ 0.0707	€ 0.0204
		D3 ≥ 200 GJ	€ 0.1580	€ 0.0782	€ 0.0180
	Industrial (Eurostat B, 2024)	I1 < 1000 GJ	€ 0.1269	€ 0.1201	€ 0.0401
		I2 1000 - 9999 GJ	€ 0.1226	€ 0.0964	€ 0.0441
		I3 10000 - 99999 GJ	€ 0.1072	€ 0.1167	€ 0.0509
		I4 100000 - 999999 GJ	€ 0.1026	€ 0.1048	€ 0.0510
		I5 1000000 - 3999999 GJ	€ 0.1014	€ 0.0892	€ 0.0485
		I6 ≥ 4000000 GJ	-	€ 0.0650	€ 0.0496
Electricity	Domestic (Eurostat C, 2024)	DA < 1000 KWh	€ 0.4465	€ 0.2664	€ 0.0640
		DB 1000 - 2499 KWh	€ 0.3944	€ 0.2047	€ 0.0647
		DC 2500 - 4999 KWh	€ 0.3683	€ 0.1966	€ 0.0702
		DD 5000 - 14999 KWh	€ 0.3154	€ 0.2210	€ 0.0825
		DE ≥ 15000 KWh	€ 0.2983	€ 0.2478	€ 0.0895
	Industrial (Eurostat D, 2024)	IA < 20 MWh	€ 0.2955	€ 0.3784	€ 0.1640
		IB 20 - 499 MWh	€ 0.2526	€ 0.3022	€ 0.1530
		IC 500 - 1999 MWh	€ 0.2153	€ 0.2615	€ 0.1424
		ID 2000 - 19999 MWh	€ 0.2126	€ 0.2512	€ 0.1307
		IE 20000 - 69999 MWh	€ 0.2084	€ 0.2453	€ 0.1227
		IF 70000 - 149999 MWh	€ 0.2129	€ 0.2487	€ 0.1181
		IG ≥ 150000 MWh	€ 0.1965	€ 0.2560	€ 0.1163

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Annual-averaged energy prices for natural gas and electricity under different domestic and industrial consumption tariffs for Switzerland from the Swiss federal administration.

Fuel type	Usage	Tariff	Switzerland
Natural Gas (Eidgenössisches Departement für Wirtschaft, Bildung und Forschung WBF A, 2017)	Domestic	Type II: 20 000 kWh	€ 0.1075
		Type III: 50 000 kWh	€ 0.1030
		Type IV: 100 000 kWh	€ 0.0997
		Type V: 500 000 kWh	€ 0.0964
	Industrial	Type VI: 500 000 kWh	€ 0.0889
		Type VII: 1 163 000 kWh	€ 0.0867
		Type VIII: 11 163 000 kWh	€ 0.0830
		Type IX: 116 300 000 kWh	€ 0.0768
		Type X: 250 000 000 kWh	€ 0.0764
		H1: 1600 kWh	€ 0.3643
Electricity (Eidgenössisches Departement für Wirtschaft, Bildung und Forschung WBF B, 2017)	Domestic	H1: 1600 kWh	€ 0.3643
		H2: 2500 kWh	€ 0.3389
		H3: 4500 kWh	€ 0.3061
		H4: 4500 kWh	€ 0.3214
		H5: 7500 kWh	€ 0.2989
		H6: 25 000 kWh	€ 0.2726
		H7: 13 000 kWh	€ 0.2909
		H8: 7500 kWh	€ 0.3111
	Industrial	C1: 8000 kWh	€ 0.3228
		C2: 30 000 kWh	€ 0.3098
		C3: 150 000 kWh	€ 0.2965
		C4: 500 000 kWh	€ 0.2866
		C5: 500 000 kWh	€ 0.2641
		C6: 1 500 000 kWh	€ 0.2572
		C7: 7 500 000 kWh	€ 0.2447

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Inflation rate per country

Average (5-year) inflation rate for the pilot's countries (Eurostat E, 2024).

Country	Inflation 5/year average
Denmark	2,98%
Poland	7,28%
Switzerland	1,04%
Turkey	42,30%

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