UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Industrial Engineering

Design of a geothermal heat pump and condensing boiler hybrid system for providing heating and cooling to an existing public building in Hohen Neuendorf, Germany.

Master's Thesis

Master's Degree in Energy Technologies for Sustainable Development

AUTHOR: Kleideiter, Luise Magdalena

Tutor: Cazorla Marín, Antonio

ACADEMIC YEAR: 2023/2024

ACKNOWLEDGEMENT

I want to thank my family, François, and Pauline very much to support and motivate me, listen to me, and make me laugh.

Thanks to the team of B4-Plan Engineering S.L. to give me the chance to write the Master thesis during the internship at the company and to help me in all technical questions.

Also, I want to thank my tutor for supporting me in questions regarding content, format and giving all kind of tips to improve the work.

Thanks to Ana-Maria, Tomás, Eduardo, and Maria for sharing, caring, and supporting.

Finally, I want to thank sincerely the foundation Rosa-Luxemburg-Stiftung for supporting financially and ideologically my master's studies.

ABSTRACT

In the context of the challenge of the renovation wave of existing buildings in Europe as one of the measures to fight climate change, the present Master thesis studies the design options, according to the applicable normative, of a new heating and cooling system for an existing building of public use in Hohen Neuendorf, Germany. This includes the determination of the design heating and cooling loads of the building and the selection and design of the energy generation system, of the distribution network and of the in-room terminal systems. Regarding the in-room terminal systems, radiant floor, ceiling, and radiators are considered as well as chilled beams. Concerning the selection of the energy generation system, a techno-economic analysis and environmental assessment is carried out to compare different possible alternatives. The best suited option consists in a hybrid system combining a brine-water geothermal heat pump and a condensing boiler. Finally, the energy generation system is designed in detail including its primary circuit with vertical ground heat exchanger, the hydraulic scheme, and additional elements.

Keywords: Refurbishment of buildings, Geothermal heat pump, Heating system, Cooling system, Renewable energies, Energy efficiency

RESUMEN

En el marco de la oleada de renovación de edificios existentes en Europa como una de las medidas para luchar contra el cambio climático, el presente Trabajo final de Máster estudia las opciones de diseño, según la normativa aplicable, de un nuevo sistema de calefacción y refrigeración para un edificios de uso público existente en Hohen Neuendorf, Alemania. Esto incluye la determinación de la carga térmica del edificio y la selección y el diseño del sistema de generación de energía, de la red de distribución y de las unidades terminales en las estancias. En cuanto a las unidades terminales, se consideran suelo radiante, techo radiante y radiadores, así como vigas frías. En relación con la selección del sistema de generación de energía, se lleva a cabo un análisis tecno-económico y una evaluación medioambiental para comparar las distintas alternativas posibles. La opción más adecuada consiste en un sistema híbrido que combina una bomba de calor geotérmica de salmuera y una caldera de condensación. Finalmente, se diseña en detalle el sistema de generación de energía incluyendo su circuito primario con intercambiador de calor enterrado vertical, el esquema hidráulico y los elementos adicionales.

Palabras Clave: Rehabilitación de edificios, Bomba de calor geotérmica, Sistema de calefacción, Sistema de refrigeración, Energías renovables, Eficiencia energética

RESUM

En el marc de l'onada de renovació d'edificis existents a Europa com una de les mesures per a lluitar contra el canvi climàtic, el present Treball final de Màster estudia les opcions de disseny, segons la normativa aplicable, d'un nou sistema de calefacció i refrigeració per a un edificis d'ús públic existent en Hohen Neuendorf, Alemanya. Això inclou la determinació de la càrrega tèrmica de l'edifici i la selecció i el disseny del sistema de generació d'energia, de la xarxa de distribució i de les unitats terminals en les estades. Quant a les unitats terminals, es consideren sòl radiant, sostre radiant i radiadors, així com bigues fredes. En relació amb la selecció del sistema de generació d'energia, es duu a terme una anàlisi tecno-econòmica i una avaluació mediambiental per a comparar les diferents alternatives possibles. L'opció més adequada consistix en un sistema híbrid que combina una bomba de calor geotèrmica de salmorra i una caldera de condensació. Finalment, es dissenya detalladament el sistema de generació d'energia incloent el seu circuit primari amb bescanviador de calor enterrat vertical, l'esquema hidràulic i els elements addicionals.

Paraules clau: Rehabilitació d'edificis, Bomba de calor geotèrmica, Sistema de calefacció, Sistema de refrigeració, Energies renovables, Eficiència energètica

CONTENTS

ACKNOWLEGMENTS

ABSTRACT

RESUMEN

RESUM

PART I: MEMORY

PART II: BUDGET

PART III: TECHNICAL DRAWINGS

PART I: MEMORY

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

AHU: Air handling unit

ASHP: Air source heat pump

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

CHP: Combined heat and power

DIN: Deutsches Institut für Normung e.V.

DWD: Deutscher Wetterdienst (German Meteorological Service)

GEG: Gebäudeenergiegesetz (German law concerning the energy efficiency of buildings)

GHG: Greenhouse gas

GSHP: Ground source heat pump

GWP: Global warming potential

ISO: International Organization for Standardization

TEWI: Total equivalent warming impact

UNE: Asociación Española de Normalización

VDI: Verein Deutscher Ingenieure

1 INTRODUCTION

1.1 Motivation

Increased greenhouse gas (GHG) levels emitted to the atmosphere by human activities have caused global warming, which facilitates extreme weather events and threatens natural resources of humans, animals, and plants (Bolles, 2024). To fight climate change, it is imperative to significantly reduce GHG emissions worldwide. For this reason, on European level, the European Union passed in 2021 the European Green Deal with the goal to achieve climate neutrality by 2050 (European Parliament & European Council, 2021, sec. 2). Furthermore, the deal defines as a milestone to reduce net emissions to at least 55% below 1990 levels by 2030 (European Parliament & European Council, 2021, sec. 4). A key contributor to the emissions is the building sector, emitting in 2021 35% of the energy-related EU emissions (European Environment Agency, 2023c), where the energy-related EU emissions were roughly 25% of all EU emissions (European Environment Agency, 2023a). This means that 8.75% of all European GHG emissions are emitted by the building sector. Those emissions are released partly by burning fossil fuels directly and partly by consuming energy in form of electricity and heat (European Environment Agency, 2023c). The mayor part with 78% of those emissions are due to space and water heating (European Environment Agency, 2023b). Besides, the energy consumption in ancient buildings is especially critical since construction policies allowed less insulated and airtight buildings as well as less-efficient high-temperature energy systems based on fossil fuels. As an answer to these problems, the EU initiated the renovation wave as one of the elements of the European Green Deal. The goals of the renovation wave are resumed in improving energy efficiency of buildings, boosting the economy, and improving the living-standards for Europeans by refurbishing worst performing and public buildings and by decarbonizing heating and cooling (European Commission, 2023). On the one hand, the refurbishment of buildings results in a reduction of the energy consumption by improving the insulation and airtightness of building envelopes and by upgrading energy transmission systems to high-efficiency low-temperature systems. On the other hand, refurbishing helps to reduce GHG emissions of the part of energy consumption which is inevitable by increasing the share of renewable energy production in-situ. The present work pretends to contribute to the realization of the renovation wave by studying the possibilities of refurbishing the energy system for heating and cooling of an existent public building complex in Germany with the aim to achieve the lowest possible GHG emissions due to heating and cooling, while guarantying the comfort of the users and considering the investment and operating costs.

1.2 Aim of the work

The aim of the work is to design a heating and cooling system of an existing public building with annex in Germany, including in-room terminal systems, the distribution network, and the energy generation system. Furthermore, the objective is to carry out an analysis and a comparison of the impact of different solutions regarding the generation system, including a techno-economic and environmental assessment. The selected solution must be technically feasible, meet legal regulations and building requirements, consider the economic impact, and reduce at its most the GHG emissions for heating and cooling of the building. Secondary objectives consist in determining the heating and cooling loads of the building complex and in developing a project for the installation including calculations and detailed plans regarding the distribution of the in-room terminal systems, the distribution network, and its hydraulic composition.

1.3 Scope

The design of the heating and cooling system for the building complex includes the above-mentioned objectives. To be able to realize the design, the work is based on plans of the building complex, its future insulation and airtightness and its user profiles provided by the architect and corresponding companies. Furthermore, the sizing of the ventilation system which must be considered for the design of the heating and cooling system has been realized by the ventilation department who shared necessary information to be able to design the heating and cooling system.

1.4 Structure of the work

The present work is structured in the following chapters:

- In chapter 2, the theoretical background and the applicable normative is developed concerning heating and cooling loads of buildings, heat distribution and transmission networks and heating and cooling generation or supply for buildings partially satisfied with regenerative energies.
- In chapter 3, the applied methodology is explained.
- In chapter 4, the building complex is described with its ubication, climate, geometry, floor plan, user time schedule and conditions for heating and cooling.
- In chapter 5, the design heating respectively cooling loads of the building are determined using the programs C.A.T.S. and AutoCAD.
- In chapter 6 and 7, the heating and cooling in-room terminal systems respectively the distribution network and its elements for the heating and cooling system of the building are selected and designed.
- In chapter 8, three suitable energy generation systems are analyzed and compared of an economic and environmental point of view, being able, in the following, to choose the heating and cooling generation system. The chosen system consists in a hybrid system combining a brine-water geothermal heat pump and a condensing boiler, which is finally designed in detail.
- The conclusions are detailed in chapter 9.

2 STATE OF THE ART

2.1 Design of heating and cooling loads of buildings

2.1.1 Theoretical background

The heating respectively cooling load of buildings are defined as the heat or cool flow which is necessary to heat up or cool down the interior of a building, with the goal to reach defined comfort temperatures and considering external design conditions (European Committee for standardization, 2017). The heating and cooling load of a building are calculated to decide about the necessity of heating and cooling in-room terminal systems and the required energy generation or supply for the building. The models to determine the heating and cooling loads are resting upon the assumption that there exists heat transfer between buildings and the surroundings by conduction, convection and radiation through the building envelope, resulting into three main thermal losses. In the first place, the thermal losses through the envelope elements are determined by their thermal transmittance, the so-called U-value, which considers the conductivity and thickness of each layer of the element as well as the convection of the air nearby. In the second place, since the building is never completely air-tight, there is air renovation inside the building by air leaks through the envelope, which is estimated by taking into account the level of airtightness of the building. Finally, due to the need to regularly renovate the interior air to guarantee a healthy environment, ventilation losses are considered depending on kind of planned ventilation. Furthermore, the models include the internal comfort temperatures defined by national regulations or agreed with the client and the external design conditions referring to the most inconvenient moment of the year. Internal gains due to external and internal heat sources are additionally comprised into the model, mainly in case of calculating the cooling load.

2.1.2 Calculation of heating load

The calculation of the design heating load is described amongst others by the Load Calculation Applications Manual published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (Spitler, 2014) and by EN-12831-1 published by the European Committee for standardization (CEN)(European Committee for standardization, 2017). In the following, the European standard will be explained. It is complemented by national annexes applying in the following the German national annex called DIN/TS 12831- 1 (DIN, 2020)

As shown in Figure 1, the standard defines the design heating load as a sum of the design ventilation heat losses due to ventilation and air infiltrations, of the transmission heat losses and of additional upheating power after stopping heating for a certain time, e.g., during the night. Optionally, heat gains can be rested from the sum to consider external or internal heat sources. Last is not taken into account by the German national annex.

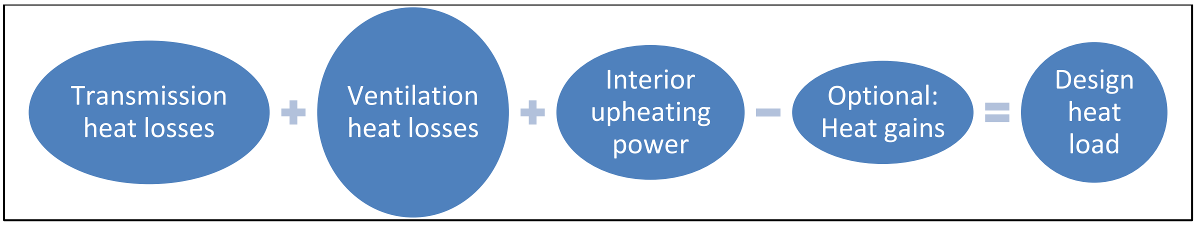


Figure 1: Design heat load according to EN-12831-1

Three different calculation methods are defined: the standard method as a versatile approach, a simplified method for the calculation of the design heating load of a single room used in case of changing single heating terminal units or hydraulic balancing and another simplified method for the calculation of the building heat load used in case of exclusively exchanging the heat generator of the building.

In the following, the standard method is described more in detail, while the simplified methods are left out because the present project does not fit into the scope of the simplified methods.

The standard method is a steady-state calculation having as outputs on the one hand, the design heating load of the heated spaces of a building used to design the heating in-room terminal systems and the heat distribution network and on the other hand, the design heating load of the entire building used to design the heat generator.

Input data are composed of building data, of exterior conditions and of interior comfort conditions. Building data include the ubication, the geometry, the airtightness and the specific heat capacity of the building, the characteristics of the construction elements and the ventilation conditions of each room. When it comes to the characteristics of the construction elements, the materials and thicknesses of the layers or directly the thermal transmittance are taken into account, as well as the possibility of thermal bridges. Regarding the ventilation conditions, natural or mechanical ventilation can be considered, always guarantying a minimum air change. Concerning interior comfort temperatures, the national annex defines values depending on the use of each room. The exterior conditions take into account the ubication of the building, the minimum average outdoor air temperature at this ubication during a defined time period and the influence of the building's specific heat capacity measured by the time constant.

Regarding the calculation of the different heat losses, the standard defines in the first place the transmission heat losses as the product of the temperature difference between interior design and exterior design temperature, the hull area of the building envelope and the thermal transmittance of the corresponding elements of the building envelope. Depending on the adjacent medium, which can be outdoor air, adjacent rooms or ground, further correction factors are introduced into the calculations. In the second place, the standard defines the ventilation heat losses as the sum of the ventilation heat losses of each ventilation zone of the building determined beforehand and which are the product of the air density and the specific heat capacity of the air under normative interior temperature, the temperature difference between the interior air design temperature and the incoming air design temperature and the sum of the air volume flows depending on the ventilation type. The ventilation type can be natural ventilation, supply air and transfer air with the corresponding incoming air temperatures. The ventilation heat losses include the heat losses due to air infiltration based on small leaks in the building's envelope. Since the interior upheating power and heat gains are not considered in the following, the calculation methods for these parts are not further described.

2.1.3 Calculation of cooling load

Calculation methods for the determination of the cooling load are described amongst others by Load Calculation Applications Manual published by ASHRAE (Spitler, 2014), by UNE-EN ISO 52016 published by Ascociación Española de Normalización (UNE) (UNE, 2017) and VDI 2078 published by Verein Deutscher Ingenieure (VDI) (VDI, 2015). In the following, the calculation method of VDI 2078 is explained and applied since this German directive is generally used to determine the cooling load in Germany although it is not legally binding.

According to VDI 2078, the cooling load is defined as "cooling or heat output, introduced into the room by a service plant through convection and/or radiation, which is needed in order to maintain a specified room air temperature" [VDI 2078:2015, part 3] and stated as a negative value. Here, the definition refers only to the sensible cooling load, supposing a dissipation of the latent cooling load by the volume air flow assured by the ventilation concept.

The scope of the standard includes the calculation of the cooling load, the room air temperature and the operative room temperature of all kinds of rooms independently of having an air-conditioning system or not. It provides a calculation method for the use of software programmed according to the standard.

The following input data are needed: the ubication of the project to determine the outdoor climate, the characteristics of the building's construction, user profiles and corresponding internal and external heat gains, the interior design temperature and the control strategies for cooling and ventilation. Concerning the outdoor climate, predetermined climate zones based on meteorological data analysis indicate the exterior design temperature and its amplitude. Furthermore, the influence on the outdoor climate of the altitude of the building, of city center environments and of the solar irradiation on the building are considered. Regarding the construction characteristics, next to the inputs already explained for the heating load, further data concerning solar parameters of transparent facades and the specific heat capacity are needed. Internal heat gains are amongst others the number and activity of room users, number and power of machines and daylight-dependent or -independent illumination. External heat gains are produced mainly by sun irradiation on transparent construction elements considered by a window model which distinguishes direct and diffuse radiation and radiant and convective fractions of the room's heat input. The interior design temperature can be defined as an absolute temperature or a temperature dependent on a certain control strategy.

For the calculation of the cooling load, the cooling design day with the representative outdoor climate is reached after an aperiodic settling period composed of 14 days with a mean outside climate of a cloudy day of the corresponding month, 4 days with a warmer outside climate and stronger solar irradiation and the final cooling design day with a mean outdoor climate of a clear day of the corresponding month. Furthermore, control strategies, which consider the influence of cooling and ventilation on interior air temperature - and vice versa - can be integrated into the calculations.

2.2 Heat distribution in buildings

To distribute heat in buildings, different systems are available using air, water, refrigerant or electricity as medium for heat transfer. Furthermore, a distribution network with all required components is necessary to distribute the heat between the energy generation equipment and the in-room terminal systems.

2.2.1 Central air-handling units

Central air-handling units (AHUs) are designed in the first place to meet ventilation requirements of the building. Furthermore, they can satisfy latent thermal loads and may additionally cover sensible thermal loads. They are composed of some of the following components depending on their design functions: outdoor and return air inlets, supply air outlets, filter, preheating, cooling, and reheating coils, mixing plenums, dampers, supply and return air fans, humidifiers and dehumidifiers, and sound control devices. Depending on their design, central air-handling units deliver a constant or variable air volume flow for low-, medium-, or high velocity air distribution. Heat fluids for the energy transfer in the heating or cooling coils can be refrigerant, chilled water, hot water or steam depending on the kind of primary equipment for heating and cooling. They are available as assembled models in different sizes, configurations, and capacities. The selection of the suitable model is best done by consultation with a manufacturer, always fixing first the systems requirements regarding supply air temperature and volume, outdoor air, heating and cooling coil capacities, humidification and dehumidification capacities, filtration, and available space. Central-air handling units can work as all-air systems satisfying all latent and sensible thermal loads or in combination with other in-room terminal systems which cover all or part of the sensible load. (ASHRAE, 2016, pp. 4.3-4.10)

2.2.2 Heating and cooling in-room terminal systems

2.2.2.1 Introduction

In-room terminal systems are used for heating or cooling transfer to individual rooms or spaces of buildings. Common types of in-room terminal systems are radiators, radiant heating and cooling panels, and air distribution terminal units e.g. duct terminal units, chilled beams, and fan coils. In the following subchapters, the mentioned in-room terminal systems are discussed regarding their definition, heat transfer, types, characteristics, design, and control.

2.2.2.2 Radiators

2.2.2.2.1 Definition

Radiators are heat-distribution devices using hot-water or steam to heat up the air temperature by convection and the mean radiant temperature by radiation for heating of building spaces. (ASHRAE, 2016, p. 36.1)

2.2.2.2.2 Heat transfer

Heat transfer from radiators to the conditioned space takes place by radiation until a share of maximum 50% of the total heat transfer depending on the surface area of the radiator and by air convection since the air layers next to the radiator are heated up, moving upwards and letting space for cooler air to be heated up. (ASHRAE, 2016, p. 36.2)

2.2.2.2.3 Types

Common types of radiators are sectional radiators, panel radiators, tubular steel radiators and specialty radiators. Sectional radiators consist of welded sheet metal sections with two, three or four tubes in section view. Panel radiators are composed of fabricated flat panels of one, two or three sheets which in some cases are linked with an extended fin surface and are typically used in Europe. Tubular steel radiators possess a supply and return header linked with straight parallel steel tubes used for example for towel drying in bathrooms. Specialty radiators are adapted to applications in ceiling grids or floor-mounting and produced of welded steel or extruded aluminum. (ASHRAE, 2016, p. 36.1)

2.2.2.2.4 Characteristics

Radiators are designed particularly for heating and are rarely used for cooling, being able to satisfy the sensible heating load of building spaces.

In terms of comfort, radiators are fast responsive systems adapting quickly to changing loads. Furthermore, they work in a quiet way if valves and water velocities are well designed. Since they transfer heat mostly by convection, they cause air motion which may lead to more asymmetric radiation temperatures and more dust circulation with possible impact on allergic persons.

Regarding the energy-efficiency, radiators commonly operate at higher temperatures because of their small to medium transmission areas. Since low-temperature energy generation improves energy-efficiency of the whole energy system, a new generation of low-temperature radiators has been developed allowing greater energy-efficiency by using greater transmission areas.

Concerning the economic costs, radiators are cheap in terms of investment and maintenance and show medium operating costs.

Radiators need a certain amount of space of the room limiting furniture configurations. They are visible but a great choice of available models offers a lot of possibilities to integrate them into the room design.

In terms of compatibility, radiators can be combined with other space-conditioning systems. They are compatible with all kinds of energy generation systems although in case of low-temperature generation systems, new generation radiators are necessary with corresponding greater transmission areas. Finally, radiators are suitable for easy and fast installation in case of refits.

2.2.2.2.5 Design

Standards concerning the design of radiators are (ASHRAE, 2016, p. 36.3), DIN 4703-1 (DIN, 1999), DIN4703-3 (DIN, 2000) and VDI 6030 (VDI, 2002). Once knowing the heating load of the conditioned room, the sizing is realized in the practice mainly by using manufacturers' data. Furthermore, planning of the distribution of the radiators is important to balance cold surfaces by placing radiators at areas of greatest heat loss nearby windows and cold walls. Finally, radiators are available as freestanding or semi recessed models or with decorative enclosures. (ASHRAE, 2016, p. 36.5). Typical supply water temperatures lie between 50°C to 70°C, although new generation radiators can work at lower supply temperatures.

2.2.2.2.6 Control strategies

Control strategies are available but not mandatory for radiators. Radiators' supply temperature may be centrally regulated, while the mass water flow is usually controlled manually at each device by room users increasing or decreasing the room air temperature.

2.2.2.3 Radiant heating and cooling

2.2.2.3.1 Definition

Radiant heating and cooling systems consist of surfaces on the ceiling, floor or walls of conditioned rooms which are heated or cooled by water, air or electric current leaded circuits embedded in or attached to the panel. They cover sensible heating or cooling loads and must be combined with a ventilation air system in case of considerable latent loads. A radiant heating or cooling system is defined as a surface which transmits 50 % or more of the design heat transfer by thermal radiation, while the rest of the heat transfer takes place by natural convection. (ASHRAE, 2016, p. 6.1)

2.2.2.3.2 Heat transfer

Thermal radiation which is transmitted in straight lines and at the light of speed is exchanged constantly between all bodies inside a building area without significantly heating or cooling the air through which it travels. The thermal radiation rate depends on the temperature difference between the emitting panel and the receiver bodies, the emittance of the panel, the absorptance, reflectance and transmittance of the receivers and the view factor between both emitting panel and receivers. Since temperatures of bodies inside buildings are low, the thermal radiation takes place mostly in the longwave region where surface roughness and texture have insignificant effects on thermal radiation. Furthermore, most of the materials used in buildings show relatively high surface emittance and absorb and reradiate heat from radiation panels. (ASHRAE, 2016, p. 6.1)

Heat transfer by natural convection takes place between the indoor air and the heating or cooling panel surface and is caused by air motion due to the temperature difference between the air layer next to the surface and the indoor air. Other factors can disturb natural convection which are mainly air infiltration, occupants' movements, and mechanical ventilation systems. Room sizes have insignificant effects on natural convection except for very larges spaces. (ASHRAE, 2016, p. 6.3)

The calculation of heat transfer by thermal radiation and thermal convection is described in detail in ASHRAE 6.2-6.5. The combined heat flux generated by an active panel surface is the sum of both components. (ASHRAE, 2016, p. 6.5)

Heat transfer is affected by the panel's thermal resistance, by the thermal resistance of coverings especially important in case of radiant floors, by the panel's performance, and by panel heat losses or gains through the backside. Last can be reduced by a reasonable insulation of adjacent ceilings, floors, and walls. (ASHRAE, 2016, pp. 6.5-6.7)

2.2.2.3.3 Types

Radiant heating and cooling surfaces can be characterized by the heat fluid, by their position in the room, and by the kind of installation of their heating and cooling loops. For heating, water, a combination of water and air or electric current are typically used as heat fluid, while for cooling, only water or the combination of air and water is available. Positioning is possible in or on ceilings, floors, or walls, although the choice depends on the use of the room and the available space, on the desired aesthetic effects and on the main need of the surface for heating or for cooling. The installation of the circuits can be realized as tubing or cables embedded in the chosen surface or as panels on which the tubing or cables are linked.

Common forms of radiant heating and cooling are the hydronic ceiling panels, the embedded systems with tubing in ceiling, walls or floors, and the electrically heated radiant systems.

Hydronic ceiling panels consists in metal ceiling panels for heating and cooling which can be provided as small units for flexible zoning or as large areas. They can be combined with other ceiling panels for acoustical comfort, illumination or with air supply or exhaust ducts. Three types of hydronic ceiling panels can be distinguished regarding their construction and size: metal ceiling panels attached to galvanized pipe laterals with sizes until 300 by 600 mm, metal ceiling panels bonded to copper tubing with sizes until 1300 by 3000 mm and extruded aluminum panels with integral copper tubes with length until 6 m. It is important to consider for the design of metal ceiling panels that they operate efficiently at low temperatures, their placement must be nearby exterior walls and areas with maximum loads, and heating design temperatures should be limited to avoid discomfort to approximately 58°C for 3m clear height. They provide a fast-response system since the metal is able to adapt quickly to load changes. Furthermore, they allow easy maintenance and exchange and run quietly, draft-free, easy to control and provide a life expectancy over 30 years.

Embedded systems with tubing in ceilings, walls, or floors are usually realized by embedding either pipes or tubes in a concrete slab, locating them nearby the conditioned room, or in a metal lath and plaster ceiling or wall. Coils are normally arranged in a sinusoidal pattern using thermoplastic tube spaced from 100 to 300mm on centers. Drying periods of the embedding materials must be considered before enabling the system. Especially in case of pipes or tubes embedded in concrete slabs, embedded connections between pipes or tubes and valves should be avoided and if not possible, their location should be labeled in drawings to help finding points of failure.

Electrically heated radiant systems are provided in forms of electric ceiling panels and electric cables, or electric preformed mats embedded in ceilings, walls, or floors. Systems embedded in walls are less recommended because of the danger of an electric shock for users in case of nailing or drilling the wall while installing furniture or pictures. Generally, electrically heated radiant systems allow a fast response, a lower panel thickness and low investment costs, but show high operating costs and are less energy efficient. They are typically applied in case of refits for small areas or as an additional system.

2.2.2.3.4 Characteristics

Radiant panels are designed for heating and cooling of building spaces, although they can only satisfy sensible thermal loads.

Radiant heating and cooling systems provide high comfort transmitting a great share of the heating or cooling load by radiation, which allows to control not only the indoor air temperature but also the mean radiant temperature of surrounding surfaces. Furthermore, air motion is reduced to ventilation requirements and the system itself is a draft-free, and therefore anti-allergic, and noise-reduced system due to the high share of radiation. Slow response time of embedded systems may diminish comfort if control strategies are not well chosen.

Regarding the energy-efficiency, radiant systems show good results because of several reasons: comfort can be reached at a lower dry-bulb air temperature leading to reduced thermal loads, moderate operation temperatures are sufficient because of great transmission areas allowing an efficient generation of supply energy, and the existing thermal energy storage in panel structure and in surfaces exposed to radiation reduce peak loads.

In terms of economic costs, radiant systems show moderate investment costs and low maintenance and operating costs. On the other hand, costs and efforts are high in case of repair and exchange of embedded systems. A good design and a proper and supervised installation help to avoid those costs.

They provide good space use and visual appearance since radiant ceiling or floor systems allow free configuration of furniture. In case of radiant wall system, the space use is reduced since radiant walls must kept empty of furniture and curtains. They are invisible in case of embedded systems and provide a great scope of design in case of panel systems. Regarding radiant floor systems, the choice of floor coverings is limited to materials with relatively low thermal resistances.

Concerning future changes of the room use, radiant panel systems are adaptable to changes regarding partitioning, optical requirements, and even thermal loads.

Finally, radiant systems can be combined with other space-conditioning systems and show a great compatibility with low-temperature sources like heat pumps due to the moderate operation temperatures.

(ASHRAE, 2016, p. 6.10)

2.2.2.3.5 Design

Radiant cooling and heating systems can be designed according to (ASHRAE, 2016, Chapter 6), according to ISO 11855-3 (UNE, 2021), according to EN 1264 (DIN, 2021) and based on manufacturers' data.

For the design of radiant cooling systems, the latent and sensible cooling load, the minimum supply air flow for ventilation and the latent and sensible cooling available from supply air need to be calculated to determine the remaining sensible cooling load to be satisfied by the radiant cooling system. For the design of radiant heating systems, the sensible heating load to be satisfied by the radiant heating system is calculated directly. (ASHRAE, 2016, p. 6.17)

In case of radiant panels, the necessary radiant area to cover the sensible heating or remaining cooling load is chosen depending on supply and return water temperature, interior design temperature, panel capacity, arrangement possibilities, and flow rate. In case of embedded systems, the tube spacing for a given average water temperature determines the possible specific capacity of the system. Multiple heating or cooling loops may be necessary because of pressure drop limits. (ASHRAE, 2016, p. 6.17)

Regarding the radiant surface temperature, several limits must be taken into account. In cooling mode, surface condensation at design conditions must be avoided controlling the minimum permissible cooling panel surface temperature at design conditions. In heating mode, comfort must be guaranteed by limiting average surface temperatures for radiant ceilings at room heights of 3 m to approximately 58°C and those of radiant floors to 29°C. (ASHRAE, 2016, pp. 6.12, 6.17, 6.20)

2.2.2.3.6 Control strategies

Control strategies must be chosen with the aim to have a system adapted to the needs of the user and working in an energy-efficient and cost-effective way. Low-mass systems like thin metal panels which show sufficiently fast responses on load changes, can be controlled with conventional control technology using indoor thermostats. High-thermal-mass panels like embedded tubes in concrete slabs have a slow response on load changes, wherefore the usual control strategy is to balance heat supply and heat losses in each moment. For this purpose, heat supply is measured considering the temperature difference between outgoing and returning water and its flow rate and controlled using mixing valves or fuel modulation. Heat losses are modulated depending on indoor and outdoor temperatures and building characteristics. Night setbacks and down periods must be chosen carefully for high-thermal-mass panels since they can cause discomfort due to the thermal inertia of the system. In cooling mode, the building space must be dried out first after down periods to avoid condensation. Embedded radiant heating floor systems should have additionally a slab-sensing thermostat limiting the surface temperature to 29°C to guaranty comfort. In cooling mode, high-thermal-mass systems allow the possibility of nighttime precooling at low energy costs and reduced outdoor temperatures. Model predictive control can increase the balance of thermal comfort and energy consumption. (ASHRAE, 2016, pp. 6.19-6.20)

2.2.2.4 Air distribution terminal units

2.2.2.4.1 Definition

Air distribution terminal units are factory-made assemblies which can control air velocity, airflow rate, pressure, or temperature of the induced air. Some units mix primary air from a duct system with air from the conditioned room or a secondary duct system, while others recirculate the conditioned room air. The terminal units may be exclusively used for ventilation requirements and for satisfying latent thermal loads, or they additionally cover sensible thermal loads. They are usually composed of several of the following components: casing, mixing section, heat exchanger, fan, sound reduction devices, and flow controller. (ASHRAE, 2016, pp. 20.7-20.12)

2.2.2.4.2 Heat transfer

Heat transfer takes place by convection of the room air, either by exchanging a share of the room air introducing unconditioned or pretreated primary air or a mix of primary air and air of the conditioned room, or by leading a stream of the room air through a heating or cooling coil inside the terminal unit transferring heat to or from the room. (ASHRAE, 2016, pp. 20.7-20.12)

2.2.2.4.3 Types

Common forms of air distribution terminal units are duct terminal units, fan coils and chilled beams. They can be characterized by their possibility to meet ventilation requirements, by their heating and cooling capacity, by the heat fluid and by their configuration types.

Duct terminal units consist of a casing and an airflow regulator, often accompanied by an actuator, an airflow-measuring device and other control systems. They are designed to ventilate the rooms to guarantee a healthy air environment. The pretreated primary air can be either mixed with part of the conditioned room air or introduced directly to the room. Their heating or cooling capacity depends on the capacity of the air-handling unit to pretreat the primary air, for which can be used hot or chilled water or a refrigerant. Since exhaust ducts are needed to balance room air pressure, heat of the exhaust air can be recovered using heat exchangers placed in the air-handling unit. Duct terminal units can be designed as single or dual duct units, second are recommended in buildings where a ventilation stop due to the changeover between heating and cooling is not acceptable. (ASHRAE, 2016, pp. 20.7-20.8)

Fan coils are composed of a filter, a fan, a temperature device, and a heating and cooling coil, which can be used as dehumidifier with a drain pan. They are designed to recirculate the conditioned room air and usually do not meet ventilation requirements, although special combinations of ducts with primary air leading to fan coils exist. Their heating and cooling capacity lies between 2 to 21 kW. They use water or direct-expansion with refrigerants leaded through finned-tube coils or electric resistance elements as heat fluids. Fan coils are available as vertical and horizontal units selected depending on room configuration requirements. (ASHRAE, 2016, pp. 20.10-20.12)

Chilled beams combine the functions of radiant panels and duct terminal units or fan coils. Active beams are composed of a duct delivering conditioned air from the central air-handling unit, which is led through a hydronic heat transfer coil and then discharged to the room. Passive beams also possess a hydronic heat transfer coil, through which recirculates the conditioned room air. By combining two systems, active beams are able to satisfy ventilation requirements, latent cooling loads and important sensible heating and cooling loads. They can be found as integrative ceiling systems or as independent panels. Passive beams can exclusively cover sensible heating and cooling and exist in form of exposed and recessed beams. (ASHRAE, 2016, pp. 20.9-20.10)

2.2.2.4.4 Characteristics

Air distribution terminal units are designed for ventilation, heating and cooling of building spaces depending on their type and configuration. Most of the terminal units are able to satisfy latent and sensible thermal loads.

Air terminal units can provide sufficient comfort if they are well-designed and sized. Problems with air temperature stratification as well as asymmetrical radiant temperatures of surrounding surfaces may lead to discomfort. Furthermore, air motion can be perceived as unpleasant draft especially in cooling mode. Air terminal units are often noisier due to the use of fans then hydronic systems. They have a fast response time which makes them adaptable to changing loads.

Regarding the energy-efficiency, duct terminal units and active chilled beams with heat recovery show good results. Furthermore, air terminal units may run with moderate operation temperatures allowing an efficient generation of supply energy.

In terms of economic costs, air distribution unit terminals show low to moderate investment costs and moderate maintenance and operating costs.

Air distribution terminal units provide a good space use and visual appearance since they allow free configuration of furniture. They are nearly invisible in case of duct air terminal units and can be integrated into the design in case of the rest of the terminal units. Duct terminal units need more ductwork in comparison to hydronic systems or systems with refrigerant like fan coils, leading to greater floor-to-floor heights increasing costs in case of new constructions or leading to lower ceilings, which may affect the visual appearance both in case of refits and new constructions.

Concerning future changes of the room use, air distribution terminal units are less adaptable to changes regarding partitioning and aesthetic requirements, especially if they are supplied by air coming from central air handling through installed ductwork.

Finally, air distribution terminal units can be combined with other space-conditioning systems and are compatible with low-temperature sources like heat pumps.

(ASHRAE, 2016, pp. 20.7-20.12)

2.2.2.4.5 Design

Air distribution terminal units can be designed according to (ASHRAE, 2016, pp. 20.1-20.4), according to DIN 1946-6 (DIN, 2019) and based on manufacturers' data.

Their design must meet the applicable requirements regarding the minimum ventilation flow rate, the heating and cooling loads of the room, placement guarantying a comfortable air distribution, dimensions matching to the aesthetics of the room, and the compatibility with other components of the energy system. (ASHRAE, 2016, p. 20.2)

2.2.2.4.6 Control strategies

The control of air distribution terminal units depends on the type of system, but generally, the volumetric flow and temperature of the delivered air is controlled adjusting manually or automatically these variables, last by a controller, a thermostat, flow regulator or a building management system. Furthermore, a thermostat of the room air temperature gives feedback on the room conditions, which may be linked to fan motors or to water control valves to automatically adapt the heating or cooling capacity. (ASHRAE, 2016, pp. 20.7-20.12)

2.2.2.5 Comparison of the in-room terminal systems

A summary of the characteristics of the in-room terminal systems discussed in the last subchapters is illustrated in Table 1, making a comparison possible.

Table 1: Summary of characteristics of in-room terminal systems

Category	**Characteristics**		**Radiant heating and cooling**			**Air distribution terminal units**		
		Radiators	**Radiant floors**	**Radiant ceilings**	**Radiant walls**	**Duct terminals**	**Fan coils**	**Chilled beams**
General	**Type of main heat transmission**	Convection	Radiation	Radiation	Radiation	Convection	Convection	Convection
	Heat fluid	Water	Water/ Electricity	Water/ Electricity	Water/ Electricity	Water/ Refrigerant/ Electricity	Water/ Refrigerant/ Electricity	Water
	Heating capacity	until 4 kW/unit	~60 W/m²	~130 W/m²	~80 W/m²	design dependent	2-21kW/unit	~300 W/m
	Cooling capacity	Limited application	~30 W/m²	~120W/m²	~40 W/m²	design dependent	2-21kW/unit	~500 W/m²
	Maximum surface temperature	No restriction	29°C in common rooms	~58°C (3m ceiling height)	~40°C	No application	No application	~58°C (3m ceiling height)
Comfort	**Control of mean radiant temperature**	Limited -> Asymmetric radiation temperatures of surrounding surfaces	Yes -> higher comfort	Yes -> higher comfort	Yes -> higher comfort	Limited -> Asymmetric radiation temperatures of surrounding surfaces	Limited -> Asymmetric radiation temperatures of surrounding surfaces	Yes -> higher comfort
	Health	Circulation of room air -> dust circulation possible	Low room air circulation -> anti-allergic	Low room air circulation -> anti-allergic	Low room air circulation -> anti-allergic	Circulation of room air -> filter impede dust circulation	Circulation of room air -> filter impede dust circulation	Circulation of room air -> filter impede dust circulation
	Response time	fast	slow	slow / fast	slow	fast	fast	fast
	Noise	quiet	quiet	quiet	quiet	possible noise of air fan	possible noise of air fan	possible noise of air fan
Energy-efficiency	**Moderate operation temperatures enhancing efficient energy generation**	Possible	Yes	Yes	Yes	Possible	Possible	Yes
	Heat recovery	No application	No application	No application	No application	Yes	No	Possible
	Thermal energy storage	Limited	Yes	Yes	Yes	Limited	Limited	Yes
	Lower dry-bulb air room temperature due to radiation possible	No	Yes	Yes	Yes	No	No	Possible
Costs	**Specific investment costs [€/W]**	~2.8	~0.5	~0.75	~1.9	-	~0.3	-
	Operation Costs	Higher	Lower	Lower	Lower	Lower	Higher	Lower
	Exchange Costs	Low	High	Medium-high	High	High	Low	High
Space & visual appearance	**Occupied space**	Volumetric, uses wall space	Reduction of clear height	Reduction of clear height	Wall use -> limited furniture configurations	Low impact	Volumetric, uses wall space	Reduction of clear height

Cate-gory	Characteristics		Radiant heating and cooling			Air distribution terminal units		
		Radiators	Radiant floors	Radiant ceilings	Radiant walls	Duct terminals	Fan coils	Chilled beams
	Aesthetics	Visible, great choice of designs	Invisible	Invisible	Invisible	Low impact	Visible, great choice of designs	Visible, adaption to aesthetics possible
	Matching coverings/finishings	No restrictions	Floor coverings limited to materials with small thermal resistance	Standard finishings possible	Standard finishings possible	No restrictions	No restrictions	Standard finishings possible
Compa-tibility	**Fitting with low-temperature energy generation systems**	Possible with special models	Yes	Yes	Yes	Possible	Possible	Yes
	Installation in existing buildings	Easy	Difficult: reduces clear height	Less difficult in case of panel systems	Less difficult in case of adding interior wall layer	Difficult: ductwork space limited	Easy	Difficult: ductwork space limited

2.2.3 Distribution network elements

The main used elements for heat distribution are pipes, ducts, manifolds, pumps, valves, pressure control systems and strainers.

Pipes are made of steel, copper, ductile iron or so-called PEX of polyethylene material. Seamless steel is welded, while other steel pipes are joint by threaded, flanged, or grooved fittings. Copper tube joints are soldered or wrought, capillary or compression fittings. In case of ductile iron, flanged or mechanical joint fittings and elastomer gaskets are used. The selection of the type of pipe depends on code requirements, the working fluid, pressure, velocity and temperature of the fluid, the external environment and installation costs. For heating and cooling applications with hot or cold water as working fluid, common pipes are seamless steel pipes, precision steel pipes and PEX-pipes for embedded systems like radiant floors. Nominal diameters of DN10 until DN100 are available withstanding corresponding nominal pressures. In case of water as working fluid and depending on the pipe installation, fluid velocity should lie between 0.3 m/s and 1.5 m/s (Baunetz_Wissen, 2024). Further considerations are necessary regarding pipe-supporting elements like hangers, which must be able to carry the load of the pipes and impede pipes to move. Expansions joints need to be planned to compensate movements due to thermal dilatation with the aim to prevent leaks, pipe failures and undesired forces in connected equipment. Finally, pipe insulation is important to reduce thermal losses and improve the energy-efficiency. Common insulation materials are mineral wool covered with a layer of aluminum or rubber. Insulation thickness requirements are dictated by national codes or laws. In case of Germany, annex 8 of the law Gebäudeenergiegesetz (GEG) must be applied.

Ducts are available in round, flat oval, or rectangular forms made of sheet metal, rigid fiberglass, or phenolic. Fittings exists in form of elbows, transitions, tees or wyes. Duct selection depends on requirements on pressure resistance, fire resistance, space availability, and installation costs. Furthermore, sealing of all transverse joints, longitudinal seams and duct penetrations must be guaranteed to ensure a proper system running and to avoid increased energy consumption and noise problems. After installation, leaking tests must be performed according to corresponding standards. Finally, ducts insulation must be considered to avoid thermal losses. (ASHRAE, 2016, pp. 19.1-19.12)

Furthermore, following elements are completing the distribution network: manifolds, pumps, valves, expansion vessels and strainers. Heating manifolds are used to distribute an incoming stream to several outgoing streams and are available in standard sizes or in customized production. They are usually made of stainless steel, galvanized steel, or reinforced synthetic materials, must have the required amount and size of connections, must be designed for the working fluid flow rate, temperature, and pressure, and should be insulated to avoid thermal losses. Pumps have the task to overcome the pressure drop in the pipes due to pipe friction and element resistances. Design parameters for pumps are the total pressure loss and the flow rate of the fluid. Pumps must be designed to be able to work properly under total and partial loads considering the characteristic curve provided by pump manufacturers. Valves control manually or automatically the fluid which may be started, stopped, directed, or regulated. Furthermore, valves may prevent backflow, relieve, or regulate pressure, or mix or divert streams. Last is performed by three-way-valves. Valves need to withstand system temperature, pressure corrosion and mechanical stress. Common materials are carbon steel, ductile iron, cast iron, stainless steel, brass, bronze, and polyvinyl chloride plastic. Expansion vessels may be opened or closed systems, second in combination with a membrane compensating the pressure. Heating piping normally uses membrane expansion vessels in form of static, compressor- or pump -controlled systems. A security valve must be installed behind the expansion vessel in case of malfunctioning. Finally, strainers have the task to filter dirt due to corrosion which could cause damage inside system elements. Manufacturer programs help to design the discussed elements properly.

2.3 Heating and cooling generation systems for buildings

2.3.1 Legal requirements

In the context of the European Green Deal and the goals of the renovation wave, specific requirements regarding the energy generation or supply for buildings have been fixed in German law GEG in 2020, revised in October 2023 adding stricter measures. The new version of the law dictates that regarding new heating installations, 65 % of the yearly heating energy must be generated by regenerative energies. Since cooling is less common in Germany, the law does not define any restrictions regarding the cooling generation or supply. The 65%-requirement can be accomplished according to §71 GEG by different heating generation or supply systems: (1) district heating complying with legal requirements, (2) heat pump systems, (3) direct electricity heating systems by reinforcing insulation of the buildings to a very high standard, (4) solar thermal systems, (5) heating installations using liquid or gaseous fuel with 65% of the fuel of liquid or gaseous biomass or green or blue hydrogen complying with several legal requirements, (6) heating installations using solid biomass complying with several legal requirements, (7) combination of heat pump systems with condensing boiler for peak loads where 30% of the heating load is covered by the heat pump capacity in bivalent-parallel operating mode, and (8) combination of solar thermal heating with condensing boiler for peak loads complying with several legal requirements regarding minimum aperture area and fuel origin (Bundesregierung, 2023). This applies as well on the production of sanitary hot water if centrally generated. Decentral sanitary hot water production complies with the law only if it is electrically generated and electronically controlled. The law does not apply to installations realized before October 2024 and to buildings in municipalities of less than 100,000 inhabitants as long as no district heating concepts of the municipality exists which must be published latest until 2028.

In the following, the possible energy systems complying with the law GEG will be commented regarding their definition, working principles, types, characteristics, and design considerations.

2.3.2 District heating and cooling (centralized energy generation)

District heating and cooling “distributes thermal energy from a central source to residential, commercial, and/or industrial consumers for use in space heating, cooling, water heating, and/or process heating”(ASHRAE, 2016, p. 12.1).

For a district heating and cooling system, three main components are necessary: a central plant, a distribution network, and the consumer systems. Different types of central plants are possible for heating: boilers, incineration, heat pumps using an air, geothermal, water or waste heat source, solar energy, or combined heat and power systems. For cooling, absorption refrigeration machines, compression equipment driven by electricity, gas, steam or an engine, or combinations of mentioned systems are available. Distribution networks are made of pre-insulated and field-insulated pipes led through concrete tunnels or directly buried in the ground. Furthermore, district heating and cooling systems can be distinguished by their connection to the consumer systems: in case of steam delivery, connection can be realized directly, using a pressure-reducing station, or a steam-to water heat exchanger, meanwhile hot- or cold-water systems deliver directly or indirectly using a heat exchanger. [ASHRAE 12.1-12.2] (ASHRAE, 2016, pp. 12.1-12.2)

Regarding the characteristics of district heating and cooling, applicability, economic investment, and environmental benefits are of special interest. District heating and cooling is most suitable for areas with high thermal load density and a great amount of annual operation hours, which is especially the case in industrial complexes, densely populated urban areas and building clusters. In the mentioned cases, economic investments are more adequate, since distribution networks can be kept comparatively small often representing the greatest part of the investment including necessary permissions for land use. District heating and cooling have positive environmental impacts since the systems, which are usually larger than single building energy generation systems, dispose often of more efficient equipment, can stage the equipment closely to the load, and benefit of the diversity of demand due to different user profiles, making them more energy efficient. Because of their energy-efficiency and the fact of a better monitoring in comparison to individual energy generation, emissions may be reduced as well. District heating is especially profitable for the environment, if central plants are using municipal waste, geothermal sources and combined heat and power systems. (ASHRAE, 2016, pp. 12.1-12.2)

Concerning the design of building supply by district heating and cooling, the first condition is the existence of such system. District heating based on steam delivery is most expanded in United States, hot-water delivery is common in Europe particularly in Scandinavian countries, and cold-water distribution exists in United States and gets more popular in Middle East lately. A request to local authorities in charge of public networks provides information about this aspect. In case of an affirmative answer, information about system temperatures, consumers connection requirements, maximum return temperature and maximum operation pressure are facilitated being able to design the energy distribution and in-room terminal units. (ASHRAE, 2016, pp. 12.1-12.2)

2.3.3 Condensing gas boiler

Boilers are pressure vessels which transfer heat produced by fuel combustion, electrical resistance, or direct action of electrodes to a fluid, usually water.

They can be distinguished by the working pressure and temperature, working fluid state, fuel use, construction materials, combustion chamber characteristics, draft types, and if they are condensing or noncondensing. Low-pressure boilers work until a pressure of 103 kPa steam and until 1100 kPa hot water and hot-water temperature is limited to 120°C, while high-pressure boilers function above these conditions. Water boilers are mostly low-pressure boilers, have capacities from 10 kW - 30 MW and are primarily applied for space heating, whereas steam boilers are low- or high-pressure boilers, have capacities from 17 kW – 30 MW and are used for space heating, auxiliary uses, and industrial steam appliances. Burned fuels may be coal, wood, oil, fuel gas or work with electricity. Regarding construction materials, noncondensing boilers are fabricated of cast iron, steel, copper, or copper-clad steel and condensing boilers are made of stainless steel or aluminum. The combustion chambers can be placed beneath fluid-backed sections called dry-based, surrounded by them called wet-based, or partly surrounded by them on top and sides called wet-legged. The placement has no influence on the efficiency of the boiler, but on the suitability of floor installations since the bottom temperature depends on the combustion chamber placement. Furthermore, boilers can dispose of a fire-tube or a water-tube design depending on whether tubes with fuel gases are completely submerged in the fluid or the other way around. Concerning the draft type, the pressure difference creating an air and/or fuel flow can be caused by natural draft, mechanical forced- or mechanical induced-draft. Noncondensing boilers are limited in their efficiency since condensing is prohibited for corrosion reasons, while condensing boilers can profit from the evaporation heat by condensing and draining the fuel gas water vapor making them more efficient. Non-condensing boilers are not permitted according to GEG and will not be discussed further.

Regarding the characteristics of condensing boilers, the efficiency, economics, controls, and emissions are considered. Condensing boilers’ efficiency in laboratory circumstances can raise until 98%. Efficiency increases with lower return temperatures of the heating fluid and depends on load variation and control adaptation. Concerning economic consideration, investment is relatively cheap but operational costs are difficult to predict since fuel price are oscillating and depend on fuel price inflation and CO2-tax development. Controls regulate the fuel input rate depending on the load using modulating controls which can vary the fuel input between the maximum load to a defined minimum load. This is realized by temperature-actuated controls. The possibility of changing the high limit set point depending on the outdoor temperature increases the efficiency avoiding cycling at low loads and allowing running with lower fluid temperatures. Further controls check the water level and the flame safeguard. Boiler emissions depend on fuel use: according to annex 9, No.3, GEG, natural gas emits 0,24 kg of CO2-equivalent emissions per kWh, while biogas is rated with 0,14 kg and solid biomass with 0,02 kg CO2-equivalent emissions per kWh (Bundesregierung, 2023).

Concerning the design, the most important sizing factor is the boiler output capacity, which is equal to the design load of the building, considering pipe distribution and initial heat up losses as negligible. Furthermore, operating characteristics of the actual loads, load distribution regarding the maximum, minimum and average load and operational characteristics of the boiler are important information for choosing a suitable boiler. Regarding operational characteristics of the boiler, data about part-load and total-load efficiency, fuel compatibility and available control systems are usually provided by the manufacturer. Finally, several boilers sized for a share of the heating load can increase the efficiency and meet redundancy requirements.

Condensing boilers meeting the legal requirements of fuel using 65% of liquid or gaseous biomass are realizable with a tank in-situ, or by considering mass balance by using gas from networks which deliver natural gas with a share of maximum 15% of biogas but buying special gas with a share of 65% of biogas which is introduced at a different place into the gas network (TGA Fachplaner, 2024). Both options result in higher operating costs. Another possibility are pellet boilers using as fuel 100% solid biomass.

2.3.4 Cogeneration

Cogeneration systems, also called combined heat and power (CHP), simultaneously generate electrical or mechanical power and thermal energy from a single energy source.

They are composed of prime mover and fuel supply system, generator and accessories, waste heat recovery system, control systems, electrical and thermal transmission and distribution systems, connections to mechanical and electrical services, and optionally thermally activated technologies. Types of CHP are distinguished by their application, kind of cycle, grid-connection, and engine system. Regarding the application of CHP, they can serve in the first place to provide power, including base-load power, peaking power, back-up power, and remote power, or they can be concepted supply thermal energy at the first place and additionally generating power. Furthermore, they differ in terms of the cycle: topping cycles produce power and use exhaust to produce heat, while bottoming cycles work the other way around and combined cycles produce power with heat exhausted from power production. CHP can be isolated or grid-connected, second leaves the choice to adapt the capacity to the thermal load and supply excessive power to the grid. Packaged CHP systems are available in a range of 5 to 5000 kW of electric power, equipped with reciprocating engines, microturbines or combustion turbines.

Regarding the characteristics of cogeneration systems, efficiency, economics, and advantages are discussed. CHP overall efficiency is the sum of the electric and thermal power output divided by the fuel power input. In terms of economic considerations, investment is moderate and operational costs are reduced in comparison to similar single systems. Since on the one hand, fuel prices depend on inflation rate and CO2-tax development, and on the other hand, electricity prices may be higher or lower in comparison to the electricity generated by the CHP system, operational costs are difficult to predict and require an economic analysis of each case. General advantages of CHP plants include improved power reliability and quality, the high energy-efficiency, and by that, the reduction of emissions in comparison to similar single systems.

A CHP plant is suitable if its electrical and thermal outputs fit best with the electrical and thermal building loads. The design depends on load profiles and may include the selection of special components for cooling or dehumidification. (ASHRAE, 2016, pp. 7.1-7.9)

The mentioned restrictions regarding fuel supply to meet the legal requirement for condensing boilers apply as well to CHP plants.

2.3.5 Heat pumps for residential applications

“A heat pump extracts heat from a source and transfers it to a sink at a higher temperature” (ASHRAE, 2016, p. 9.1), generally referred on applications which permit heating, and which may be used for cooling too.

Heat pumps consist of the combination of a compressor, a condenser, an expansion device, and an evaporator, mostly working as a closed vapor compression cycle powered by electricity. Heat pumps differ depending on the heating and cooling distribution fluid, on the kind of changeover, on the capacity, and on the heat source and sink. The heat pump cycle fluid is a refrigerant, and the heating and cooling distribution fluid is air or water depending on the in-room terminal systems. Changeover between heating and cooling is realized by changing the refrigerant direction or in case of water-to-water-heat pumps the water direction. Heat pumps are available in the range of 2 kW to 44 MW. Sink and source mediums can be air, water, ground, and solar energy. Air source heat pumps (ASHP) have the advantage to be easily installed and widely used in residential applications. Limitations are the dependency on outdoor air temperature variations causing lower efficiencies and capacities during extreme weathers, noise generation, and frost problems. Defrosting of the outdoor coil is acceptable until approximately -8°C and 60% of relative humidity. Water-to-water heat pumps can be linked to sewage water or groundwater, benefitting of the relatively constant water temperatures ranging from 8°C-12°C in case of north-east Germany (Senatsverwaltung Berlin, 2024) improving the systems efficiency. Limitations are water use restrictions, the alteration of the water temperature and quality, which may cause damage to the environment and the higher costs of investment. Ground source heat pumps (GSHP) may be closed-looped using a secondary loop with brine which connects the ground-to-brine and brine-to-water heat exchangers, or direct-expansion looped burying a ground-to-refrigerant heat exchanger directly. Loops can be buried horizontally with serpentine heat exchanger pipes in a depth and inter-pipe distance of 1 to 2 m or in slinky loop configuration, or vertically using concentric tube or U-tube heat exchangers. GSHPs profit of the constant temperature of the ground throughout the year which increases system’s efficiency. Limitations are space restrictions, the thermal diffusivity of the soil which must be determined in-situ performing a thermal response test, the alteration of the soil temperature and the higher costs of investment.

Regarding the characteristics of heat pumps, the efficiency, the costs, the control systems, additional heating, and the environmental impact are discussed. In terms of efficiency, heat pumps are compared by the coefficient of performance (COP) for heating and the energy efficiency ratio (EER) for cooling, and the seasonal correspondents SCOP and SEER. Typically, COPs are ranging between 3 to 6 depending on source type. Most efficient are systems with constant source or sink temperatures as explained above. Concerning installation costs, air source systems mean low, water-source systems medium and ground-source systems high expenses, while operating costs are moderate in case of air- and water-source systems and low in case of closed-loop ground-source systems. Controls include defrost control, control for changing from heating to cooling, and flow control to avoid running the heat pump cycle while there is no flow of the distribution fluid. For satisfying peak loads at extraordinary cold days, an economic analysis can provide information if either additional heating or adding compressor capacity is best suited. In terms of environmental impact, heat pumps have reduced emissions during operation due to the use of environmental heat although the quantity of emissions depends finally on the kind of electricity generation. Furthermore, the emissions of the whole life cycle are influenced by the refrigerants global warming potential. Finally, in case of water and ground source heat pumps, the environmental impact can be reduced by balancing the injected and extracted heat over the year, and by using a closed-loop system. If heat injection is too high in GSHPs, loop heat rejection through a cooling tower or air-cooled condenser are available.

Concerning the design of heat pumps, the building heating and cooling load, the available source options and corresponding local restrictions, the available space and the costs of installation and operation must be considered. (ASHRAE, 2016, pp. 9.1-9.9)

Heat pumps meeting the legal requirements provide a heating capacity which covers at least 30 % of the heating load in bivalent-parallel operating mode. Under typical conditions, this means a satisfaction of approximately 65% of the yearly heating energy.

2.3.6 Solar thermal energy generation

Solar thermal energy generation is based on the direct absorption of solar energy transferred by radiation. The absorber must have a high absorption coefficient which is influenced by the absorber material, color, and spectrum of wavelength absorption. Furthermore, the absorber must be highly conductive to transfer the absorbed energy to the fluid cycling inside the absorber. To increase the heat gain, the greenhouse effect is generated by leaving an air layer and a glazing with a high transmission coefficient of solar radiation and low transmission coefficient of outgoing long-wave radiation, and the thermal losses are reduced at its back side by using conventional insulation materials. Further components are the pipe system to distribute the fluid in a balanced way and the thermal storage to guarantee energy supply in moments without sun radiation.

Solar thermal energy systems may be using air or a liquid as a fluid. Air-heating systems are used in forced-air space heating and in drying processes for industrial or agricultural purposes. Liquid heating systems using water, or a mix of water and an anti-freezing liquid, are applied to hydronic space heating, pool heating, sanitary hot water generation, industrial water heating and heat-driven air conditioning. Common types of solar thermal energy systems using liquid fluids are thermosiphons working by natural convection of the fluid saving the need of a pump and designed for smaller capacities, flat-plate collectors using pumps for fluid transport and making great system capacities possible, and evacuated tube collectors also using pumps for fluid transport and reaching higher temperatures and efficiencies.

Regarding the characteristics of solar thermal energy systems, the efficiency, costs, environmental impact, control, and special considerations regarding thermal storage, and anti-freezing are discussed. The efficiency of a solar thermal energy system depends on the collector efficiency and the heat losses of the pipe system. The collector's efficiency is influenced by the type of collector, the solar irradiation, the ambient temperature, and the supply and return temperature to the collector and can reach a maximum efficiency of around 70% but falls below 25% at cloudy days. In terms of installation costs, flat plate collectors are more economic while evacuated tube collectors mean higher investment costs. Thermal solar energy systems convince with very low emissions during operation. Regarding the controls, automatic temperature control by using a differential temperature controller between collectors and storage and control to protect against overheating are necessary. A thermal storage is required to improve the reliability of the system during times of low sun irradiation and can be characterized by its construction material, insulation, stratification possibility and connections. Its size should be between 40 to 80 l tank volume per square meter collector area. Besides, an anti-freezing agent, usually propylene glycol, must be added to the liquid inside the primary circuit to avoid freezing which may take place at temperatures above the freezing point of the liquid because of the radiation to the cold sky. (Cazorla, 2022)

Concerning the selection and design of a thermal solar energy system, the first step is to determine the suitability of the system regarding the local conditions of sun irradiation and of available space and orientation for collector installation. In case the conditions are suitable, the type of collector must be selected depending on application and climate. The total capacity of the system is calculated considering the collectors' capacity, its aperture area, and the total available surface. Furthermore, the piping configuration of rows and arrays and the adequate size of the thermal storage must be designed.

(ASHRAE, 2016, pp. 37.1-37.11)

Solar thermal energy systems meeting the legal requirements must provide at least a ratio between aperture area and effective building area of 0.06 according to §71h, GEG (Bundesregierung, 2023). In case of evacuated tube collectors, the minimum area reduces of 20%. Additional systems may be condensing gas boilers if using at least 60% of liquid, gaseous or solid biomass.

2.3.7 Direct electricity heating

Since direct electricity heating is only possible if a building complies with increased thermal insulation standards in comparison to normal requirements, this option will be left out since the present building is not planned to conform with the requirements. Furthermore, this alternative shows higher operating costs, provides no cooling, and is normally applied for small rooms or as an additional system.

2.4 Thermal storage for residential applications

"Thermal storage systems remove heat from or add heat to a storage medium for use at another time"(ASHRAE, 2016, p. 51.1). Thermal storage is applied for space cooling or heating by mainly using water as a sensible storage medium. The main advantages of thermal storage are the possibility to satisfy loads when energy generation is unavailable, to reduce the equipment size for energy generation by balancing peak loads, to save operational and initial costs and to improve operation flexibility of the system. Regarding the design of thermal storage, a load profile and an energy generation profile helps to size the storage correctly. For small applications, empirical sizing values depending on the energy generation system may be used. Finally, an operation and control strategy must be defined according to the energy generation and energy distribution system. More information about thermal storage is detailed in (ASHRAE, 2016, Chapter 51)

3 METHODOLOGY

3.1 General methodology

The general methodology is divided in a theoretical and applied part as illustrated in Figure 2. In a first step, the present work gives an overview about the state of the art and the applicable normative in respect of heating and cooling loads of buildings, of heat distribution elements including different heating and cooling terminal units and of different heat generation systems for buildings.

In a second step, the theoretical knowledge is applied on the case of study, which consists in the design of the heating and cooling installation of an existing public building and its annex. For this purpose, the heating and cooling load of the building complex is determined based on existing plans, and the in-room terminal systems, the distribution network and the energy generation system are selected and dimensioned.

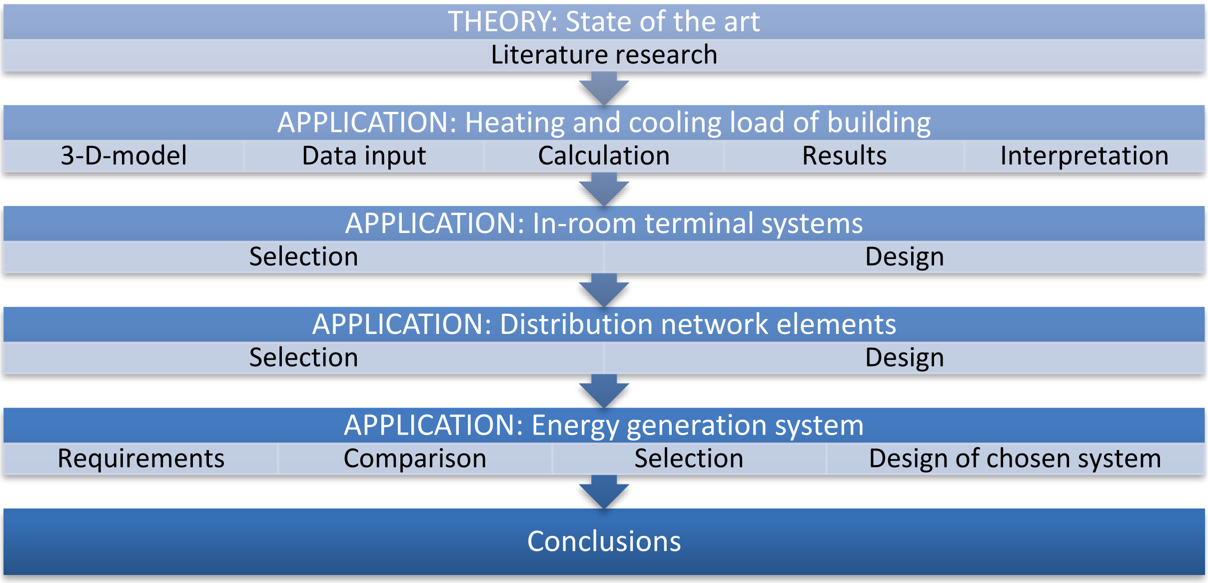


Figure 2: Illustration of the main steps of the applied methodology

3.2 Methodology regarding the design heating and cooling load (see Chapter 5)

The design heating load of the building is calculated based on the standard EN 12831-1 and the corresponding German national annex, while the design cooling load is determined on the basis of the German directive VDI 2078 published in 2015 by Verein Deutscher Ingenieure.

For the calculations, the MEP-software C.A.T.S and the drawing software AutoCAD have been used.

Necessary input data which particularly apply to the heating load respectively to the cooling load have been added to the developed 3D-model. Next, the calculations have been performed with the help of the software. Reviewing the results, some improvements of the model have been introduced. Finally, the analysis of the results and the interpretation of the gained data has been carried out.

3.3 Methodology regarding the selection and design of in-room terminal systems (see Chapter 6)

To select and design the heating and cooling in-room terminal systems, first necessary knowledge is gathered in the state of the art. Second, the heating and cooling loads satisfied by the AHU are calculated, increasing the volume air flow if necessary to cover latent loads or to cover remaining cooling loads of less than a determined threshold (here fixed at -200 W). On base of the results regarding the total heating and cooling loads determined in Chapter 5, the remaining thermal loads are calculated, which must be covered by in-room terminal systems. A selection diagram is developed helping to choose the adequate terminal system for each room. With the help of data sheets of chosen manufacturers, the terminal systems are designed in term of size, power, type, and other factors depending on the kind of terminal system carried out with the help of Microsoft Excel software. Finally, a summary of the selected heating and cooling terminal systems is added.

3.4 Methodology regarding the selection and design of the distribution network (see Chapter 7)

Using the program C.A.T.S., the distribution networks for heating and cooling including the in-room terminal systems are drawn and the power and pressure drop of each in-room terminal systems is introduced with the aim to determine in a first step the required pipe diameters of the heating respectively cooling distribution network. On the base of this knowledge, the secondary elements as manifolds, valves and strainers are designed using the programs MAGplan 6.0.1.28 for the manifolds, Kieback&Peter for the three-way-valves, and manufacturer data sheets for the rest of the elements. The resulting pressure drops of the elements are introduced into the program C.A.T.S. Finally, the total pressure drop in each heating and cooling loop is calculated. On this basis, the pumps are designed with the help of the program Wilo-Select 4.

3.5 Methodology regarding the selection and design of the energy generation system (see Chapter 8)

For the selection and the design of the energy generation system, the first step is to determine the requirements concerning the thermal loads, the legal regulations, and the buildings characteristics.

Second, a preselection using a decision matrix leads to a base case and two alternatives which are analyzed and compared regarding their energy consumption, their environmental impact, and their economic impact, resulting in the selection of the energy generation system. For the calculations, the efficiencies and further characteristics of the different systems are extracted of corresponding data sheets. Investment and operating costs are provided by quotes of the manufacturers or extracted from suitable sources. Besides, weather data of the nearest weather station are analyzed and prepared resulting in a data set of mean hourly outdoor air temperatures for each month. Furthermore, primary energy factors and emission factors as well as energy prices and inflation rates are extracted of suitable data bases. Based on the previous information, the heating and cooling consumption are modeled, the total equivalent warming impact is determined and the amortization time of the alternatives in comparison to the base case are calculated with the help of Microsoft Excel software.

Third, the selected hybrid energy system consisting of a geothermal heat pump and a condensing gas boiler is designed. The heat pump model is chosen in function of power, size, efficiency, and noise levels. The ground heat exchanger is calculated according to recommendations of the International Ground Source Heat Pump Association (IGSHPA) (International Ground Source Heat

Pump Association, 1988) and an analysis of the best exchanger length to economic benefit ratio is carried out to find the best solution regarding the heat exchanger length with the help of Microsoft Excel software. The primary and secondary circuit design including the selection of suitable materials, pressure drop due to the elements and the necessary circulation pumps is realized using corresponding data sheets, the pressure drop program published by Software-Factory Schmitz and the program Wilo-Select 4 for the pump selection. The condensing gas boiler is designed according to recommendations of (ASHRAE, 2016, p. 32.5) and the buffer tanks considering the response time of temperature sensors. Regarding the pressure maintenance and refiling station, the design program Reflex Solutions Pro Version 24.02 from the manufacturer Reflex Winkelmann GmbH is employed.

Finally, all results are resumed in a hydraulic scheme.

4 DESCRIPTION OF THE CONSTRUCTION PROJECT

4.1 General description

The planned building complex is composed of two buildings, an existent building (in the following also called “old building”) built in 1924 which has been used as a train station building (see Figure 3) and an annexed new building which will be directly added to the northern wall of the existent building allowing the passage through a door in each floor level. Both buildings consist of five floor levels, three of them above the ground and two of them partly underneath the ground and partly opened in direction to the train tracks. The future building complex will be used as a public cultural center. The existent building will be compromising library rooms, a consulting room, exercise rooms, a staircase, restrooms, tea kitchens and a big event room amongst others. Furthermore, a passageway from the train station to the public road leads through the building for which reason a bistro is planned next to the passage. The new building accommodates another staircase, a lift and different technical installation rooms as well as two further consulting rooms. In total, the simultaneous use of the building complex is limited to 200 persons maximum. To be able to comply with energy efficiency requirements, the existent building’s envelope will be refurbished adding thermal insulation and improving airtightness on the one hand and the new building will be planned to comply the newest standards concerning insulation and airtightness requirements. On the other hand, all technical building installations e.g. electricity installations, heating and cooling installations and sanitary installations will be renewed to meet the needs of the building complex.

Figure 3: Front view of existent station building (Jivee Blau, 2012)

4.2 Ubication and climate

The building complex is located in Hohen Neuendorf, a city of approximately 27,000 inhabitants (Stadt Hohen Neuendorf, 2024) around 20 kilometers north of Berlin in Germany in the community Oberhavel (see Figure 4 and Figure 5).

Map data ©2023 GeoBasis-DE/BKG (©2009), Google 50 km

Figure 4: Ubication of building complex (large scale) (GoogleMaps, 2024)

Kartendaten © 2023 GeoBasis-DE/BKG (©2009),Google 200 m

Figure 5: Ubication of building complex (small scale) (GoogleMaps, 2024)

The climate is a warm-temperate climate with precipitations throughout the year and warm summers (Kottek, 2006). The minimum mean temperature of the year is in January with 1.1°C and the maximum average temperature lies in July with 19.7°C. In Figure 6, the mean temperature and the maximum and minimum temperature of each month of the year is illustrated, based on weather data from the years 2008 to 2022 published by Deutsche Wetterdienst (DWD) for the nearest weather station in Buch with the identification number 400 (Deutscher Wetterdienst, 2023).

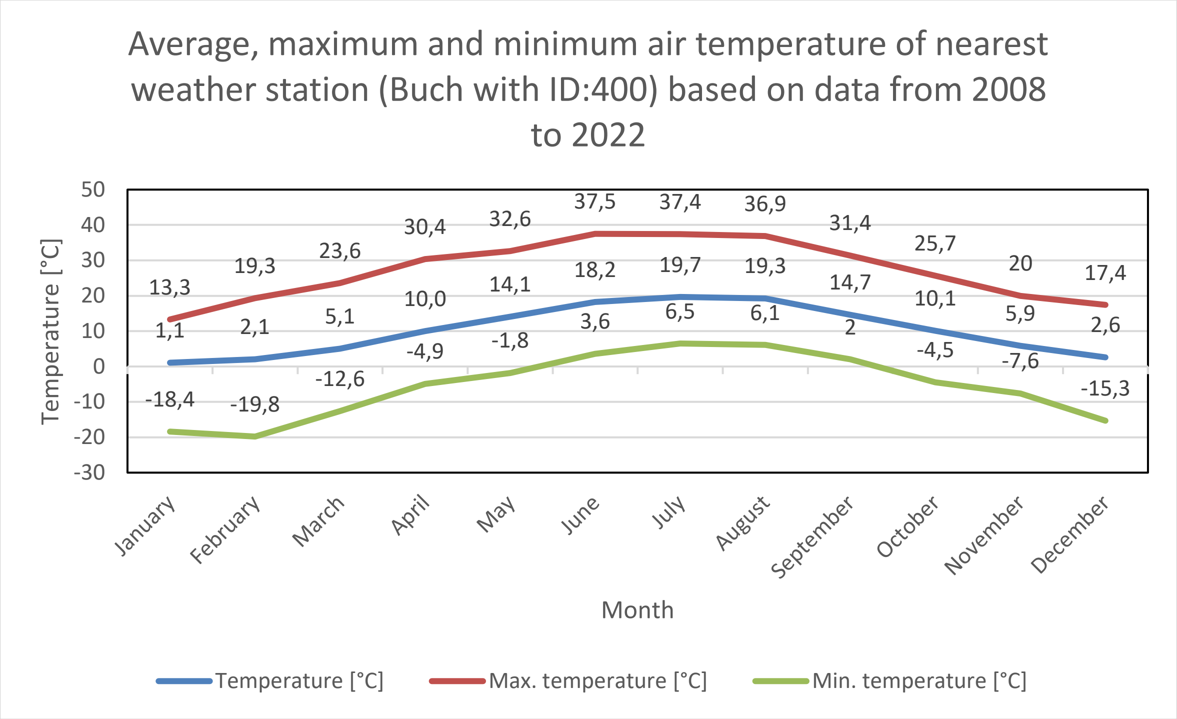


Figure 6: Average, maximum and minimum air temperature nearby the building complex

Furthermore, a good approximation regarding the earth temperature in lower depths is the yearly mean outdoor air temperature., which is calculated on base of the above-mentioned weather data and lies at 10.22°C for the present building complex.

4.3 Geometry of the building complex

For the calculation of the heating and cooling loads, the input of the geometry and their characteristics of the building envelope is necessary to obtain a 3D-model of the building into the MEP-software C.A.T.S. and AutoCAD.

First, all types of walls, floors, ceilings, roofs, doors and windows and their characteristics concerning their layers with thicknesses and thermal conductivity, and the adjacent mediums are inputted resulting in a list of construction elements and their thermal transmittances resumed in Table 2. The thermal transmittance of the exterior walls in contact with the earth are generally between 0.13 W/m²K and 0.29 W/m²K with a maximum admissible value of 0.30 W/m²K according to No. 6a, annex 7, GEG (Bundesregierung, 2023). Concerning the exterior walls in contact with the outdoor air, the values lie between 0.12 W/m²K and 0.23 W/m²K with the maximum admissible value of 0.24 W/m²K (No. 1a, annex 7, GEG). Furthermore, the roofs show values between 0.11 W/m²K and 0.19 W/m²K with a maximum admissible value of 0.24 W/m²K (No. 5a, annex 7, GEG). Regarding the floors in contact with the earth, the values lie between 0.15 W/m²K and 0.23 W/m²K with a maximum admissible value of 0.30 W/m²K (No. 6a, annex 7, GEG). The ceilings have thermal transmittances between 0.25 W/m²K and 1.97 W/m²K and the interior walls between 0.31 W/m²K and 2.94 W/m²K, both without legal requirements concerning the thermal transmittance. Exceptions are the exterior wall in contact with the earth “AE1c” with a thermal transmittance of 0.58 W/m²K and the exterior wall “AW2” with a thermal transmittance of 1.51 W/m²K, showing higher values than the admissible once but kept as they are indicated by the architect considering a conservative estimation. Regarding the openings, the windows are assumed to have a thermal transmittance between 0.80 W/m²K and 1.10 W/m²K and the doors between 1.80 W/m²K and 2.00 W/m²K, taking into account the maximum value for exterior windows of 1.30 W/m²K and for exterior doors of 1.8 W/m²K (No. 2a and No. 4, annex 7, GEG).

Table 2: Buildings construction characteristics

Type	Short cut	Element name	Thickness [mm]	Thermal transmittance [W/m²K]	Based on information of	Amount [-]	Accumulated area [m²]
Exterior walls earth	AE0	EW1_410_earth	410	0.13	Building physicist	24.00	224.85
	AE1	EW2_610_earth	610	0.29	Architects	19.00	106.80
	AE1a	EW3_720_earth	720	0.28	Architects	3.00	67.48
	AE1b	EW4_1130_earth	1130	0.24	Architects	1.00	24.20
	AE1c	EW5_1230_earth	1230	0.58	Architects	4.00	47.27
Exterior walls	AW0	EW6_560_InteriorInsulation	560	0.23	Building physicist	3.00	80.06
	AW0a	EW7_450_ExteriorInsulation	450	0.13	Building physicist	42.00	410.13
	AW1	EW8_650_ExteriorInsulation	650	0.12	Building physicist	5.00	94.33
	AW1a	EW9_500_DormerWest	500	0.19	Architects	2.00	19.02
	AW1b	EW10_480_DormerWest_Side	480	0.13	Architects	4.00	8.17
	AW1c	EW11_450_DormerEast	450	0.19	Architects	14.00	182.66
Exterior walls	AW1d	EW12_300_DormerEast2	300	0.20	Architects	5.00	53.31
	AW2	EW13_400_Existent	400	1.51	Architects	3.00	5.15
	AW2a	EW14_500_ExistentInsulated	500	0.19	Architects	1.00	8.05
	AW2b	EW15_520_ExistentInsulated	520	0.19	Architects	9.00	114.32
Roofs	DA0	RO1_Flat	402	0.11	Building physicist + architects	4.00	85.70
	DA1	RO1b_Flat	500	0.19	Building physicist	0.00	0.00
	DA2	RO2_Inclined	295	0.19	Building physicist	4.00	277.34
Ceilings	DE0	CE4_Tiles1_NewBuilding	325	1.04	Sections floors	22.00	424.50
	DE0a	CE5_Tiles2_NewBuilding	305	1.05	Sections floors	7.00	170.70
	DE0b	CE6_Lino_NewBuilding	323	0.79	Sections floors	3.00	88.40
	DE1	CE1_Lino_OldBuilding	385	0.25	Sections floors	28.00	731.25
	DE2	CE2_Tiles1_OldBuilding	252	1.97	Sections floors	21.00	627.02
	DE2a	CE3_Tiles2_OldBuilding	272	1.00	Sections floors	20.00	579.74
Floors	FB0	FL1_NewBuilding	800	0.23	Architects	6.00	85.30
	FB1	FL2_OldBuilding	442	0.15	Sections floors	6.00	246.34
Interior walls	IW1	IW1_200_Concrete	200	2.94	Architects	39.00	218.60
	IW1a	IW2_300_Concrete	300	2.63	Architects	22.00	124.90
	IW2	IW3_75_Drywall	75	0.55	Architects	55.00	279.93
	IW2a	IW4_145_Drywall	145	0.31	Architects	24.00	213.22
	IW2b	IW5_150_Drywall	150	0.36	Architects	2.00	23.55
	IW2c	IW5a_100_Drywall	100	0.52	Architects	4.00	15.24
	IW3	IW6_240_Brick_New	240	1.63	Architects	15.00	105.50
	IW3a	IW7_390_Brick_Existant	390	1.35	Architects	0.00	0.00
	IW3b	IW8_420_Brick_Existant	420	1.28	Architects	0.00	0.00
	IW3c	IW9_520_Brick_Existant	520	1.11	Architects	12.00	87.05

Type	Short cut	Element name	Thickness [mm]	Thermal transmittance [W/m²K]	Based on information of	Amount [-]	Accumulated area [m²]
	IW3d	IW10_400_Brick_Existant	400	1.33	Architects	29.00	319.34
	IW3e	IW11_270_Brick_Existant	270	1.68	Architects	33.00	266.56
	IW3f	IW12_175_Brick_Existant	175	2.10	Architects	26.00	226.23
	IW3g	IW13_115_Brick_New	115	2.33	Architects	11.00	66.29
	IW3h	IW14_310_Brick_Existant	310	1.55	Architects	4.00	33.01
Openings	AF0	EWindow1_NewBuilding	-	0.80	Building physicist	12.00	48.50
	AF1	EWindow2_OldBuilding	-	1.10	Building physicist	32.00	121.53
	AF2	Roof windows	-	1.00	Building physicist	9.00	11.07
	AT0	EDoor1	-	1.80	Software defaults	1.00	6.30
	IF0	IWindow1	-	1.10	Software defaults	8.00	21.78
	IT0	IDoor1_Standard	-	2.00	Software defaults	79.00	223.65
	IT1	IDoor2_Lift	-	1.80	Software defaults	10.00	25.60

Second, the geometry of the walls, windows and doors are drawn on the basis of the floor plans given by the architects. The amount and accumulated area of each element is indicated in Table 2 above.

Third, by introducing room stamps for each room, more characteristics are assigned to each room like the room number, the height of the floor level and the clear height.

Fourth, the rooms are parametrized assigning floors, ceilings and roofs and the corresponding adjacent outside conditions to each room. The inclined roofs and the roof windows are introduced manually. A detailed list of introduced floors, ceilings and roofs and the outside conditions can be found in Appendix I in 11.1.2.

As illustrated in Figure 7, the geometry has been carefully introduced into the program to obtain a result reflecting at its best the reality.

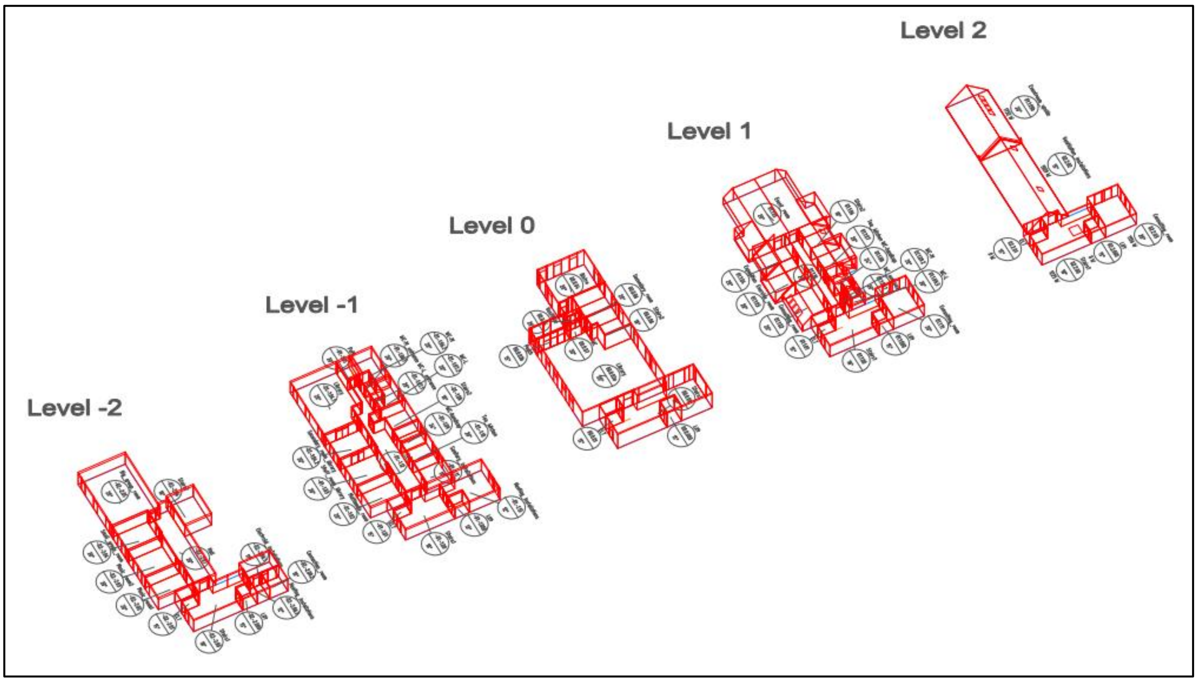


Figure 7: 3-D model of building complex illustrated inside the program C.A.T.S. and AutoCAD

4.4 Floor plan

An overview of the room distribution of each floor level with the corresponding room numbers is added in plans 1-5 in Part III: Technical drawings as well as plan 6 with the 3-D model in a better resolution.

4.5 User time schedule

The building is planned to be used as a public building. The opening hours are generally estimated to be from 8h until 18h for all rooms except for the event room, which is expected to be used from 18h to 21h.

4.6 Requirements and conditions for technical building installations

Most of the rooms are required to be heated during winter and some rooms should be additionally cooled during summer. There is a demand of sanitary hot water due to tea kitchens, bistro and restrooms, which can be planned as a decentral system. Furthermore, ventilation is planned in several rooms, in which an air renovation is necessary to guarantee a healthy air environment. Figure 8 shows the type of conditioning, which is planned for each room, illustrating non-conditioned (blue), heated (salmon) and both heated and cooled rooms (purple), as well as rooms with planned ventilation (hatched). In Part III, plan 7 provides the type of conditioning in a better resolution.

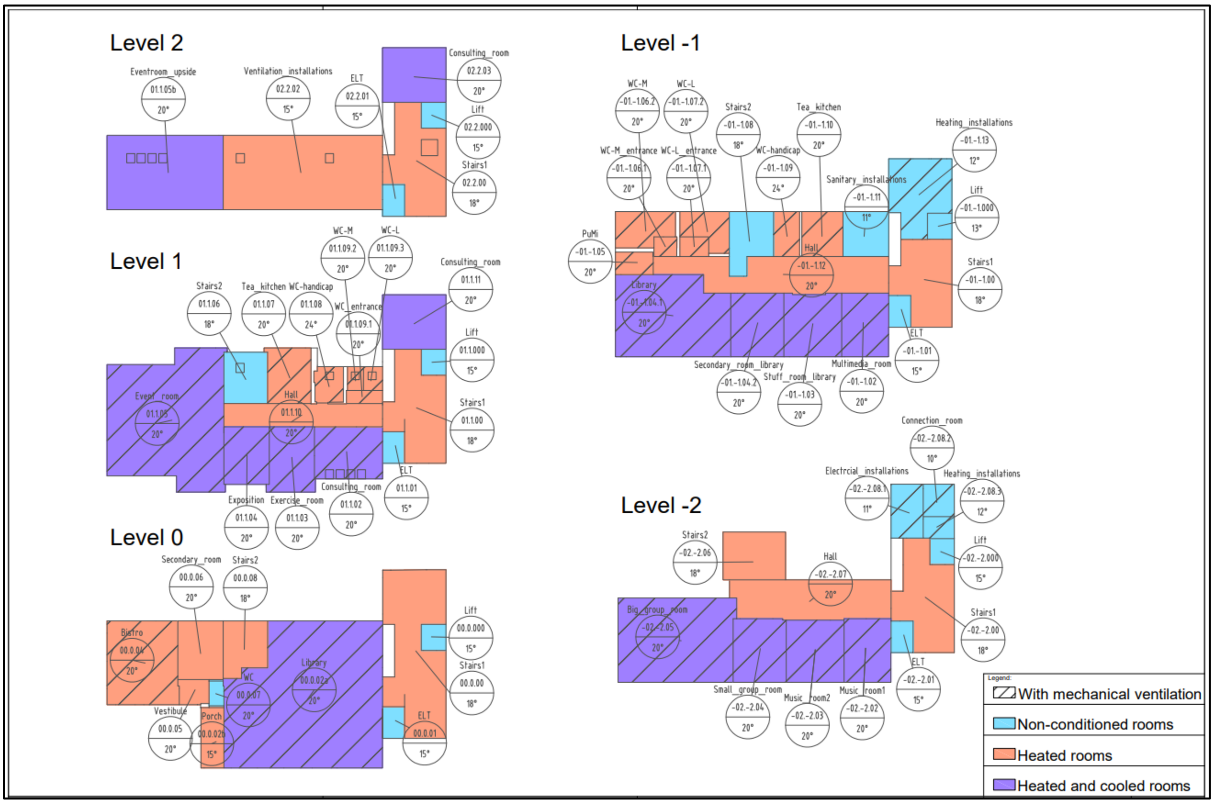


Figure 8: Illustration of non-conditioned, heated, cooled and ventilated rooms

Concerning the space needed for the technical installations, several rooms are reserved for heating, sanitary and electrical installations. For the distribution elements, an installation duct is planned inside of the new building making possible the vertical distribution. Horizontal distribution in each floor level can be planned either in destinated spaces hidden in the ceiling or as visible pipes underneath the ceiling.

Since the zone of the bistro which includes a secondary room and a vestibule are planned to be rented to a company, the design must consider a water, heating and cooling supply independent of the rest of the building complex.

An air-handling unit (AHU) for ventilation is planned by the ventilation department. The data provided and used are listed in Table 3.

Table 3: Input data of air-handling unit provided by ventilation department

Mode	Characteristics	Input value	Unit
-	Total volume supply air flow	3,500	m³/h
-	Temperature efficiency (EN 308)	76.6	%
Cooling	Supply air temperature	18.0	°C
	Relative humidity of supply air	87.6	%
	Exhaust air temperature	28.0	°C
	Relative humidity of exhaust air	55.0	%
	Outdoor air temperature	32.0	°C
	Relative humidity of outdoor air	42.0	%
Heating	Supply air temperature	20.0	°C
	Relative humidity of supply air	7.6	%
	Exhaust air temperature	20.0	°C
	Relative humidity of exhaust air	50.0	%
	Outdoor air temperature	-12.7	°C
	Relative humidity of outdoor air	87.2	%
Volume supply air flow of each room illustrated in Appendix I in 11.1.3			

5 DESIGN HEATING AND COOLING LOAD

5.1 Data input

5.1.1 Data input for design heating load

In this subchapter, the input data particularly used for calculating the design heating load are indicated. For this purpose, the following assumptions have been made: transmission heat losses and ventilation heat losses are considered while the interior upheating power and heat gains are left out (see Figure 9). Concerning the interior upheating power, the heat losses during heating stop are negligible due to the high insulation grade of the envelope and high airtightness of the building, considering no ventilation during heating stops. The consideration of heat gains is not intended by the German national annex.

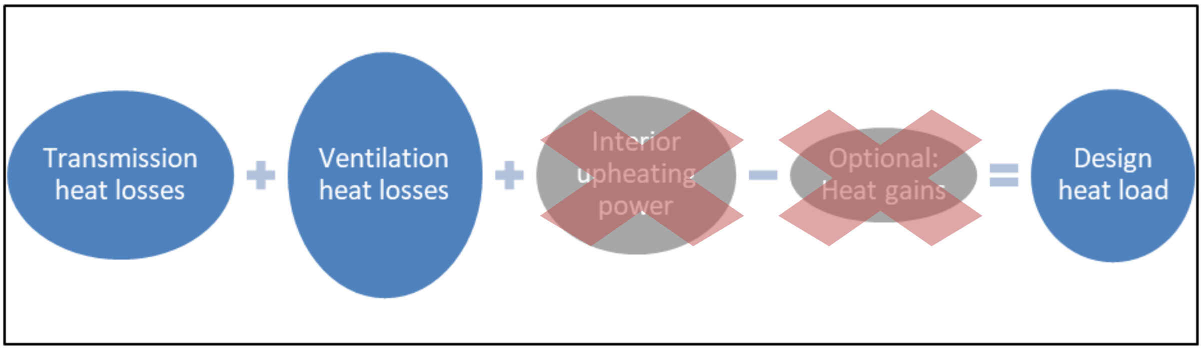


Figure 9: Considered heat losses to calculate design heat load

First, the basic data of the building characteristics are introduced concerning the buildings ubication, the climate zone, the height of the building above sea level, the ground water level, the airtightness of the building envelope, the correction factor for thermal bridges and the existence of breaks during heating. The exterior design temperature results of the ubication, in this case with -12,7°C and is published as an electronical annex of DIN/TS 12831-1(DIN, 2020). Since precise data about the effective overall thermal storage capacity of the building is missing, the correction of the exterior design temperature using the time constant is not applied. An overview of data input concerning the basic data of the building characteristics is given in Table 4.

Table 4: Basic input data regarding the heating load

Characteristic	Input value	Unit
Ubication	Hohen Neuendorf, Germany	-
Climate zone (DIN 4710)	4	-
Exterior design temperature	-12.7	°C
Height above sea level	55	m
Building height (old building)	10.35	m
Building height (new building)	14.76	m
Ground water level	-10	m
Airtightness ($q_{env,50}$)	3	m^3/m^2h
Existence of breaks during heating	not considered	-

By means of room stamps, the interior design temperature is introduced. For this purpose, reference values are taken from table 32 of DIN/TS 12831-1:2020-04 (DIN, 2020, p. 58). An overview of introduced interior design temperatures depending on the use of the rooms is given in Table 5. Most of the rooms are common rooms or restrooms and must be heated to 20°C. Technical rooms are generally not heated unless they could undercool to less than 10°C without heating in which case they are considered as heated rooms. Stairs are designed with an interior temperature of 18°C and bathrooms or changing areas with an interior temperature of 24°C. Some rooms have been considered in the first place as heated rooms, but changed during the calculations to unheated rooms as they would need only a very low heating load of less than 50 W, which can be provided by adjacent heated rooms, always guarantying the interior design temperature according to the standard. A detailed table with interior design temperatures for each room of the building can be found in Appendix I in 11.1.1.

Table 5: Interior design temperatures depending on room use according to DIN/TS 12831-1

Room use	Temperature heating mode [°C]	Minimum temperature unheated [°C]
Technical rooms	unheated	10
Rooms with very low heating load	unheated	according to standard
Technical rooms with high heating load	15	-
Stairs	18	-
Common rooms, restrooms	20	-
Bathrooms, Changing rooms	24	-

Finally, the ventilation parameters are inputted since they strongly influence the ventilation heat losses. The standard specifies the possibility of dividing the building into ventilation zones or handling the building as one ventilation zone. Last is used in case of one-family houses. In case of the existing building complex, each floor level in each building has been defined as an independent ventilation zone. The standard obligates to consider a minimum air change depending on the use of the rooms as described in table 12 of DIN/TS 12831-1 (DIN, 2020, p. 29). Rooms which are permanently occupied and kitchen and sanitary facilities with windows must be considered with a minimum air change of 0.5 1/h while all other type of rooms do not have any specification concerning the minimum air change. Furthermore, an air handling unit (AHU) is projected for the old building which is why mechanical ventilation is planned in some rooms. Common rooms with an expected long-term use by several people must be ventilated mechanically as specified in the ventilation concept provided by the ventilation department to guarantee a healthy air environment. Those rooms possess a balanced supply and exhaust air flow with a supply air temperature of 20°C provided by the AHU. The AHU recovers part of the energy of the exhaust air flow, here assumed with an efficiency of 76.6% as indicated in the data sheet of the air handling unit (see Appendix IV in 11.4.1) The rest of the needed energy to heat up the supply air is delivered by the heat generation system. Besides, some rooms must possess only an exhaust air flow as it is the case for the toilettes, the bistro, the cleaning room, the tea kitchens, and the technical installation rooms. For the calculation of the heating load in these rooms, the needed supply air flow is assumed to be a transfer air flow coming from adjacent rooms and having an average temperature of 20°C. More details can be found in Appendix I in 11.1.3.

Having introduced all the necessary input data, the design heating load can be calculated by means of the programs C.A.T.S. and AutoCAD.

5.1.2 Data input for design cooling load

The data input for the calculation of the cooling load includes the climate zone according to the applied directive, the interior design temperature and its control strategy, the internal and external heat gains, the room type regarding the inertia behavior of the building and the ventilation conditions.

According to VDI 2078, the building is located in cooling load zone 2.

The interior design temperature in summer is generally limited to 26°C considering a medium level of expectation towards the indoor environmental quality (category II) (UNE, 2020, p. 45). In case of the present buildings, it has been agreed with the client upon raising the interior design temperature to 28°C, reducing future energy consumption and being able to design smaller in-room terminal systems and a lower refrigeration generation. A constant interior design temperature during all day has been chosen as control strategy.

Concerning the internal heat gains, heat emitted by occupants, by illumination and by machines are considered. The period of occupation is set from 8h to 18h for all cooled rooms, expect for the event room with a time schedule from 18h to 21h. The number of occupants is adopted from the ventilation concept. The activity level of the occupants depends on the room use and oscillates between activity level 1 and 2, corresponding to relaxed sitting activity with 100 W/person of internal heat gains respectively sitting activity with 125 W/person of internal heat gains [vgl. VDI 2078, 6.2.1]. Illumination is set on during the same period as occupation time, expect for the event room where illumination is defined from 8h to 21h. According to the directive for working places ASR-A3-4, the illumination source strength has been set to 300 lux for all rooms expect for the library rooms where the recommended strength of 500 lux is considered (Ausschuss für Arbeitsstätten, 2023, pp. 19–25). The power of the illumination source is indicated with 8 W/m² achievable with LED spots. Finally, multimedia computers with a power of 100 W are added in library, multimedia and consulting rooms adapting the number of computers to the number of occupants.

To reduce the external heat gains, sun shading, and shadings of the surroundings are taken into account. For all windows expect dormer and roof windows, sun shading in form of exterior pale venetian blinds is provided with a supposed angle of 45°. Dormer and roof windows are introduced without sun shading because the program does not allow the input. Shadings of the surroundings are provoked by one adjacent building complex located eastwards which is composed of the train station and its entrance building. The distances between train station respectively entrance building and old building is estimated with 5 m. The height of the train station is around 3 m, and the height of the entrance building is around 10 m referring both to ground level -2. This results in shadows on all the walls and windows directed eastwards of the cooled rooms in the old building in levels -2, -1 and 0. More detailed information about the input of the internal and external heat gains can be found in Appendix I in 11.1.4.

With the aim to consider the influence of the inertia of the building due to its specific heat capacity, VDI2078 proposes different exemplary room types which have a range of XL (very light) until XS (very heavy). For the present building complex, the exemplary room type M (medium) is chosen for all rooms, corresponding best to the real construction characteristics (VDI, 2015, p. 131).

Regarding the ventilation conditions, the program assumes the existence of an AHU with a sufficient capacity for satisfying momentaneous loads. Concerning the rooms without mechanical ventilation, a window ventilation with an air change of 0.5 1/h of the room air volume is introduced to cover the latent loads.

Finally, the program provides the output of the maximum latent, sensible, and total cooling load of each room at the most inconvenient hour and month of the cooling period.

5.2 Results

5.2.1 General results

In the following, the results of the calculations regarding the design heating load and the design cooling load of the building complex are illustrated.

The total design heating load of the building complex is 39.8 kW, approximately 8.1 kW needed for the new building and approximately 31.7 kW for the old building. Regarding the cooling load, the old building demands -20.1 kW and the new building -1.3 kW approximately, resulting in a total design cooling load of -21.4 kW. In Table 6, the design transmission and ventilation heat losses, the design heating load and the specific design heating load of each room are indicated. Furthermore, the latent, sensible and total cooling load and the corresponding specific cooling load can be found.

Table 6: Results of the design heating and cooling load

Room data				Design heating load				Design cooling load			
Building	**Number**	**Name**	**Area [m²]**	**Design transmission heat losses [W]**	**Design ventilation heat losses [W]**	**Design heating load [W]**	**Specific heating load [W/m²]**	**Latent cooling load [W]**	**Sensible cooling load [W]**	**Total cooling load [W]**	**Specific cooling load [W/m²]**
New	2.001	Lift	3.7	0	0	0	0				
New	2.000	Stairs 1	36.6	916	309	1225	33				
New	2.010	ELT	3.5	0	0	0	0				
Old	2.020	Ventilation installations	84.7	1082	227	1309	15				
New	2.030	Consulting room	22.2	824	332	1156	52	-1*	-687	-688	-31
New	1.001	Lift	3.5	0	0	0	0				
New	1.000	Stairs 1	36.4	663	203	866	24				
New	1.010	ELT	3.5	0	0	0	0				
Old	1.020	Consulting room	25.6	494	166	660	26	-68	-1207	-1275	-50
Old	1.030	Exercise room	22.0	535	238	773	35	-288	-1218	-1506	-68
Old	1.040	Exposition	19.0	458	357	815	43	-288	-1206	-1494	-79
Old	1.050	Event room	105.2	1768	922	2691	26	-1192	-3904	-5096	-48
Old	1.05b	Eventroom_upside	62.6	1023	709	1732	28	0	-1115	-1115	-18
Old	1.060	Stairs 2	15.9	0	0	0	0				
Old	1.070	Tea kitchen	17.4	617	349	966	56				
Old	1.080	WC handicap	7.1	141	151	292	41				
Old	1.091	WC entrance	3.1	26	52	79	25				
Old	1.092	WC-M	2.4	57	24	81	34				
Old	1.093	WC-L	2.2	105	58	163	74				
Old	1.100	Hall	28.3	298	86	384	14				
New	1.110	Consulting room	22.1	725	335	1061	48	0*	-583	-583	-26
New	0.001	Lift	3.9	0	0	0	0				
New	0.000	Stairs 1	59.3	1839	257	2095	35				
New	0.010	ELT	3.5	0	0	0	0				
Old	0.02a	Library	156.3	2028	622	2650	17	-1022	-2079	-3101	-20
Old	0.02b	Porch	6.5	451	98	550	85				
Old	0.040	Bistro	36.7	1244	389	1633	44				
Old	0.050	Vestibule	4.7	42	93	136	29				
Old	0.060	Secondary room	17.9	251	351	602	34				
Old	0.070	WC	2.6	0	0	0	0				
Old	0.080	Stairs 2	14.6	83	129	212	15				

Room data				Design heating load				Design cooling load			
Building	**Number**	**Name**	**Area [m²]**	**Design transmission heat losses [W]**	**Design ventilation heat losses [W]**	**Design heating load [W]**	**Specific heating load [W/m²]**	**Latent cooling load [W]**	**Sensible cooling load [W]**	**Total cooling load [W]**	**Specific cooling load [W/m²]**
New	-1.001	Lift	3.6	0	0	0	0				
New	-1.000	Stairs 1	31.3	634	68	701	22				
New	-1.010	ELT	3.6	0	0	0	0				
Old	-1.020	Multimedia room	19.7	252	396	648	33	-68	-249	-317	-16
Old	-1.030	Staff room library	26.0	298	291	588	23	-68	-311	-379	-15
Old	-1.04a	Library	63.5	1085	1903	2988	47	-375	-1176	-1551	-24
Old	-1.04b	Secondary room library	24.1	288	334	622	26	-170	-292	-462	-19
Old	-1.050	Cleaning room	5.2	122	248	370	71				
Old	-1.061	WC-M Entrance	3.5	48	70	118	34				
Old	-1.062	WC-M	11.2	377	789	1166	104				
Old	-1.071	WC-L Entrance	4.4	61	89	150	34				
Old	-1.072	WC-L	9.8	306	709	1015	104				
Old	-1.080	Stairs 2	15.3	0	0	0	0				
Old	-1.090	WC handicap	7.5	501	737	1238	165				
Old	-1.100	Tea kitchen	12.3	524	725	1249	102				
Old	-1.110	Sanitary installations	12.5	0	0	0	0				
Old	-1.120	Hall	54.4	411	835	1246	23				
New	-1.130	Heating installations	27.8	0	0	0	0				
New	-2.001	Lift	3.6	0	0	0	0				
New	-2.000	Stairs 1	36.8	868	120	989	27				
New	-2.010	ELT	3.6	0	0	0	0				
Old	-2.020	Music room 1	19.7	348	190	538	27	-204	-329	-533	-27
Old	-2.030	Music room 2	25.6	378	157	535	21	-273	-458	-731	-29
Old	-2.040	Small group room	23.9	363	147	509	21	-238	-405	-643	-27
Old	-2.050	Big group room	61.5	980	575	1555	25	-865	-1025	-1890	-31
Old	-2.060	Stairs 2	10.3	354	228	582	57				
Old	-2.070	Hall	39.6	556	332	889	22				
New	-2.081	Electrical installations	11.2	0	0	0	0				
New	-2.082	Connection room	6.1	0	0	0	0				
New	-2.083	Heating installations	4.4	0	0	0	0				
*Latent cooling loads covered by window ventilation					**TOTAL**	39827				-21364	

In Table 7, an overview of the design heating load respectively of the design cooling load of each building depending on the floor level can be observed.

Table 7: Overview of design heating and cooling load of each building and floor level

	Design heating load [W]			Design cooling load [W]		
	Old building	**New building**	**Total**	**Old building**	**New building**	**Total**
Level 2	1309	2381	**3690**	0	-688	**-688**
Level 1	8636	1927	**10563**	-10486	-583	**-11069**
Level 0	5783	2095	**7878**	-3101	0	**-3101**
Level -1	11398	701	**12099**	-2709	0	**-2709**
Level -2	4608	989	**5597**	-3797	0	**-3797**
Total	**31734**	**8093**	**39827**	**-20093**	**-1271**	**-21364**

5.2.2 Specific results regarding the design heating load

Regarding the design heating load, more specific results are indicated in Figure 10, which shows the contribution of heat transmission losses through different types of construction elements as well as the ventilation heat losses due to both infiltration and natural ventilation, due to supply air flow and due to transfer air exchange with adjacent rooms for each of the two buildings.

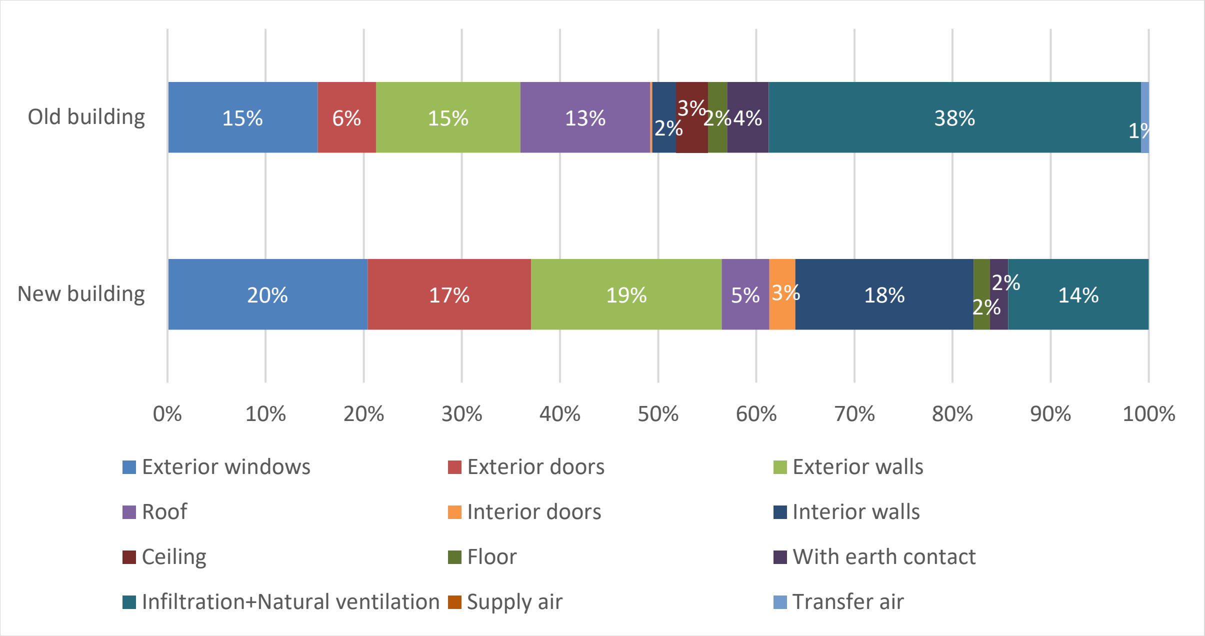


Figure 10: Contribution of transmission heat losses and ventilation heat losses to design heating load

Concerning the old building, infiltration and natural ventilation losses contribute most to the heating load with 38%, followed by heat transmission through exterior windows and walls with both 15% and through the roof with 13%. The new building loses most heat through the exterior windows and walls with 19% respectively 20%, through interior walls to unheated rooms with 18%, through exterior doors with 17% and due to infiltration and natural ventilation with 14%.

5.2.3 Specific results regarding the design cooling load

For each cooled room, the sensible and latent cooling load due to occupants and the course of the total cooling load along a type day can be calculated. Type days are defined as clear, medium, or cloudy days of a chosen month. Since for the present building complex maximum values of the cooling load are indicated at clear days in the month of July, the following results are all referred to this type day. As an exemplary room, the results of the library in level 0 as one of the biggest and most occupied rooms are illustrated in the following. For better presentation, the cooling loads are exceptionally illustrated in positive values in the following figures. Figure 11 indicates the sensible and latent cooling load due to occupants. The results show a sensible cooling load with low variations with values between -1524 W and -1471 W and a constant latent cooling load of -1022 W from hour 9 to hour 18.

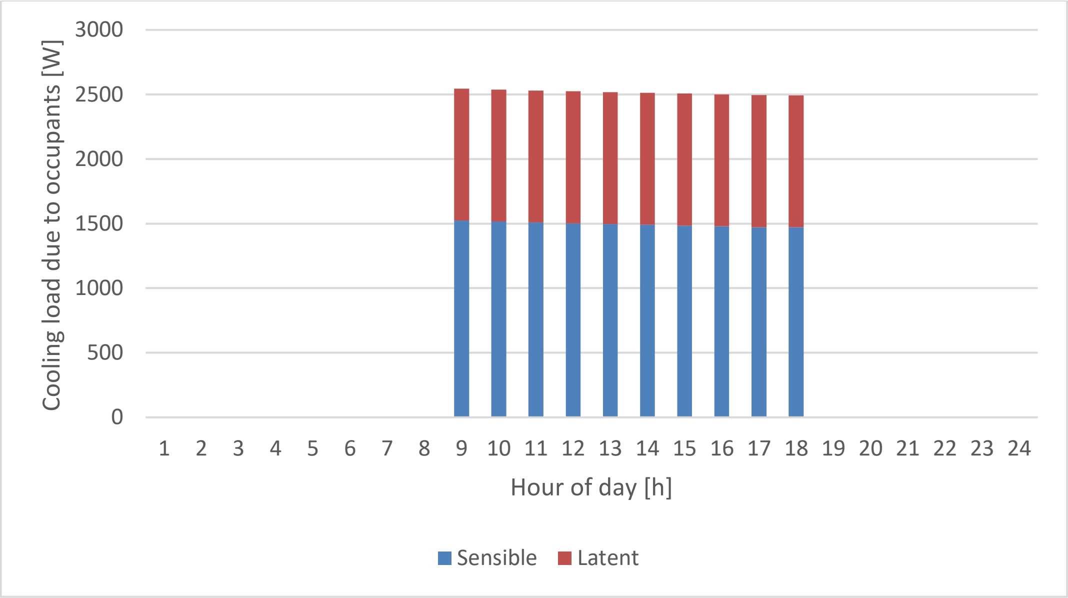


Figure 11: Cooling load due to occupants at clear day in July in library (room no. 0.02a)

Furthermore, the course of the cooling load as well as the interior room and outdoor air temperature in the library of level 0 along a clear day of July is illustrated in Figure 12. The design room temperature is set to a constant value of 28°C. The outdoor air temperature is between 16°C in the coldest moment during night and 31°C in the warmest moment during hour 16 and 17 in the afternoon. The latent cooling load is constantly -1022 W from hour 9 until hour 18. The sensible cooling load starts and ends with positive values, which are changing to negative values from hour 9 until hour 20, with a peak during hour 18. During this time period, the outdoor air temperature lies between 23.8°C and 28.0°C.

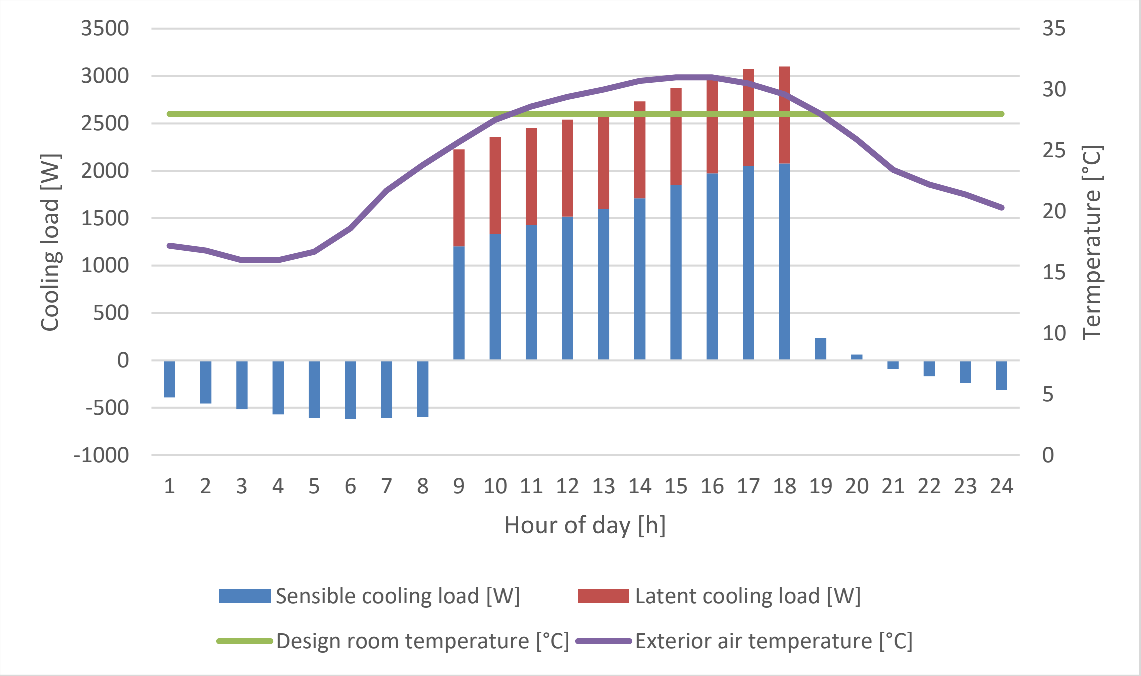


Figure 12: Course of cooling load, room and exterior temperature along a clear day of July in library (room no. 0.02a)

5.3 Interpretation

5.3.1 Interpretation of results regarding the design heating load

With the help of the program C.A.T.S., an analysis of the specific heating load has been conducted as shown in plans 8-12 in Part III. The rooms can be distinguished by a color code, showing unheated rooms, rooms with heating loads until 40 W/m², until 80 W/m², until 120 W/m² and until 170 W/m². Most of the rooms have a heating load of less than 40 W/m², which is a value easy to cover by different heating terminal units including radiant floor heating. Higher demand of until 80 W/m² are showed by more exposed rooms with more construction elements in contact with the outdoor air, for example by the consulting rooms in the new building in level 1 and 2, by the rooms which are partly covered by the inclined roof in level 1 and by the library in level -1 underneath the train station passage. Exceptional high demands can be found in the porch since it is very exposed to the exterior conditions, and in some rooms of level -1, probably because of the high thermal transmittance of the corresponding exterior wall with U=0.29 W/m²K. Furthermore, higher heating loads are observed only in the existing building where retrofitted insulation has smaller thicknesses while the new building shows generally low values of the heating load, confirming the plausibility of the calculated values.

Furthermore, it is important to mention that the event room has been separated into two parts with the room numbers 1.05 (event room) and 1.05b (event room – upside), while in reality, it is one big room opened to the roof. The reason for this way of introducing the rooms is due to an easier program input. The internal heat gains have been counted only once to avoid altering the results. The results of each room are summed up in order to obtain the heating respectively cooling load for the entire event room.

The contribution to the design heating load due to transmission and ventilation heat losses seems plausible. The values of the two buildings are similar and show that most of the heat losses are due to transmission through exterior walls, windows, and doors and through the roof or due to ventilation heat losses due to infiltration and natural ventilation confirming theoretical considerations beforehand. Differences between the buildings can be observed on the one hand regarding the contribution of the ventilation heat losses due to infiltration and natural ventilation which has a higher contribution in the old building with 38% to the total heating load than in the new building with only 14% to the total heating load. This can be explained by the fact that nearly all rooms of the new building do not need any minimum air changes due to their use, while more than the half of the rooms of the old building needs a minimum air change of 0.5 1/h. On the other hand, the new building shows a higher contribution to the heating load due to transmission heat losses through interior walls to adjacent unheated rooms, which makes sense since a lot of the unheated technical installation rooms are located in the new building, while the rooms in the old building are mostly heated.

5.3.2 Interpretation of results regarding the design cooling load

The results regarding the specific cooling loads are depicted in plans 8-12 in Part III, where rooms are hatched with a specific cooling load of until -20 W/m² in color green, between -20 W/m² and -40 W/m² in color yellow, between -40 W/m² and -60 W/m² in color orange and between -60 W/m² and -80 W/m² in color red. It can be observed that the rooms in levels underneath the ground and in the ground level 0 show specific cooling loads of less than -40 W/m² which is plausible since they have internal gains due to occupants, machines, and illumination but few external gains because they are more protected from the sun irradiation and have less contact to the outdoor air. The cooled rooms in the new building have also specific cooling loads until -40 W/m² which can be explained by better insulation of the new building. Finally, the rooms of the old building in level 1 present higher values of the specific cooling load of until -80 W/m² which can be justified by higher exposition to the sun irradiation on the top of the inclined roof and through exposed windows, the lower insulation of the walls and roofs and the high transmission surface in contact with the outdoor air.

Regarding the cooling load due to occupation (see Figure 11), the results illustrated for the library room in level 0 0.02a are convincing, since the occupation time period of the library is supposed to be from 8h to 18h with an occupation of constantly 11 persons. Taking into account the latent and sensible cooling load, the occupants of the library cause a total cooling load of approximately -230 W/person.

Concerning the course of the cooling load along a typical clear day of July, it can be observed that the sensible cooling load starts and ends with positive values which means that theoretically, the room needs to be heated to reach the set room temperature of 28°C. This is due to the chosen control strategy of setting a constant interior room temperature, which could be improved in future calculations by setting a maximum interior room temperature allowing lower values in hours with lower outdoor air temperatures. On the one hand, it can be constated that the latent cooling load is completely caused by the heat emitted by occupants inside the room, being the same value, which has been observed by analyzing the latent cooling load due to occupation. On the other hand, the sensible cooling load is provoked by internal heat gains due to occupants, machines, and illumination but also by external heat gains in particular due to the outdoor air temperature. The strong influence of the internal heat gains on the sensible cooling load can be observed in Figure 12 by the step of its values between hour 8 and 9 and between hour 18 and 19 corresponding to the start and end of occupation, illumination, and machine use. The influence of the outdoor air temperature can be noticed in Figure 12, where a correlation between the raising of the outdoor air temperature and the increasing of the sensible heat load can be detected. This is also why the peak of the sensible cooling load corresponds to the peak of the outdoor air temperature with a delay of one to two hours.

5.3.3 Conclusion

In conclusion, the results of the design heating load with a total value of 39.8 kW and of the cooling load with a total value of -21.4 kW are in the range of expected values and are considered plausible. The results can be used in the following for the design of the in-room terminal systems for heating and cooling and for the design of the energy generation system.

6 SELECTION AND DESIGN OF IN-ROOM TERMINAL SYSTEMS

6.1 Heating and cooling loads satisfied by AHU and by in-room terminal systems

The planned air-handling unit satisfies a part of the sensible cooling load supplying air with a temperature lower than interior room temperature, while it does not satisfy any part of the sensible heating load since supply and interior room air temperature are equal in heating mode. Furthermore, it must satisfy the latent cooling load in those rooms with mechanical ventilation. To determine the share of the sensible and latent cooling load covered by the planned AHU, the supply volume air flow, the difference between the absolute humidities and the difference between the temperatures between supply air and interior design air of each ventilated room are taken into consideration as illustrated in equations (1), (2) and (3).

$$\dot{Q}_{vent} = \dot{Q}_{vent,latent} + Q_{vent,sensible} \tag{1}$$

$$\dot{Q}_{vent,latent} = \dot{V} * \rho_{air} * h_{we} * \left(AH_{supply} - AH_{int}\right) \tag{2}$$

$$\dot{Q}_{vent,sensible} = \dot{V} * \rho_{air} * c_{p,air} * (T_{supply} - T_{int}) \tag{3}$$

$with$

$\dot{Q}_{vent}: cooling\ load\ covered\ by\ air\ handling\ unit\ [W]$

$\dot{V}: volume\ supply\ air\ flow\ \left[\frac{m^3}{s}\right]$

$\rho_{air}: density\ of\ the\ air\ \left[\frac{kg}{m^3}\right]$

$h_{we}: latent\ heat\ of\ vaporization\ of\ water\ [\frac{J}{kg}]$

$c_{p,air}: specific\ heat\ of\ air\ [\frac{J}{kgK}]$

$AH_{supply}: absolute\ humidity\ of\ supply\ air;\ here\ 0{,}0114 \frac{kg\ water}{kg\ air}$

$AH_{int}: absolute\ humidity\ of\ interior\ room\ air; here\ 0{,}0130 \frac{kg\ water}{kg\ air}$

$T_{supply}: supply\ air\ temperature; here\ 18°C$

$T_{int}: interior\ room\ air\ temperature; here\ 28°C$

The calculations are realized with the program Psychrometric diagram viewer 3.2.0 from Daikin N.V. The results (see Appendix II in 11.2.1) are subtracted from the latent and sensible part of the cooling load resulting in the sensible cooling load which must be satisfied by in-room terminal systems. The results are illustrated in Table 8, showing the supply air flow, the design latent, sensible and total cooling load, the share of the latent and sensible cooling load possible to satisfy by the AHU using the supply air flow for ventilation requirements, the total cooling load satisfied by the AHU, and the remaining share of the sensible load, which must be satisfied by other in-room terminal systems. The total cooling load satisfied by the AHU is determined as the sum of the minimum absolute value between the latent design cooling load and the latent cooling load possible to satisfy by the AHU, and the sensible cooling load possible to satisfy by the AHU.

Table 8: Cooling load satisfied by AHU and by other means – preliminary version

Room data				Cooling data						
				Design cooling load			**Cooling load satisfied by systems**			
Buil-ding	**Num-ber**	**Name**	**Supply air flow [m³/h]**	Latent [W]	Sen-sible [W]	Total [W]	Possible latent by AHU [W]	Possible sensible by AHU [W]	Total satisfied by AHU [W]	Sensible satisfied by other means [W]
New	2.030	Consulting room	0	-1	-687	-688	0	0	0	-688
Old	1.020	Consulting room	100	-68	-1207	-1275	-136	-339	-407	-868
Old	1.030	Exercise room	**150**	-288	-1218	-1506	-204	-508	-712	-794
Old	1.040	Exposition	**150**	-288	-1206	-1494	-204	-508	-712	-782
Old	1.050	Event room	875	-1192	-3904	-5096	-1190	-2965	-4155	-941
Old	1.05b	Eventroom_upside	0	0	-1115	-1115	0	0	0	-1115
New	1.110	Consulting room	0	0	-583	-583	0	0	0	-583
Old	0.02a	Library	750	-1022	-2079	-3101	-1020	-2541	-3561	460
Old	-1.020	Multimedia room	**50**	-68	-249	-317	-68	-169	-237	-80
Old	-1.030	Staff room library	**50**	-68	-311	-379	-68	-169	-237	-142
Old	-1.04a	Library	**290**	-375	-1176	-1551	-394	-983	-1358	-193
Old	-1.04b	Secondary room library	**110**	-170	-292	-462	-150	-373	-522	60
Old	-2.020	Music room 1	150	-204	-329	-533	-204	-508	-712	179
Old	-2.030	Music room 2	200	-273	-458	-731	-272	-678	-950	219
Old	-2.040	Small group room	175	-238	-405	-643	-238	-593	-831	188
Old	-2.050	Big group room	**450**	-865	-1025	-1890	-612	-1525	-2137	247
		TOTAL	3500			-21364			-16533	-4831

The table shows that the latent cooling load cannot be satisfied by the AHU with the given ventilation supply air flow rates in four rooms. The corresponding latent loads are highlighted in light red. In these cases, the supply air flow rate must be incremented until all latent cooling loads can be discharged by the AHU. Furthermore, the remaining sensible cooling load to be satisfied by in-room terminal systems is classified as very low in three rooms, showing lower absolute values than -200W, here highlighted in yellow. In this case, it is better to increase slightly the supply air flow rate to satisfy the total cooling load by the AHU rather than to plan an additional system. Finally, the rooms which show a positive value of the cooling load to be satisfied by other means highlighted in green, do not require any further in-room cooling systems since the AHU is satisfying already the total design cooling load.

By increasing the supply volume air flow of 15 to 185 m^3/h in the mentioned rooms, all latent cooling loads are satisfied, and the three rooms -1.02, -1.03 and -1.04a do not require any additional cooling system. The total air flow rate is raised from 3500m^3/h to 3950 m^3/h, which is still matching to the working range of the planned AHU-model, which is important because a bigger model is not acceptable due to space requirements. The results with increased supply air flow rates are illustrated in Table 9.

Table 9: Cooling load satisfied by AHU and by other means – final version

Room data				Cooling data						
				Design cooling load			**Cooling load satisfied by systems**			
Buil-ding	**Num-ber**	**Name**	**Supply air flow [m^3/h]**	Latent [W]	Sen-sible [W]	Total [W]	Possible latent by AHU [W]	Possible sensible by AHU [W]	Total satisfied by AHU [W]	Sensible satisfied by other means [W]
New	2.030	Consulting room	0	-1	-687	-688	0	0	0	-688
Old	1.020	Consulting room	100	-68	-1207	-1275	-136	-339	-407	-868
Old	1.030	Exercise room	**210**	-288	-1218	-1506	-286	-712	-998	-508
Old	1.040	Exposition	**210**	-288	-1206	-1494	-286	-712	-998	-496
Old	1.050	Event room	875	-1192	-3904	-5096	-1192	-2966	-4158	-938
Old	1.05b	Eventroom_upside	0	0	-1115	-1115	0	0	0	-1115
New	1.110	Consulting room	0	0	-583	-583	0	0	0	-583
Old	0.02a	Library	750	-1022	-2079	-3101	-1022	-2542	-3564	463
Old	-1.020	Multimedia room	**75**	-68	-249	-317	-102	-254	-322	5
Old	-1.030	Staff room library	**95**	-68	-311	-379	-129	-322	-390	11
Old	-1.04a	Library	**350**	-375	-1176	-1551	-477	-1186	-1561	10
Old	-1.04b	Secondary room library	**125**	-170	-292	-462	-170	-424	-594	132
Old	-2.020	Music room 1	150	-204	-329	-533	-204	-508	-712	179
Old	-2.030	Music room 2	200	-273	-458	-731	-272	-678	-950	219
Old	-2.040	Small group room	175	-238	-405	-643	-238	-593	-831	188
Old	-2.050	Big group room	**635**	-865	-1025	-1890	-865	-2153	-3017	1127
		TOTAL	3950			-21364			-18504	-2860

6.2 Selection of heating and cooling in-room terminal systems

6.2.1 Selection diagram

The decision tree illustrated in Figure 13 shows some of the main factors which determine the selection of the terminal systems for each room. First, it is important to know if additional cooling apart from cooling provided by the AHU is necessary. In the negative case, the required comfort is considered: rooms used permanently by occupants are selected for a higher comfort standard. In case of new constructions or existent buildings with need of renewing the floor, radiant floor heating is suitable. Another option may be radiant ceiling panels for heating if the space underneath the ceiling and the clear height allows this possibility. Otherwise, usually radiators provide the best solution, although the given window situation needs to be checked to be sure radiators can be located underneath or nearby the cold window surfaces to guaranty comfort. If this is not possible, radiant floor or ceiling heating is a good alternative.

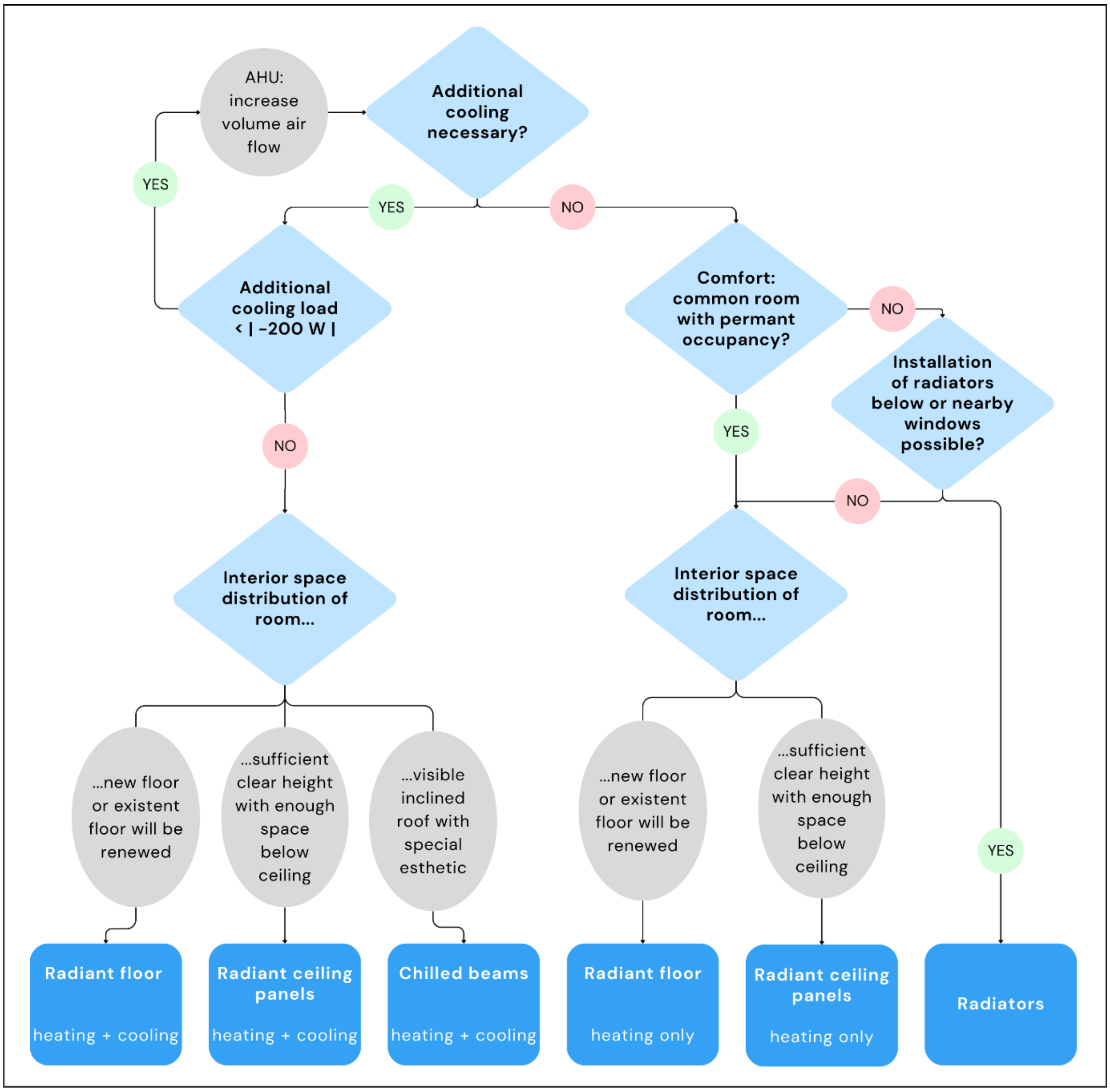


Figure 13: Decision tree for selecting of heating and cooling terminal units

In case that additional cooling by other means than the AHU is required, radiators are excluded from the possible outcomes as they are less suitable for this application due to their smaller transmission area. If the remaining cooling load to satisfy by other means is very small, additional cooling systems are redundant. In this case, the volume air flow of the AHU should be increased to satisfy the total cooling load. Here, the limit is set at a remaining cooling load of -200 W, resulting in a low additional supply air flow. If the remaining cooling load is greater, the available space inside the room is a determining factor for choosing the kind of in-room terminal system. If an existing floor is planned to be renewed anyway, radiant floor heating and cooling can be a good choice. If there is sufficient clear height and free space below the ceiling, radiant ceiling panels for heating and cooling can be considered. An advantage of these terminal units is the easy installation and refurbishment and higher heating and cooling capacities in comparison to radiant floor heating and cooling. Finally, in case of particular requirements regarding aesthetics as given in rooms with a visible inclined roof, special solutions may be needed. A possible solution is the use of chilled beams which occupy less space and can provide very high heating and cooling capacities.

Although not illustrated in the selection diagram, an important factor plays the possible heating and cooling capacities each terminal unit system can deliver. In case, the capacities given by a chosen system are inadequate, either another system with more suitable capacities is considered or additional systems are chosen to cover the remaining cooling or heating load.

6.2.2 Justification of selection of heating and cooling terminal systems for each room

6.2.2.1 Rooms without permanent occupancy

Rooms, which do not require additional cooling, and which are not permanently used, are equipped with radiators, since radiators are more economic, present an easy installation in existing buildings and show a fast response in case rooms need to be heated up quickly. The heating capacity of the radiators is chosen depending on the corresponding heating load of each room. Concerned rooms are the stairs, the tea kitchens, restrooms, halls, secondary rooms such as the cleaning room and the porch and the ventilation installation room. The sill heights of the windows have been checked and, in most cases with existent windows, there is sufficient space for radiators below the windows. Exceptions present the stairs 1, where the windows are in the staircases and the radiators are located more central to guaranty a better heat distribution, and the restrooms for persons with handicap, where other furniture is already planned beneath the windows. In the last case, radiators have been placed the nearest possible to the cold window areas.

6.2.2.2 Bistro area

The bistro area which includes the bistro, the secondary bistro room and the vestibule, is fit with radiators, although they represent rooms with permanent occupancy. This is because the bistro area will be rented in the future and the use is not totally certain yet. Next to the above-mentioned advantages of radiators, they can be easily exchanged to adapt in case of a modified use of the rooms, which has been decisive for choosing this type of terminal systems here.

6.2.2.3 Common rooms in level -2, -1

The common rooms in level -2 and -1, which are all inside the old building, need to be heated and cooled. Here, the cooling load is totally satisfied by the AHU. The rooms require high comfort since they are permanently occupied. The clear height is with 2.50 m until 2.60 m already low, which is why radiant ceiling panels are less recommended. Furthermore, because the windows of the rooms have low sill heights, radiators cannot be considered as main system. Since the existent floor needs to be renewed, radiant floor heating is suitable for heating and cooling of these rooms, under the condition that the heating and cooling loads covered by the radiant floor are lower than 40 W/m² respectively 20 W/m². Those values represent the limit of heating respectively cooling capacities, which can be provided by radiant floor systems. All rooms show lower values except the library in level -1 (room number -1.04.1) with a heating load of 47 W/m². In this special case, a radiator is added as support placed between two windows.

6.2.2.4 Common rooms in level 0,1,2

The common rooms in level 0, 1 and 2, which are mostly in the old building, require heating and cooling. Except for the library in level 0, the total cooling load of the rooms is not satisfied by the AHU, resulting in the need of in-room terminal systems which can provide both heating and cooling. Furthermore, the rooms require high comfort since they are rooms with a permanent occupancy. In this case, radiant floor heating and cooling is less suitable since the floor of the concerned levels of the old building will be preserved and the required heating and cooling capacities are mostly higher than the limit of heating respectively cooling capacities, which can be provided by radiant floor systems. Since the clear heights of the rooms are higher with 2,68m until 3,43m, radiant ceiling panels are considered. The panels are able to satisfy the needed heating and cooling capacities. Furthermore, the client gained positive experience with the same type of heating and cooling panels in another project and is interested to use the same system in this project.

6.2.2.5 Event room

The event room requires special attention as it is a room with a very high clear height due to the planned opening to the attic. The total heating load summing up the results of the rooms “event room” 1.05 and “event room – upside” 1.05b is 4423 W or 42 W/m² and the total cooling load is -6211 W or -59 W/m², showing a high heating load and a very high cooling load. Besides, particular aesthetical effects need to be considered impeding continuous horizontal panels.

Two systems have been considered: on the one hand, a radiant ceiling system on the basis of a drywall system with option of inclined installation parallel to the existing roof and on the other hand, chilled beams which are composed of pipes with hot or cold water and ventilation ducts to introduce supply air and small fins which help to transmit the energy.

The first system has the great advantage to be invisible but comes along with several inconveniences. Due to the high distance between floor and ceiling or roof and due to the inclination, the manufacturer recommends lowering the heating respectively cooling capacity for the calculations to 60% of usually reachable capacity, resulting in a low efficient but costly system. Furthermore, the drywall system can cover the total heating respectively cooling load by using 95% of the available roof and wall area, but without leaving flexibility in case of space changes.

The second system, the chilled beams, can cover the total heating and cooling loads and needs less space than conventional panels. Since it integrates the ventilation supply air flow, no additional terminal units for ventilation are required. Disadvantageous is the fact, that the system is visible and modifies the aesthetics of the room, and its high complexity.

Finally, the second system is chosen, since it is one closed system, uses less area than conventional radiant panels, the aesthetical impact can be reduced by integrating it into an industrial design and it covers largely the total heating and cooling load.

6.3 Design of heating and cooling in-room terminal systems

6.3.1 Terminal units for ventilation

All rooms which require ventilation need terminal units for the supply and exhaust air flow. The present work will not discuss the design of terminal units for ventilation since these terminal units are planned by the ventilation department. Concerning the rooms where a slightly greater air flow rate is sufficient to cover the entire cooling load, the necessary total flow rate is reported to the ventilation department to adapt the air handling unit design.

6.3.2 Radiators

The size of the radiators is chosen in function of the heating load, of the available space in the rooms and of the sill height in case of existent windows.

The heating capacity of the chosen radiators is determined by means of the C.A.T.S. program based on standard VDI 6030 (VDI, 2002), introducing the supply and return temperature chosen with 45°C and 30°C and the required level of comfort with level 1 of 3, which means to cover the heating load without covering additional comfort requirements. The reason for choosing the indicated supply and return temperatures lies in the possible use of a low temperature energy generation system, which provides supply temperatures until 45°C and functions better with lower return temperatures. As reference, the program uses libraries with data sheets provided by several manufacturers. The flat radiators therm-x2 Plan-K type 12, 22 and 33 from the manufacturer Kermi GmbH are selected since they provide several advantages. They are composed of 2 respectively 3 convectors linked with an interior fin structure and come along with a covering illustrated in Figure 14. They are energy efficient, designed and produced in Europe and have an elegant visual appearance as shown in Figure 15. Regarding the energy efficiency, they are equipped with a serial flow function called “x2-technology” which increases the radiation share during low demand by warming up the front convector before warming up the other convectors. This results in a better comfort of the user despite constant room air temperatures (Harnischmacher, 2006). The type 12 has a thickness of 66mm, the type 22 a thickness of 102mm and the type 33 a thickness of 157mm. The heights of all radiators are restricted to 405mm or 905mm with the aim to reduce the risk of mixing up different radiators during installation. The length is adapted at its best to the required heating load of each room, leading to length between 405mm and 2605mm. Furthermore, they come along with 4 connections of DN15 with an internal screw thread. The available space in the room and the sill height of the windows is considered, placing the radiators underneath windows or in corners with low passage. The minimum distance between radiator and floor is 200 mm and to the installation wall 80 mm.

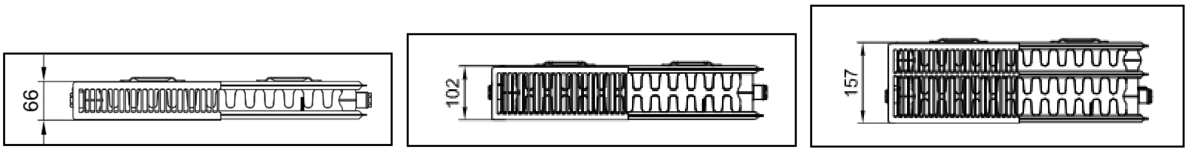


Figure 14: Top view and section of the radiators therm-x2 Plan-K type 12, 22 and 33 from Kermi GmbH (Kermi GmbH, 2024, p.23)

Figure 15: Design of the chosen radiators (Kermi GmbH, 2024, p.192)

The result is illustrated in Table 10 which shows the rooms with the corresponding type and number of radiators, their measurements, power and the satisfaction of the heating load. The placement of the radiators can be observed in the plans 14-18 in Part III.

Table 10: Overview: design of radiators as terminal units

Room data			Heating terminal units: Radiators - Kermi therm-x2 Plan-K							
Buil-ding	**Num-ber**	**Name**	**Type**	**Thick-ness [mm]**	**Height [mm]**	**Length [mm]**	**Power /Model [W]**	**Num-ber**	**Total Power [W]**	**Satisfaction of load [%]**
Old	2.020	Ventilation installations	33	157	405	2605	1443	1	1443	110%
New	2.000	Stairs 1	33	157	905	1605	1304	1	1304	106%
Old	1.100	Hall	33	157	405	1005	390	1	390	102%
Old	1.093	Womens toilettes	12	66	405	905	168	1	168	103%
Old	1.092	Mens toilettes	12	66	405	505	94	1	94	116%
Old	1.091	Toilettes entrance	12	66	405	505	94	1	94	119%
Old	1.080	Toilettes, handicap	33	157	905	705	323	1	323	111%
Old	1.070	Tea kitchen	33	157	405	2605	978	1	978	101%
New	1.000	Stairs 1	33	157	905	1105	898	1	898	104%
Old	0.02b	Porch	33	157	405	1005	557	1	557	101%
Old	0.080	Stairs 2	22	102	405	705	217	1	217	102%
Old	0.060	Secondary room	33	157	905	905	626	1	626	104%
Old	0.050	Vestibule	33	157	405	405	157	1	157	115%
Old	0.040	Bistro	33	157	905	1205	834	2	1668	102%
New	0.000	Stairs 1	33	157	905	2605	2116	1	2116	101%
New	-1.000	Stairs 1	33	157	905	905	735	1	735	105%
Old	-1.041	Library	33	157	905	1205	834	1	834	103%
Old	-1.050	Cleaning room	33	157	405	1005	390	1	390	105%
Old	-1.061	Mens toilettes entrance	22	102	405	505	132	1	132	112%
Old	-1.062	Mens toilettes	33	157	905	1805	1249	1	1249	107%
Old	-1.071	Womens toilettes entrance	22	102	405	605	158	1	158	105%
Old	-1.072	Womens toilettes	33	157	905	1605	1110	1	1110	109%
Old	-1.090	Toilettes, handicap	33	157	905	905	415	3	1245	101%
Old	-1.100	Tea kitchen	33	157	905	2005	1387	1	1387	111%
Old	-1.120	Hall	33	157	905	1805	1249	1	1249	100%
New	-2.000	Stairs 1	33	157	905	1305	1060	1	1060	107%
Old	-2.060	Stairs 2	33	157	905	805	654	1	654	112%
Old	-2.070	Hall	33	157	905	1305	903	1	903	102%

6.3.3 Radiant floor

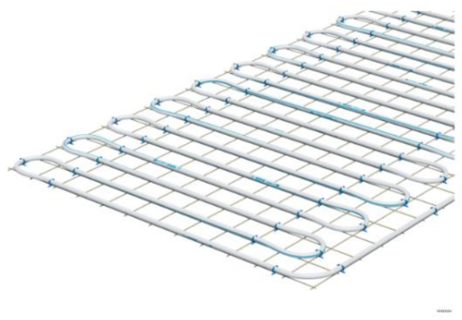


Figure 16: Illustration of the chosen radiant floor (Uponor GmbH, 2024, p.1)

General design criteria for the design of hydronic radiant floor heating and cooling as an embedded system are the heating and cooling loads to be satisfied by the system, the specific capacity of the radiant floor system and the room area. The heating respectively remaining cooling loads are calculated in Chapter 5 and Chapter 6.1.

The specific capacity of the radiant floor system depends on the type of radiant floor, the thermal resistance of the covering floor layers, the configuration of the tubes, the supply and return water temperature and the interior room air temperature and is determined by using manufacturers' data. For designing the radiant floor, the chosen type of radiant floor is the system "Classic-Comfort Pipe PLUS 17x2mm" by Uponor GmbH as shown in Figure 16 since it offers an easy and fast installation, is a long-lifetime proven technology, provides flexibility in terms of thermal insulation and allows to improve the acoustical insulation.

According to DIN EN 1264-4 (DIN, 2021), thermal insulation must be given with a minimum of 30 mm of expanded polystyrene (EPS) with a thermal transmittance of maximum 0.035 W/m²K in case of ceilings adjacent to heated rooms, and 50 mm in case of ceilings adjacent to unheated rooms. Furthermore, the inputs chosen for the determination of the specific capacity are listed in Table 11.

Table 11: Input data for determining specific capacity of radiant floor

Characteristics	Input value	Unit
Thickness of floor layer 1: Covering	15	mm
Thickness of floor layer 2: Cement screed	45	mm
Thickness of floor layer 3: Radiant floor system	23	mm
Thickness of floor layer 4: Insulation of EPS 035	30 - 50	mm
Thickness of floor layer 5: Leveling layer	10	mm
Water supply temperature (ϑ_S)	40	°C
Water return temperature (ϑ_R)	30	°C
Average temperature of the heating medium (ϑ_H with $\vartheta_H = ((\vartheta_S + \vartheta_R)/2)$)	35	°C
Interior air temperature (ϑ_I)	20	°C
Temperature difference between heating medium and room ($\Delta\vartheta_H$ with $\Delta\vartheta_H = \vartheta_H - \vartheta_I$)	15	°C
Pipe spacing (T)	20	cm
Thermal resistance of floor layer 1: Covering ($R_{\lambda,B}$)	0.15	m²K/W

Since additional cooling beside the cooling provided by the AHU is not required, only the specific heating capacity is determined. Using the design diagram provided by the manufacturer (see Appendix II in 11.2.2) for the chosen system, the specific heating capacity is approximately 38 W/m².

Once the specific capacity is determined, the necessary active area for heating is calculated and must be smaller than the room area to be able to satisfy the room heating load, as shown in Table 12. All rooms with radiant floor system have a sufficient room area to satisfy the total heating load except the library in level -1 (room number -1.041), where only 73% of the heating load are satisfied. An additional radiator placed nearby the windows and next to an exterior wall with a capacity of 834 W covers the remaining heating load.

Table 12: Results of radiant floor design

Room data								Heating capacity		
Buil-ding	**Num-ber**	**Name**	**Room area [m²]**	**Design heating load [W]**	**Specific design heating load [W/m²]**	**Active area / room area [%]**	**Active area [m²]**	**Specific heating capacity [W/m²]**	**Total heating capacity [W]**	**Heating load satisfaction [%]**
Old	-2.020	Music room 1	19.7	538	27	76%	14.9	38	565	105%
Old	-2.030	Music room 2	25.6	535	21	58%	14.8	38	564	105%
Old	-2.040	Small group room	23.9	509	21	59%	14.1	38	536	105%
Old	-2.050	Big group room	61.5	1555	25	70%	43.1	38	1636	105%
Old	-1.020	Multimedia room	19.7	648	33	90%	17.7	38	674	104%
Old	-1.030	Staff room library	26.0	588	23	63%	16.3	38	618	105%
Old	-1.041	Library	63.5	2988	47	90%	57.2	38	2172	73%
Old	-1.042	Secondary room library	24.1	622	26	71%	17.1	38	650	105%

Furthermore, the heating loop characteristics are illustrated in Table 13. First, the number of heating loops is determined depending on the total necessary pipe length and the maximum admissible pipe length per heating loop to avoid an excessively high pressure drop. With the amount of heating loops and the mass flow per heating loop, the pressure drop per heating loop can be determined with the help of manufacturer data (see Appendix II in 11.2.3). The maximum pressure drop per floor level, here highlighted in light grey, is determining the pressure drop of the manifold used in each floor level for distributing the water to the different heating loops and needed in the following for sizing the distribution network components.

Table 13: Heating loop characteristics of radiant floor

Room data				Heating loop characteristics				
Buil-ding	**Number**	**Name**	**Active area [m²]**	**Total pipe length [m] ***	**Number of heating loops [-] ****	**Area / heating loop [m²]**	**Mass flow per heating loop [kg/h]**	**Maximum pressure drop per heating loop [kPa]**
Old	-2.020	Music room 1	14.9	68	1	15	48.6	2.5
Old	-2.030	Music room 2	14.8	68	1	15	48.5	2.5
Old	-2.040	Small group room	14.1	65	1	14	46.0	2.3
Old	-2.050	Big group room	43.1	198	2	22	70.3	3.6
Old	-1.020	Multimedia room	17.7	82	1	18	57.9	2.4
Old	-1.030	Staff room library	16.3	75	1	16	53.1	2.2
Old	-1.041	Library	57.2	263	3	19	62.2	2.5
Old	-1.042	Secondary room library	17.1	79	1	17	55.9	2.3

*with 4.6 m pipe/m² active area in case of pipe spacing of 20cm

**with a maximum admissible length of 100 m pipe / heating loop

Finally, the placement of the radiant floor systems for heating can be observed in the plans 14-18 in Part III, showing each heating loop placement and its corresponding active area.

6.3.4 Radiant ceiling

General design criteria for the design of hydronic radiant ceiling heating and cooling panels are the heating and cooling loads to be satisfied by the system, the specific capacity of the radiant ceiling panels and the available ceiling area. The heating respectively remaining cooling loads are calculated in Chapter 5 and Chapter 6.1.

The specific heating and cooling capacities of the radiant ceiling panels depend on the type of panel system, the supply and return water temperature and the interior room air temperature and is determined by using manufacturers' data. For designing the radiant ceiling panels, the chosen type of ceiling panels is the system "Heated and chilled Canopy Ceilings - Plafotherm DS320 with Plafotherm Cu" by Lindner Group KG shown in Figure 17, since these panels offer high heating and cooling capacities, a good sound absorption, an easy and fast installation and maintenance and a great choice in terms of aesthetical design.

Plafotherm® DS 320 Type 2
65°-turn-up as individual panel
canopy length: depending on requirements
canopy width: 200 - 1,250 mm
panel length: 500 - 3,000 mm
panel width: 200 - 1,250 mm

Figure 17: Illustration of chosen radiant ceiling panels (Lindner GmbH, 2024, p. 47)

The inputs chosen for the determination of the specific capacity are listed in Table 14.

Table 14: Input data for determining specific capacity of radiant ceiling panels

Mode	Characteristics	Input value	Unit
Cooling	Water supply temperature (ϑ_S)	17.0	°C
	Water return temperature (ϑ_R)	20.0	°C
	Average temperature of the cooling medium (ϑ_C with $\vartheta_C = ((\vartheta_S + \vartheta_R)/2)$)	18.5	°C
	Interior air temperature (ϑ_I)	26.0	°C
	Temperature difference between cooling medium and room "Insufficient temperature" ($\Delta\vartheta_C$ with $\Delta\vartheta_C = \vartheta_I - \vartheta_C$)	7.5	°C
Heating	Water supply temperature (ϑ_S)	35.0	°C
	Water return temperature (ϑ_R)	30.0	°C
	Average temperature of the heating medium (ϑ_H with $\vartheta_H = ((\vartheta_S + \vartheta_R)/2)$)	32.5	°C
	Interior air temperature (ϑ_I)	20.0	°C
	Temperature difference between heating medium and room "Excess temperature" ($\Delta\vartheta_H$ with $\Delta\vartheta_H = \vartheta_H - \vartheta_I$)	12.5	°C

Using the design diagram provided by the manufacturer (see Appendix II in 11.2.4) for the chosen system, the specific heating capacity is approximately 130 W/m² and the specific cooling capacity is approximately 95 W/m².

Once the specific capacities are determined, the necessary active area for heating and cooling is calculated, which must be smaller than the available ceiling area to be able to satisfy the room heating respectively cooling loads, which is the case for all rooms equipped with radiant ceiling panels. The panel dimensions are chosen in function of the active area and by trying to reduce the amount of different panel forms to ease transport and installation. Furthermore, access door measurements must be considered to enter the panels into the room. Four panel forms are selected as shown in Table 15, which are inside the range of available widths and lengths provided by the manufacturer.

Table 15: Radiant ceiling - panel dimensions

Chosen panel dimensions			
Form	**Width [m]**	**Length [m]**	**Area [m²]**
Form 1	0.90	1.80	1.62
Form 2	0.90	2.00	1.80
Form 3	1.25	1.85	2.31
Form 4	1.10	2.10	2.31

The results are illustrated in Table 16, showing the room data with the necessary active heating respectively cooling area, the panel data indicating the form and the number of panels, and the specific and total heating respectively cooling capacities and the corresponding load satisfactions.

Table 16: Results of radiant ceiling panel design

Room data								Panel data		Heating capacity			Cooling capacity		
Building	**Number**	**Name**	**Ceiling area [m²]**	**Heating load [W]**	**Active heating area [m²]**	**Cooling load [W]**	**Active cooling area [m²]**	**Form [-]**	**Number [-]**	**Specific [W/m²]**	**Total [W]**	**Satisfaction [%]**	**Specific [W/m²]**	**Total [W]**	**Satisfaction [%]**
Old	0.02a	Library	156	2650	20	0	-	2	12	130	2808	106%	-	-	-
Old	1.02	Consulting room 2	15	660	5	868	9	4	4	130	1201	182%	95	878	101%
Old	1.03	Exercise room	22	773	6	508	5	1	4	130	842	109%	95	616	121%
Old	1.04	Exposition	19	815	6	496	5	1	4	130	842	103%	95	616	124%
New	1.11	Consulting room 1	22	1061	8	583	6	3	4	130	1203	113%	95	879	151%
New	2.03	Consulting room A1	22	1156	9	688	7	Form 3	4	130	1203	104%	95	879	128%

The panels must be equipped with a suitable control system and valves to be able to regulate the mass flow rates and supply water temperatures in an adequate manner, especially in case of over dimensioning the heating capacity to comply with the cooling capacity (or the other way around). The maximum pressure drop per heating or cooling loop is indicated by the manufacturer with 25 kPa and will be used for the design of the distribution network components.

Finally, the placement of the radiant ceiling panels for heating and cooling can be observed in plans 14-21 in Part III, showing each radiant ceiling panel and its corresponding active area.

6.3.5 Chilled beams

General design criteria for the design of the chilled beams are the heating and cooling load to be satisfied by the system, the heating and cooling capacity of each chilled beam and the available ceiling area.

In case of chilled beams, the heating and cooling load must be calculated without considering any heating or cooling load satisfied by the AHU, since the capacity indicated for chilled beams is including the introduced air flow of the AHU. This results in a design heating load of 3541 W in the lower part of the event room and of 1732 W in the upper part, while the design cooling load consists of -5096 W in the lower part and -1115 in the upper part of the event room.

The heating and cooling capacity of the chilled beams depends on the volumetric supply air flow, the supply air flow temperature, the water supply and return temperature and the interior room air temperature. For designing the chilled beams, the chosen system is the “Chilled ceiling panels INDUCOOL-Compact” by Kiefer Klimatechnik GmbH shown in Figure 18.

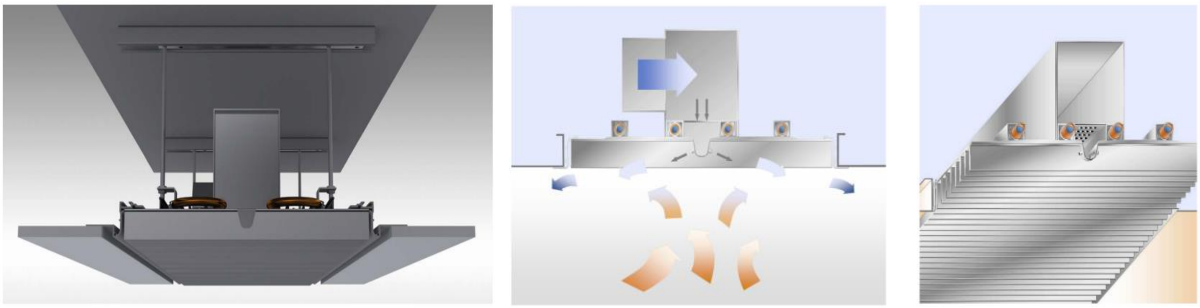


Figure 18: Illustration of chosen chilled beams (Kiefer Klimatechnik GmbH, 2024, p. 1)

The inputs chosen for the determination of the specific capacity are listed in Table 17.

Table 17: Input data for determining specific capacity of chilled beams

Mode	Characteristics	Input value	Unit
Cooling	Water supply temperature (ϑ_S)	17.0	°C
	Water return temperature (ϑ_R)	19.5	°C
	Air supply temperature (ϑ_A)	18.0	°C
	Interior air temperature (ϑ_I)	28.0	°C
	Volumetric air flow (V)	850	m^3/h
Heating	Water supply temperature (ϑ_S)	32.0	°C
	Water return temperature (ϑ_R)	29.2	°C
	Air supply temperature (ϑ_A)	20.0	°C
	Interior air temperature (ϑ_I)	20.0	°C
	Volumetric air flow (V)	850	m^3/h

The calculation is realized by the manufacturer, resulting in a heating capacity of 330 W per chilled beam panel and a cooling capacity of 538 W per chilled beam panel. The heating load can be satisfied to 106 % by installing 17 chilled beam panels, while the cooling load is over dimensioned in this case, as shown in Table 18. This can be avoided by enabling only 12 of the 17 panels in cooling mode, resulting in a satisfaction of 104% of the cooling load. Since the dimensions of the chilled beam panels are with 1.5m by 0.95m comparatively small, the ceiling area is more than sufficient and is covered only to 7% by the chilled beams.

Table 18: Results of chilled beam design

Room data							Heating capacity			Cooling capacity		
Building	Number	Name	Ceiling area [m^2]	Number of panels [-]	Heating load [W]	Cooling load [W]	Specific [W/m^2]	Total [W]	Satisfaction [%]	Specific [W/m^2]	Total [W]	Satisfaction [%]
Old	1.05	Event room (upside part inclusive)	107	17	5273	-6211	330	5610	106%	-538	-9146	147%

The maximum pressure drop per chilled beam panel is indicated by the manufacturer with 5 kPa and will be used for the design of the distribution network components.

Finally, the placement of the chilled beam panels for heating and cooling can be observed in plans 14-21 in Part III.

6.4 Summary of selected heating and cooling in-room terminal systems

In Figure 19, the selected heating and cooling in-room terminal systems are resumed. The non-conditioned rooms are highlighted in grey, the rooms with radiators in light blue, the rooms with radiant floor in brown, the rooms with radiant ceiling panels in light red and the event room and its upper part with the chilled beams are shown in yellow. Additional secondary terminal units are not illustrated. The plan in a better resolution can be found in Part III, plan 13.

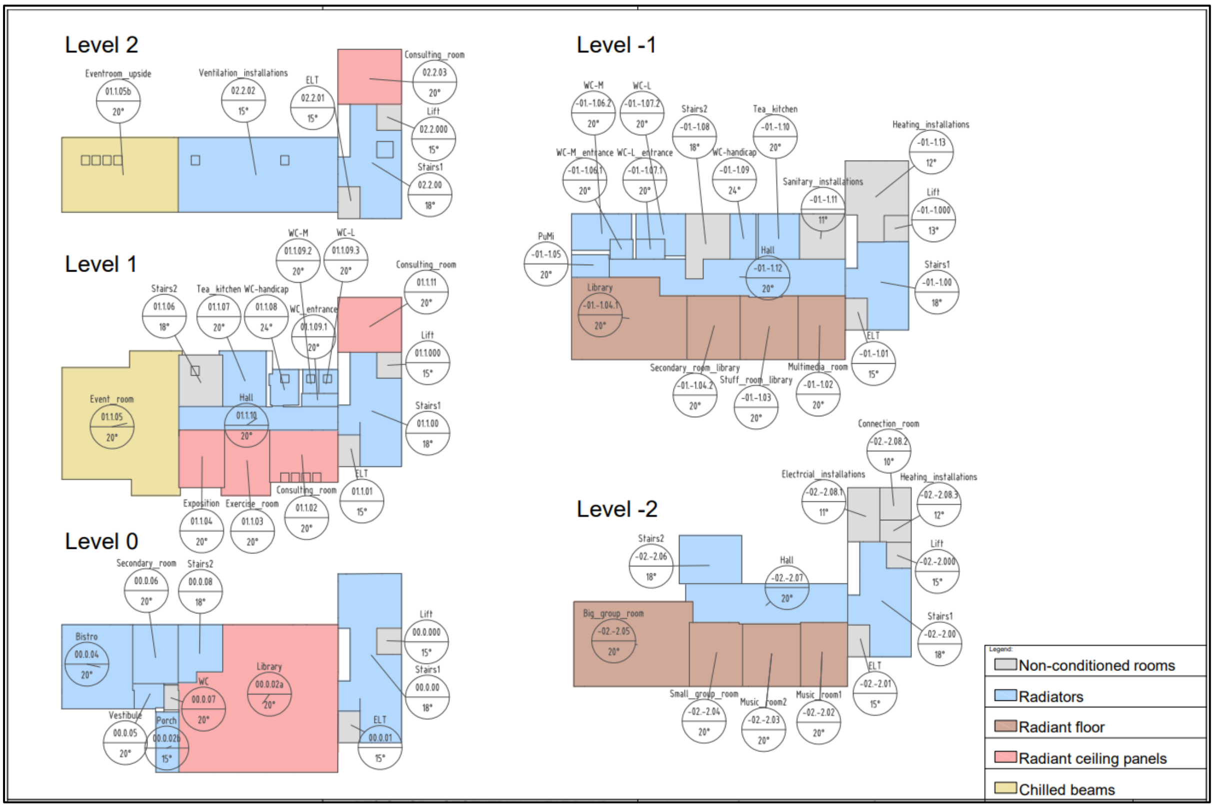


Figure 19: Illustration of in-room terminal system selection for each room

7 SELECTION AND DESIGN OF DISTRIBUTION NETWORK

7.1 Heating and cooling loops

For each heating and cooling loop, the supply and return temperature is introduced. Furthermore, all heating respectively cooling in-room terminal systems with their corresponding power and pressure drop as described in Chapter 6 are added. Heating and cooling ceiling panels are considered with a capacity which satisfies 105% of the corresponding thermal load, although they may be able to reach higher capacities. The required additional energy for heating or cooling the air to the design temperature is taken from the data sheet of the manufacturer of the AHU (see Appendix IV in 11.4.1).

The inputs are resumed in Table 19.

Table 19: Inputs for calculation of heating and cooling loops

Heating and cooling loops - Inputs					
Number	**Mode**	**Name**	**Supply temperature [°C]**	**Return temperature [°C]**	**Power [kW]**
HL 01	Heating loop	AHU	45	25	8.67
HL 02	Heating loop	Radiant floor	40	30	7.41
HL 03	Heating loop	Radiators	45	30	18.77
HL 04	Heating loop	Radiant ceiling	35	30	7.45
HL 05	Heating loop	Chilled beams	32	29	5.61
HL 06	Heating loop	Radiators Bistro	45	30	2.37
				TOTAL HEATING POWER	**50.29**
CL 01	Cooling loop	AHU	10	16	22.90
CL 02	Cooling loop	Radiant ceiling	17	20	3.26
CL 03	Cooling loop	Chilled beams	17	19.5	6.46
				TOTAL COOLING POWER	**32.62**

7.2 Determination of pipe material, diameters, fittings, and insulation

The pipes of the distribution network will be made of seamless steel with a pressure drop of 100 Pa/m and a maximum speed of 0.3 m/s. The design of the distribution network is shown in the plans 14-21 in Part III.

The results are illustrated Table 20 for heating and cooling mode, showing the total length of pipes of different diameters and the number of elbows, T-pieces and reducers.

Table 20: List of distribution network elements

Element	HEATING - value	COOLING - value	Unit
Total length of seamless steel pipe with DN 15	690	123	m
Total length of seamless steel pipe with DN 20	192	18	m
Total length of seamless steel pipe with DN 25	53	48	m
Total length of seamless steel pipe with DN 32	120	12	m
Total length of seamless steel pipe with DN 40	0	80	m
Total length of seamless steel pipe with DN 50	0	73	m
Number of Elbows 90° with DN 15	473	90	-
Number of Elbows 90° with DN 20	58	8	-
Number of Elbows 90° with DN 25	17	16	-
Number of Elbows 90° with DN 32	38	0	-
Number of Elbows 90° with DN 40	0	26	-
Number of Elbows 90° with DN 50	0	18	-
Number of T-Pieces with DN 15 - DN 15 - DN 15	85	28	-
Number of T-Pieces with DN 20 - DN 15 - DN 20	25	3	-
Number of T-Pieces with DN 20 - DN 20 - DN 20	2	1	-
Number of T-Pieces with DN 25 - DN 15 - DN 25	4	0	-
Number of T-Pieces with DN 25 - DN 20 - DN 25	5	3	-
Number of T-Pieces with DN 25 - DN 25 - DN 25	3	4	-
Number of T-Pieces with DN 32 - DN 15 - DN 32	4	2	-
Number of T-Pieces with DN 32 - DN 20 - DN 32	4	2	-
Number of T-Pieces with DN 32 - DN 25 - DN 32	0	4	

Element	HEATING - value	COOLING - value	Unit
Number of T-Pieces with DN 40 - DN 15 - DN 40	0	2	
Number of Reducers with DN 20 - DN 15	13	6	-
Number of Reducers with DN 25 - DN 15	2	4	-
Number of Reducers with DN 25 - DN 20	7	1	-
Number of Reducers with DN 32 - DN 25	4	2	
Number of Reducers with DN 40 - DN 32	0	2	-

The pipes are visible and are planned beneath the ceiling. The distance between the pipes is designed to leave sufficient space for the required insulation. The insulation should be made of stone wool with aluminum protection layer for the heating distribution network and of AF/ArmaFlex or similar product for the cooling distribution network to avoid condensation. The required minimum insulation thicknesses for each pipe diameter are listed in Table 21. The thicknesses are considering the legal requirements according to §§69-71, GEG in case of the heating distribution network and are calculated with the help of the manufacturer program ArmaWin from Armacell International S.A. according to ISO 12241 in case of the cooling distribution network.

Table 21: Required insulation thicknesses for distribution pipes

Mode	Insulation type	Thickness [mm]
Heating	Pipes and fittings with DN 15	20
	Pipes and fittings with DN 20	20
	Pipes and fittings with DN 25	30
	Pipes and fittings with DN 32	30
Cooling	Pipes and fittings with DN 15	9
	Pipes and fittings with DN 20	9
	Pipes and fittings with DN 25	10
	Pipes and fittings with DN 32	11
	Pipes and fittings with DN 40	11
	Pipes and fittings with DN 50	12

7.3 Manifold

The manifolds are designed using the program MAGplan 6.0.1.28 of MAGRA Maile + Grammer GmbH, considering the minimum distances between the connections according to national standards, the number of connections and their diameters calculated beforehand, the maximum mass flow, the maximum operation pressure, the maximum operation temperature, and the material selection.

The heating manifold consists of two single-chamber manifolds, one for supply and one for return water. The dimensions are 60 mm by 60 mm, the material is steel with anti-corrosion finish according to AGI Q151, the maximum operation pressure is 6 bar, and the maximum operation temperature is 110 °C. The maximum mass flow rate of 7 m^3/h is suitable since the total flow rate is 5.1 m^3/h. Insulation of stone wool of 100 mm all around the manifolds is planned. A plan of one of the two identical heating manifolds is shown in Figure 20.

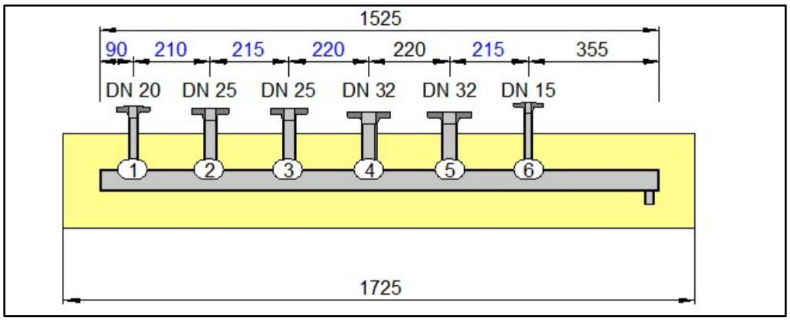


Figure 20: Illustration of heating manifold (secondary circuit)

For cooling, a double-chamber manifold of 100 mm by 100 mm of galvanized steel is planned, with the same maximum operation pressure and temperature of 6 bar and 110°C, but without insulation and with a maximum mass flow of 11 m³/h although the real maximum mass flow is 6.5 m³/h, because smaller manifolds are not suitable for the greatest pipe diameter of DN50. A plan of the cooling manifold can be observed in Figure 21.

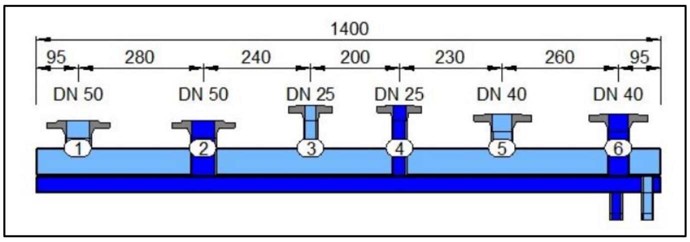


Figure 21: Illustration of cooling manifold (secondary circuit)

The corresponding design data sheets of the program MAGplan 6.0.1.28 can be found in Appendix IV in 11.4.8.3.

7.4 Valves

The selection of the valves includes gate valves, control valves and three-way-valves.

Concerning the gate and control valves, the pressure drop is determined by using the data sheet of valves “Kombi-3-plus V5000 and V5010” by the manufacturer Resideo Technologies, Inc. (see (Resideo Technologies, 2021), resumed in Table 22.

Table 22: Pressure drop of control valves in distribution network

Valvetype	DN	Total number	Flow coefficient Cv [m³/h]
Kombi-3-plus V5000	15	12	2.5
Kombi-3-plus V5000	20	11	4.5
Kombi-3-plus V5000	25	9	6.5
Kombi-3-plus V5000	32	7	13.0
Kombi-3-plus V5000	40	4	20.0
Kombi-3-plus V5000	50	5	35.0
Kombi-3-plus V5010	15	12	2.7
Kombi-3-plus V5010	20	11	6.4
Kombi-3-plus V5010	25	9	6.8
Kombi-3-plus V5010	32	7	21.0
Kombi-3-plus V5010	40	4	22.0
Kombi-3-plus V5010	50	5	38.0

Regarding the three-way-valves, the design program from Kieback&Peter GmbH & Co. KG has been used. The inputs and outputs are resumed in Table 23.

Table 23: Pressure drop of three-way-valves in distribution network

Mode	Three-way-valve for…	DN	Power [kW]	Cv-value [m³/h]	Pressure drop [kPa]
Heating	HL 01: AHU	20	8.7	1.6	5.4
	HL 02: Radiant floor	25	7.4	2.5	6.5
	HL 03: Radiators	25	18.8	4.0	7.2
	HL 04: Radiant ceiling	32	7.5	6.3	4.1
	HL 05: Chilled beams	32	5.6	6.3	6.5
	HL 06: Radiators Bistro	15	2.4	0.6	4.7
Cooling	CL 01: AHU	50	22.9	16.0	4.2
	CL 02: Radiant ceiling	25	3.3	4.0	5.5
	CL 03: Chilled beams	40	6.5	10.0	4.9

7.5 Strainers

A strainer is introduced in each heating respectively cooling loop to avoid corrosion dirt damages. The additional pressure drop due to the strainers are resumed in Table 24 based on manufacturer data from ARI-Armaturen Albert Richter GmbH & Co. KG for the model ARI-Strainer 050 -Y-pattern with flanges with fine screens (see (ARI Armaturen Albert Richter GmbH & Co. KG, 2019)).

Table 24: Pressure drop of strainers in distribution network

Strainer	DN	Total number	Discharge coefficient ζ [-]
ARI-050 fine screen	15	1	2.1
ARI-050 fine screen	20	1	2.5
ARI-050 fine screen	25	3	2.2
ARI-050 fine screen	32	2	2.8
ARI-050 fine screen	40	1	3.8
ARI-050 fine screen	50	1	4.1

7.6 Pumps

7.6.1 Pressure drop calculation

Introducing the pressure drops determined in the last subchapters into the distribution network calculations, the total pressure drop can be calculated. The results regarding the total pressure drop but also regarding the mass flow, the water volume and the starting diameter at the manifold are resumed in Table 25 for each heating respectively cooling loop.

Table 25: Results of pressure drop calculations of distribution network

Heating and cooling loops - Outputs						
Number	**Mode**	**Name**	**Mass flow [m³/h]**	**Pressure drop [kPa]**	**Water volume [l]**	**Diameter**
HL 01	Heating loop	AHU	0.37	16.5	30	DN 20
HL 02	Heating loop	Radiant floor	0.64	29.8	38	DN 25
HL 03	Heating loop	Radiators	1.08	38.3	465	DN 25
HL 04	Heating loop	Radiant ceiling	1.29	40.0	97	DN 32
HL 05	Heating loop	Chilled beams	1.61	43.1	105	DN 32
HL 06	Heating loop	Radiators Bistro	0.14	17.0	77	DN 15
CL 01	Cooling loop	AHU	3.29	27.8	170	DN 50
CL 02	Cooling loop	Radiant ceiling	0.94	49.8	61	DN 25
CL 03	Cooling loop	Chilled beams	2.23	36.3	136	DN 40

7.6.2 Pump design

The pressure drop and the mass flow of each loop are determining the design of the pumps, which has been realized using the program Wilo-Select 4 from WILO SE. The chosen pumps for each loop are listed in Table 26. They all dispose of a connection diameter of DN25 and a connection pressure of PN10. The corresponding data sheets can be found in Appendix IV in 11.4.8.1.1 and 11.4.8.1.2.

Table 26: Pump selection for heating loops of distribution network

Number	Mode	Loop name	Pump model	Power input [kW]
Pump 01	Heating loop	AHU	Stratos MAXO 25/0,5-4 PN10	0.08
Pump 02	Heating loop	Radiant floor	Stratos MAXO 25/0,5-4 PN10	0.08
Pump 03	Heating loop	Radiators	Stratos MAXO 25/0,5-6 PN10	0.13
Pump 04	Heating loop	Radiant ceiling	Stratos MAXO 25/0,5-6 PN10	0.13
Pump 05	Heating loop	Chilled beams	Stratos MAXO 25/0,5-6 PN10	0.13
Pump 06	Heating loop	Radiators Bistro	Stratos MAXO 25/0,5-4 PN10	0.08
Pump 07	Cooling loop	AHU	Stratos MAXO 25/0,5-4 PN10	0.08
Pump 08	Cooling loop	Radiant ceiling	Stratos MAXO 25/0,5-6 PN10	0.13
Pump 09	Cooling loop	Chilled beams	Stratos MAXO 25/0,5-6 PN10	0.13

8 SELECTION AND DESIGN OF ENERGY GENERATION SYSTEM

8.1 Requirements for the energy generation system

8.1.1 Total heating and cooling load

An important determining factor for choosing the energy generation system is the total heating and cooling demand. In the present case, the total heating capacity which must be provided by the energy generation system is 50.29 kW, while the total cooling capacity is -32.62 kW. This includes the energy needed for the AHU and for the in-room terminal systems. The energy for hot sanitary water is generated by decentral electric boilers since the demand is low and meets the legal requirements according to §71 (5), GEG, always if the boilers are electronically controlled.

8.1.2 Legal requirements

The building complex includes an existent and a new building, both for public use. The legal requirements concerning the share of renewable energies explained in Chapter 2.3.1 do not apply before 2028 in the present case, since the building is located in a municipality of less than 100,000 inhabitants without a district heating concept. As the reduction of GHG emissions is one of the goals of this work and the building with its public character has a role model function, the further planning will be following to the stricter legal requirements which normally must be applied only by 2028.

8.1.3 Special requirements due to the building complex

The building itself shows particular requirements. The space around the building is limited and composed of a public place with urban furniture, a street, another station building and the train rails. Inside the new building, several rooms are reserved for the heating installations. The heating period is fixed to be from October to April inclusive and the cooling period from May to September inclusive. Finally, no district heating and cooling is available for the building complex.

8.2 Analysis of suitable energy generation systems

8.2.1 Alternatives

8.2.1.1 Preselection

In reference to the possible options meeting the existent legal requirements, a decision matrix has been elaborated to preselect the alternatives generally suitable for the present project. In Table 27, each option according to GEG in its actual version from 2023 is evaluated regarding its advantages and disadvantages and its general economic feasibility, leading to a decision concerning its suitability for the project.

Table 27: Decision matrix for preselecting alternatives regarding the energy generation system

Decision matrix for choosing regenerative energy generation according to GEG from October 2023			
Type of energy generation	**Advantages vs. Disadvantages**	**Economic feasibility**	**Decision**
District heating	+ low primary energy factor + adaptation to future load changes possible + maintenance by provider - dependency on provider regarding supply security - regenerative energy share depends on provider	Low costs for connection to existing district heating networks.	Not suitable since no district heating is available according to client.
Air source heat pumps	+ easy installation + cooling possible - low efficiency at very low (heating) or very high (cooling) outdoor air temperatures - space occupation and visual impact - noise emissions	Good cost-value ratio.	Recommended, in combination with an additional system for peak heating loads.
Geothermal brine-water heat pumps with horizontal collectors	+ cooling possible + good efficiencies since source/sink temperatures relatively constant - lower capacities than vertical collectors - high area use for installation	Medium high investment costs.	Not suitable since areas around the building complex already used.
Geothermal brine-water heat pumps with vertical collectors	+ cooling possible + good efficiencies since source/sink temperatures relatively constant - high technical effort - Thermal-Response-Test necessary	High investment costs, economically interesting in case of both heating and cooling.	Recommended, in combination with an additional system for peak heating loads.

Decision matrix for choosing regenerative energy generation according to GEG from October 2023			
Type of energy generation	**Advantages vs. Disadvantages**	**Economic feasibility**	**Decision**
Deep-ground geothermal plants	+ high heating capacity - very high technical effort - Thermal-Response-Test necessary	Very high investment costs, permissions of mining authority.	Not suitable, since too high costs in comparison to project size.
Water-water heat pumps	+ high heating capacity + cooling possible + good efficiencies since source/sink temperatures more constant - high technical effort - survey report for thermal use of ground water and water quality necessary	High investment costs, economically interesting in case of both heating and cooling.	Less suitable, depends strongly on ground water quality and amount, which is unknown.
Direct electricity heating systems	+ no energy generation system necessary - high operating costs - renewable share depends on electricity provider - only for very well-insulated buildings	Low investment costs, but high operating costs. Cost-value ratio good in case of very small or additional systems.	Not suitable since building not very well-insulated according to legal definition and because of high operating costs.
Solar thermal energy production	- high availability at times of low heating energy demand	Interesting in case of central supply of hot sanitary water. Usually, photovoltaic panels economically more interesting.	Not suitable, since hot water generation is decentral, and demand is low.
Cogeneration using biomass for minimum 65% of the fuel	+ high total efficiency + renewable source - delivery and storage installations necessary, especially for solid biomass - raising prices for biogas - high maintenance effort - additional system for peak loads necessary in case of cogeneration	Cost-value ratio economically interesting in the range of the base load but depends on type of biomass and necessary installations. Best would be delivered gaseous biomass by gas distribution networks with 65 % renewable share, but not existing yet.	Less suitable since an additional system for peak loads and for cooling and a storage tank are necessary.
Cogeneration using gaseous biomass for minimum 15% of the fuel	+ high total efficiency + renewable source - additional system for peak loads necessary in case of cogeneration - does not comply with future legal requirements	Cost-value ratio economically interesting in the range of the base load.	Possible, in combination with an additional system for peak loads, and for cooling, and gas supply from gas distribution networks.
Condensing gas boiler using biomass for minimum 65% of the fuel	+ renewable source + no additional system for peak loads - delivery and storage installations necessary, especially for solid biomass - raising prices for biogas - high maintenance effort in case of solid biomass - lower efficiency in comparison to cogeneration	Cost-value ratio economically interesting but depends on type of biomass and necessary installations. Best would be delivered gaseous biomass by gas distribution networks with 65 % renewable share, but not existing yet.	Less suitable since an additional system for cooling and a storage tank are necessary.

The decision matrix results in three suitable options. First, the thermal energy may be generated by an air source heat pump in combination with a condensing gas boiler for peak heating loads without any restrictions regarding the boiler fuel, always if the heat pump is designed with a capacity of 30% of the heating load in bivalent-parallel use. Second, by using a geothermal brine-water heat pump combined with a condensing gas boiler for peak heating loads without any restrictions regarding the boiler fuel, always if the heat pump is also designed with a capacity of 30% of the heating load in bivalent-parallel use. Third, with a cogeneration system using natural gas from distribution networks, in combination with an air-water heat pump designed to satisfy the total cooling load and not more than 30% of the heating load meeting legal requirements, and an additional condensing gas boiler for peak loads.

8.2.1.2 Base case: ASHP and condensing gas boiler

The base case consists of a reversible air source heat pump (ASHP) working with water as a secondary fluid and a condensing gas boiler. This is the most economic and easiest realizable option offering heating and cooling and therefore chosen as the base case.

The air-water heat pump's capacity is chosen in function of the total cooling load of -32.6 kW. The model "Zeta Sky Hi HP R7" from Swegon (for data sheet see Appendix IV in 11.4.3) complies this requirement with a refrigeration capacity of 33.4 kW and offers furthermore a heating capacity of 35.4 kW. The indicated price by the manufacturer with all complementary components for reversible systems is approximately 41 k€.

The condensing gas boilers capacity is designed in function of the remaining heating load since the boiler will only satisfy peak loads in bivalent-parallel use. The condensing gas boiler "Vitocrossal 300" with a capacity of 35 kW is chosen (for data sheet see Appendix IV in 11.4.5), resulting in a price of approximately 13.5 k€ including necessary additional components.

The yearly maintenance is estimated to cost around 250 €/year for air-water heat pumps and 300 €/year for condensing gas boilers.

8.2.1.3 Alternative 1: GSHP and condensing gas boiler

The first alternative is composed of a ground-source heat pump (GSHP) and a condensing gas boiler. The GSHP is working with brine as a primary fluid using for the heat exchange vertical collectors, and with water as a secondary fluid.

The geothermal heat pump is a reversible system, and its capacity is designed in function of the total cooling load. The model "Vitocal 301.A45 G" with a refrigeration capacity of 34.2 kW and a heating capacity of 47 kW is therefore chosen with an indicated price of around 28 k€ including required additional components (for data sheet see Appendix IV in 11.4.2). Furthermore, the drilling of the boreholes, the installation of the collectors including materials and a Thermal Response Test (TRT) are estimated to cost 61 k€. The number of boreholes is estimated to be 9 with a length of 97 m, based on the estimation of the soil heat extraction rate of 50 W/m, a heat extraction in heating mode of around 36.5 kW and a heat injection in cooling mode of around 43.5 kW. Calculation details are given in Appendix III in 11.3.2.4.

The condensing gas boiler shows the same characteristics than the one described in the base case in Chapter 8.2.1.2.

The yearly maintenance is estimated to cost around 250€/year for geothermal brine-water heat pumps and 300 €/year for condensing gas boilers.

8.2.1.4 Alternative 2: ASHP, CHP and condensing gas boiler

The second alternative consists of a reversible ASHP, a combined heat and power (CHP) system, and a condensing gas boiler. The air-water heat pump is necessary to provide cooling and the cogeneration system is introduced as alternative to produce part of the necessary electricity for the heat pump in heating mode.

The selected air-water heat pump has the same characteristics than the one described in the base case in Chapter 8.2.1.2, chosen to satisfy the total cooling load. Unlike the base case, the heat pump is satisfying here only the minimum share of the total heating load which must be covered by the heat pump to comply with the law GEG is determined. In the present case, the heat pump will be used in bivalent-parallel use and must satisfy 30% of the total heating load of 50.3 kW, which corresponds to 15.1 kW.

Furthermore, the condensing gas boiler corresponds to the one used in the other options and described in Chapter 8.2.1.2, operated only for peak loads.

The selected cogeneration system is called "Buderus XRGI 6" from Bosch Thermotechnik GmbH and provides a heating capacity of 12.4 kW_{th} and an electrical power of 6 kW_{el} at full load, being able to module between 3 to 6 kW_{el} (for data sheet see Appendix IV in 11.4.4). This capacity is chosen since the minimum heating load of each hour of the month after subtracting the load covered by the heat pump lies between 15.7 kW in January to 0 kW in April and October. Choosing this size, the cogeneration system can operate during one month in full load, and during two months in part load, providing the corresponding share of electrical power.

The yearly maintenance is estimated to cost around 250 €/year for air-water heat pumps, 300 €/year for condensing gas boilers and 2 €cent per kWh resulting in 357 €/year for small cogeneration systems.

8.2.2 Analysis

8.2.2.1 Considering the energy consumption

In the following, the total building energy consumption and the comparison of the three options regarding the renewable share of energy consumption and regarding the final and primary energy consumption will be discussed.

8.2.2.1.1 Input

For calculating the annual cooling respectively heating consumption, the corresponding thermal loads for each hour of the month is modeled with a linear function depending on the outdoor temperature, where 100 % of the thermal load corresponds to the outdoor design temperature (-12.7°C in heating mode and 32°C in cooling mode) and 0 % corresponds to the temperature of heating respectively cooling limit (set here at 15°C in heating mode and 24°C in cooling mode). The resulting functions are illustrated in Figure 22.

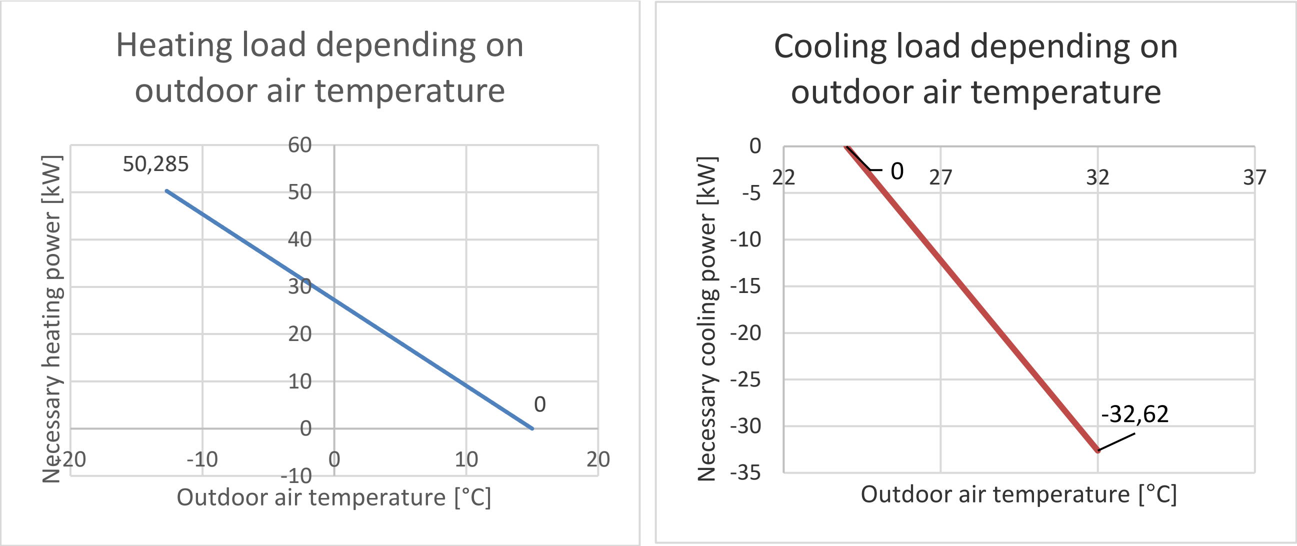


Figure 22: Heating and cooling load depending on outdoor air temperature

Regarding the outdoor air temperature, hourly weather data of the nearest weather station “Berlin-Buch” with ID 400 of the Deutsche Wetterdienst (DWD) from 2008 to 2022 are prepared obtaining the temperature of each hour of each month (Deutscher Wetterdienst, 2023). In cooling mode, the 85th percentile of the weather data has been considered, while in heating mode, the 25th percentile has been used, taking into account unfavorable weather conditions. The resulting temperatures are added to Appendix III in 11.3.1.

Regarding the regenerative share of the annual heating consumption, the maximum heating capacity of the heat pumps in each hour of the year has been modeled depending on the outdoor air temperature in case of the ASHP with the help of manufacturer data or has been considered as a constant value given by the manufacturer in case of the GSHP. More details are available in Appendix III in 11.3.2.

For the calculation of the annual final energy consumption, the efficiencies are taken as given in the corresponding data sheets (see Appendix IV) and resumed in Appendix III in 11.3.4.

Finally, for the determination of the primary energy consumption, the corresponding primary energy factors are extracted from annex 4, GEG (Bundesregierung, 2023) and resumed in Appendix III in 11.3.5.

The detailed calculations and results are added in Appendix III in 11.3.3.

8.2.2.1.2 Results

The building consumes annually 115 MWh for heating and -13 MWh for cooling. The consumption is distributed throughout the year as illustrated in Figure 23.

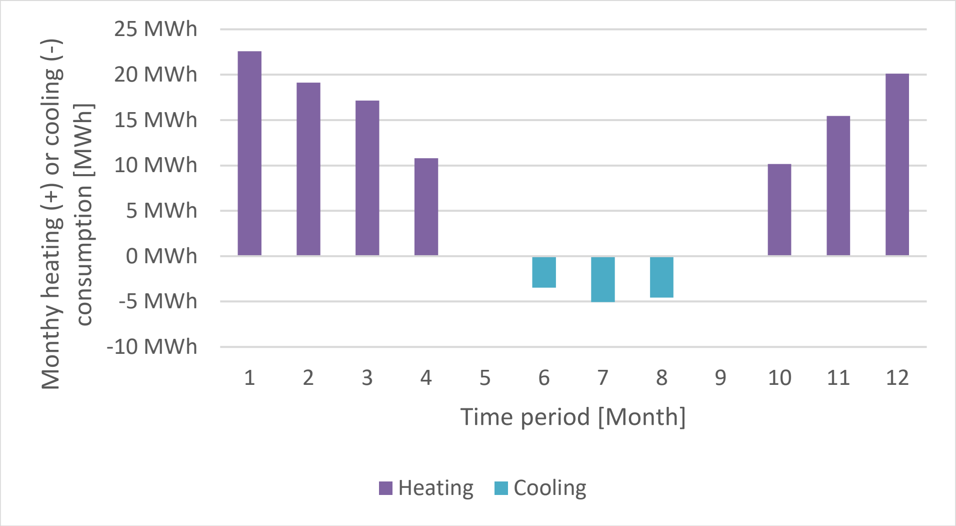


Figure 23: Monthly heating and cooling consumption

For better understanding, the monthly consumption of each option is depicted in Figure 24, Figure 25, and Figure 26. Concerning the renewable share of energy, all three options are meeting the legal requirements about the renewable capacity share of at least 30% of the total heating load in bivalent-parallel use of a heat pump in combination with an additional system. Furthermore, the cooling consumption is covered to 100 % by the corresponding heat pump system in all three cases. Regarding the heating consumption, the base case provides 95 % by the heat pump, which is considered as renewable share of the heating consumption, alternative 1 provides 100 %, and alternative 2 64 %. The remaining part of the heating consumption is generated by the condensing gas boiler in case of the base case and by the CHP-system (20 %) and the condensing gas boiler (16 %) in case of alternative 2.

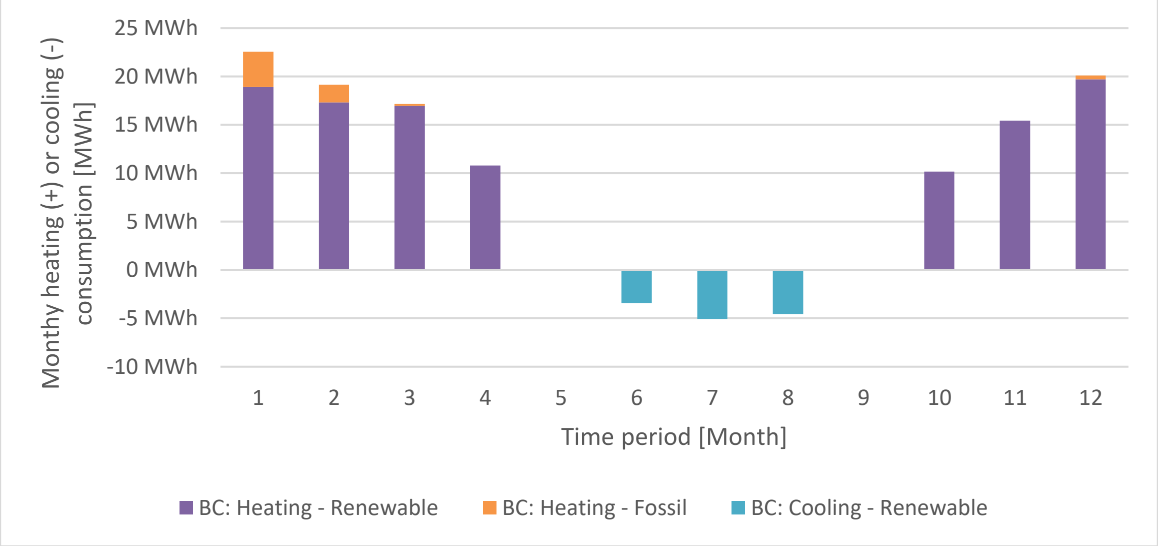


Figure 24: Monthly heating and cooling consumption – Base case (BC)

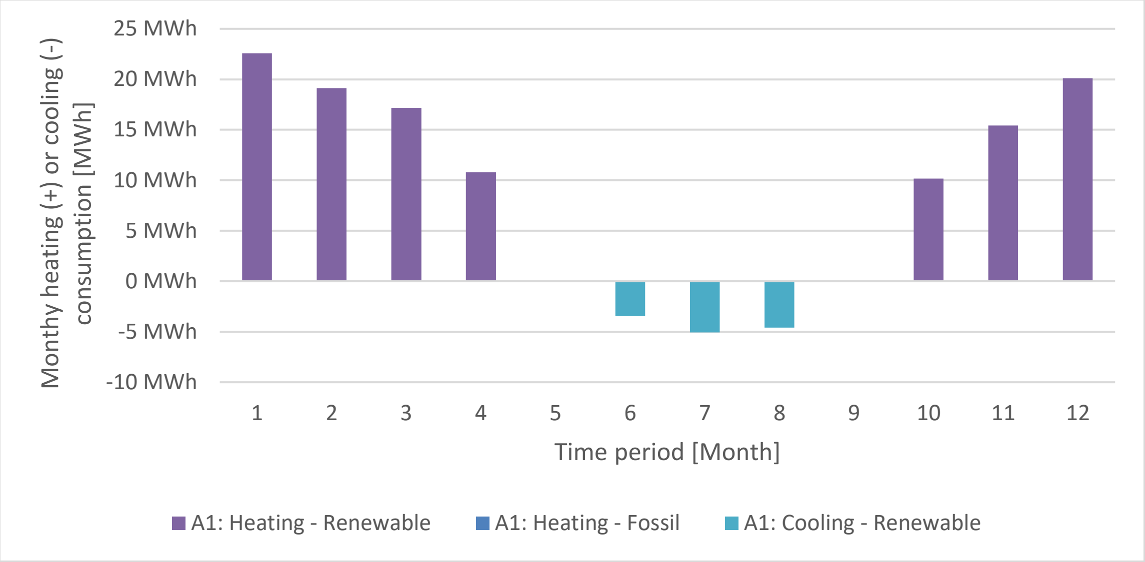


Figure 25: Monthly heating and cooling consumption – Alternative 1

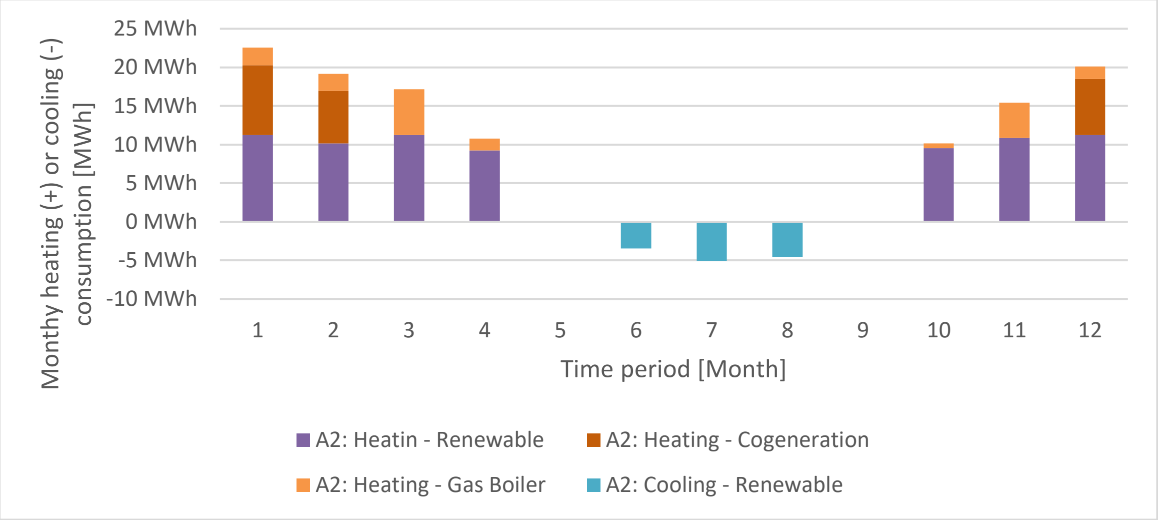


Figure 26: Monthly heating and cooling consumption – Alternative 2

Regarding the annual final energy consumption, the results are shown in Figure 27 with 53 MWh/year in case of the base case covered to 88 % by electricity, 29 MWh/year in case of alternative 1 completely covered by electricity, and with 66 MWh/year in case of alternative 2 with a share of 33 % covered by electricity, 38 % covered by natural gas for the CHP and 29 % of natural gas for the condensing gas boiler.

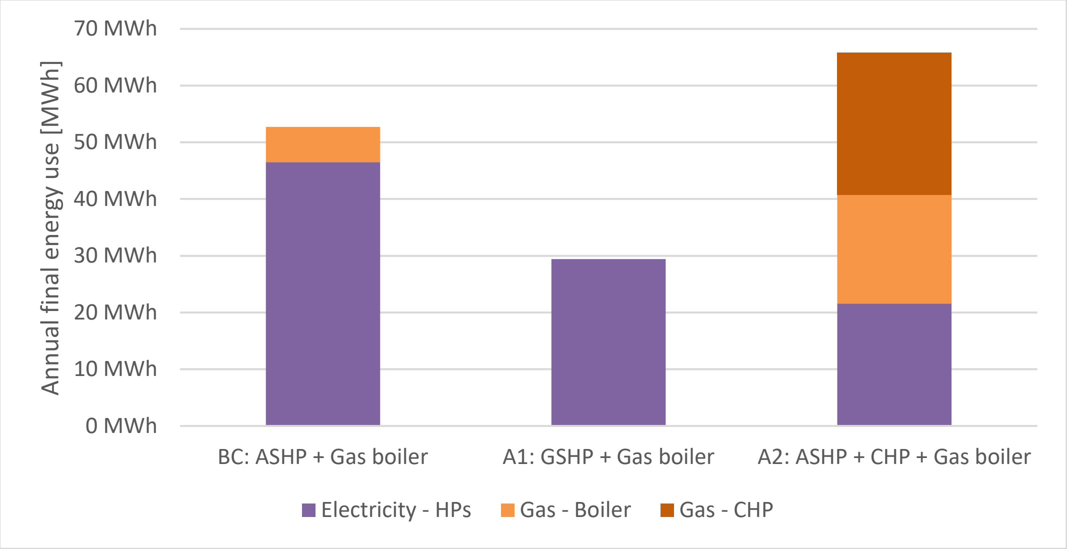


Figure 27: Comparison - Annual final energy consumption

Concerning the annual primary energy consumption, the base case needs approximately 91 MWh, the alternative 1 around 53 MWh and the alternative 2 around 88 MWh as shown in Figure 28.

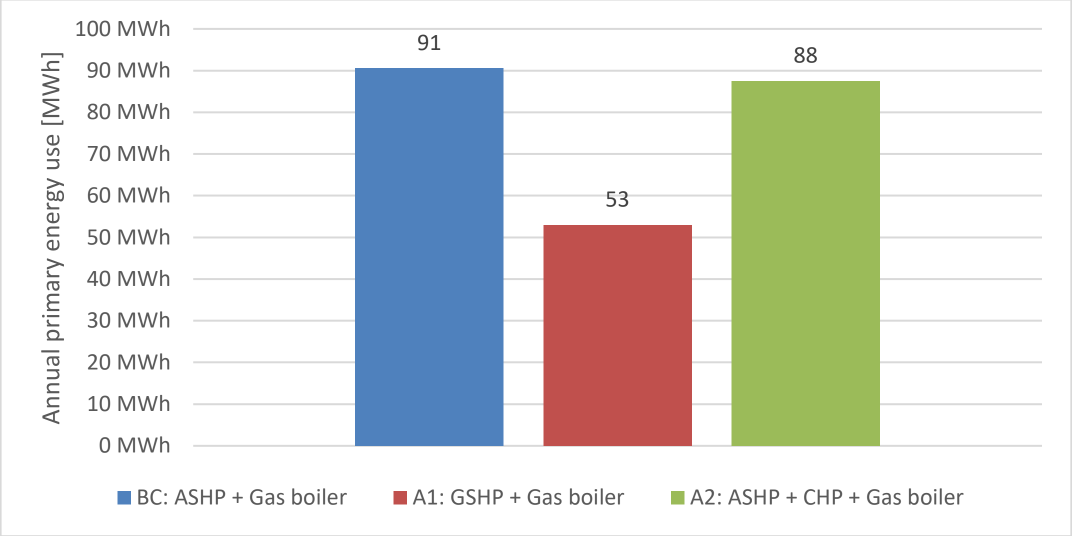


Figure 28: Comparison – Annual primary energy consumption

8.2.2.1.3 Interpretation

The alternative 1 (GSHP) is showing the best results regarding the energy consumption, with a reduction of the final energy consumption of 44 % in comparison to the base case and a decrease of the primary energy consumption of 42 %.

This is due to the fact that the final energy consumption is relatively low in alternative 1 since the GHSP shows very good efficiencies both in heating and cooling mode. Alternative 2 shows a higher final energy use (+25 %) than the base case since the share of energy generation by the ASHP is around 41 % greater for the base case (referred to the cooling and heating energy consumption) and ASHPs are working with high efficiencies in comparison to boiler or CHP systems. This is partly counterbalanced by the fact that 47 % of the electricity for the ASHP in alternative 2 is autogenerated by the CHP-system. Regarding the annual primary energy consumption, the base case turns out the worst option. Alternative 2 indicates a reduction of the annual primary energy consumption of 3 %. This is on the one hand due to the fact, that the primary energy factor of electricity from the net is relatively high with 1.8 in Germany in comparison to the primary energy factor of natural gas of 1.1, which is partly justified due to the high share of electricity produced by coal plants, but regarding the probable future evolution of electricity production in favor of renewable energies it seems penalizing the use of electricity-based energy systems exceedingly. On the other hand, this is due to the electricity generation of the CHP system in alternative 2 used for the HP in heating mode, and so reducing the final and even more the primary energy consumption of alternative 2.

8.2.2.2 Considering the environmental impact

Concerning the environmental impact, the comparison of the three options regarding the equivalent CO2 emissions and regarding the environmental impact of the used refrigerant will be discussed.

8.2.2.2.1 Input

For the determination of the annual indirect equivalent CO2 emissions, the final energy consumption is multiplied by the corresponding emission factors extracted from annex 9, GEG (Bundesregierung, 2023) and resumed in Appendix III in 11.3.5.

The global warming potential of the used refrigerants are taken from the data sheets (see Appendix IV).

Finally, the total equivalent warming impact (TEWI) is calculated according to equation (4).

$$TEWI = GWP * L * n + GWP * m_{RC} * (1 - \alpha_{Re}) + n * E_{year,x} * \beta \qquad (4)$$

$$
\begin{aligned}
&with\\
&TEWI\colon total\ equivalent\ warming\ impact\ [eq.kg\ CO_2]\\
&L\colon leakage\ rate\ of\ system;\ here\ considered\ 3\ \%\ of\ charge\ annually\ \left[\frac{kg\ refrigerant}{year}\right]\\
&n\colon number\ of\ years;\ here\ considered\ 25\ years\ [years]\\
&m_{RC}\colon refrigerant\ charge;\ see\ data\ sheets\ in\ Annex\ 4\ [kg]\\
&\alpha_{Re}\colon factor\ for\ recovery;\ here\ considered\ 95\ \%\ [\%]\\
&E_{year,x}\colon annual\ final\ energy\ consumption\ of\ energy\ source\ x\ [kWh]\\
&\beta\colon emission\ factor\ of\ energy\ source\ x;\ see\ Annex\ 3.5\ \left[eq.kg\frac{CO_2}{kWh}\right]
\end{aligned}
$$

8.2.2.2.2 Results

The equivalent CO2 emissions emitted during operation for each option are shown in Figure 29. It can be observed that the base case scenario emits 27.5 t equiv. CO2/year, alternative 1 16.5 t equiv. CO2/year and alternative 2 22.7 t equiv. CO2/year.

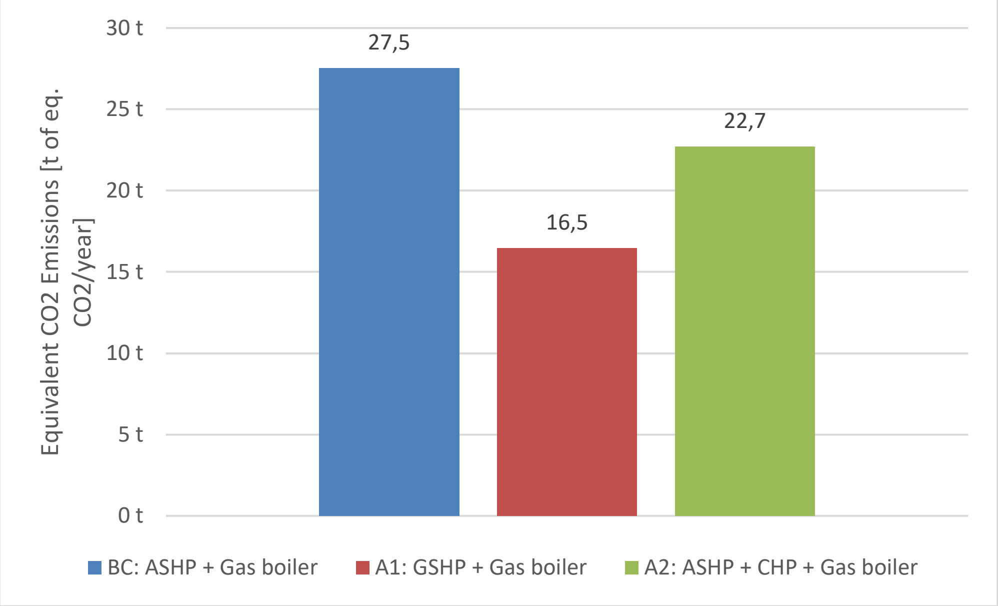


Figure 29: Comparison – Annual indirect equivalent CO2 emissions

Regarding the refrigerant used in the corresponding heat pump systems, the ASHPs planned for the base case scenario and alternative 2 show a global warming potential (GWP) 677 kg of equivalent CO2 for each kg of refrigerant, while the refrigerant of the GSHP (alternative 1) is indicated with a GWP of 2088 kg of equivalent CO2.

Considering the GWP, the liquid capacity, and the leakage rate of the refrigerants as well as the number of operational years and the annual indirect CO2 emissions, the total equivalent warming impact is determined with the results shown in Figure 30. The TEWI of the base case shows a value of 693 t of eq. CO2 emissions, the alternative 1 432 t of eq. CO2 and the alternative 2 572 t of eq. CO2. Direct emissions due to the use of refrigerants are determined with approximately 4 t of eq. CO2 for the base case and the alternative 2 and 20 t of eq. CO2 for alternative 1.

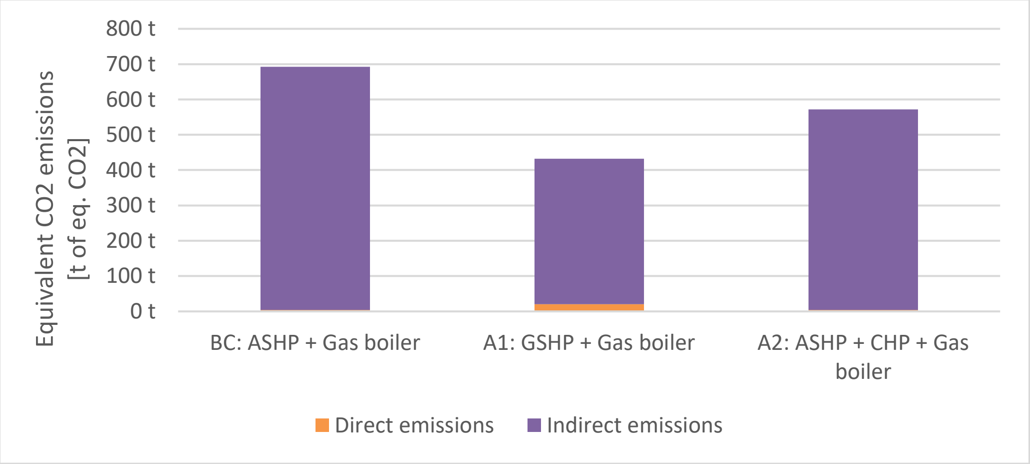


Figure 30: Comparison – Total equivalent warming impact during operation period

8.2.2.2.3 Interpretation

The alternative 1 is showing the best results in terms of environmental impact with a reduction of annual indirect emissions of 40 % in comparison to the base, while alternative 2 shows 18 % less annual indirect emissions than the base case.

Regarding the GWP of the refrigerants, the alternative 1 uses a refrigerant with a nearly 4 times higher GWP than the other options. The calculation of the TEWI shows that the resulting direct emissions represent only a small share of approximately 1% of the TEWI for the base case and alternative 2 and of 5 % of the TEWI for alternative 1 while the remaining share is due to indirect emissions. Considering the TEWI, alternative 1 remains the best option with a reduction of the TEWI of 38 % in comparison to the base case, while alternative 2 only reduces the TEWI of 17 % in comparison to the base case.

8.2.2.3 Considering the economic impact

Concerning the economic impact, the comparison of the three options regarding the investment costs, the annual operating costs and the annual accumulated operating costs savings will be discussed.

8.2.2.3.1 Input

The investment costs are either obtained from quotes provided by manufacturers or in case of the CHP-system, the costs are estimated based on the table given by (Energieagentur NRW, 2021).The maintenance costs are based on estimations given by (Thermondo, 2024) and (Buderus GmbH, 2023). The investment and maintenance costs are resumed in Appendix III in 11.3.6.

Prices and inflation rates of electricity, gas and consumer goods are provided by the statistical institution of Germany published in energy price developments (Statistisches Bundesamt, 2023) and consumer price index (Statistisches Bundesamt, 2022), considering the prices of the first semester of 2022 and the average of inflation rates of the time period from 2018 until 2022. In case of electricity used for heat pumps, special contracts are offered with an estimated price reduction of 20% of the general electricity price (Viessmann Climate Solutions SE, 2023c).

Finally, the operating costs are calculated according to equation (5).

$$C_{operating} = \left(\sum_{x} C_{maintenance,x}\right) + \left(\left(E_{year,el} - G_{year,el}\right) * p_{el\_WP}\right) + \left(E_{year,gas} * p_{gas}\right) \tag{5}$$

$with$

$C_{operating}: annual\ operating\ costs\ \left[\frac{€}{year}\right]$

$C_{maintenance}: annual\ maintanence\ costs\ of\ each\ energy\ system\ x$

$E_{year,el}: annual\ final\ energy\ consumption\ in\ form\ of\ electricity\ [kWh]$

$\mathrm{G_{year,el}}$: annual autogenerated electricity by the system in − situ [kWh]

$p_{el,WP}: price\ of\ electricity\ for\ heat\ pump\ consumption\ \left[\frac{€}{kWh}\right]$

$E_{year,gas}: annual\ final\ energy\ consumption\ of\ form\ of\ natural\ gas\ [kWh]$

$p_{gas}: price\ of\ natural\ gas\ \left[\frac{€}{kWh}\right]$

Detailed calculations and results are added in Appendix III in 11.3.7 and 11.3.8.

8.2.2.3.2 Results

Regarding the investment costs, the results are shown in Figure 31. The base case is the most economic option with investment costs of 55 k€, alternative 1 is the most expensive option with investment costs of 102 k€ and alternative 2 represents an intermedium option with investment costs of 87 k€.

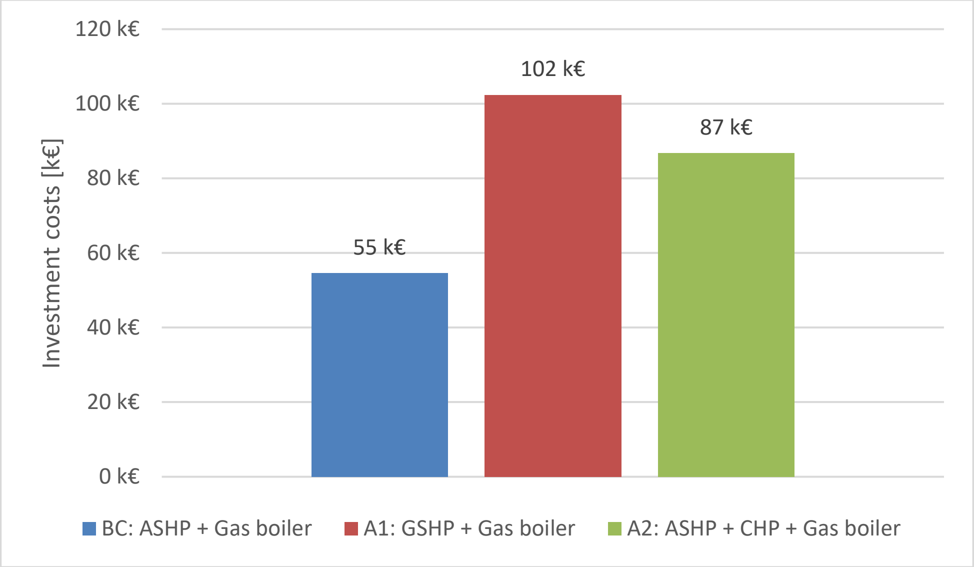


Figure 31: Comparison – Investment costs

Concerning the annual operation costs, the operating costs in year 1 are the lowest in case of alternative 1 with 8265 €/year, followed by alternative 2 with 8449 €/year and by the base case with 13254 €/year. As shown in Figure 32, the operating costs are increasing in case of all three options, but in comparison to the base case and alternative 1, where the operating costs are increasing in a similar way (42 % respectively 39 % increase of costs from year 1 until year 25), the operating costs of alternative 2 increase faster (86 % increase of costs from year 1 until year 25). In year 1, the operating costs of alternative 2 are similar to the ones of alternative 1, while in year 25, they are closer to those of the base case.

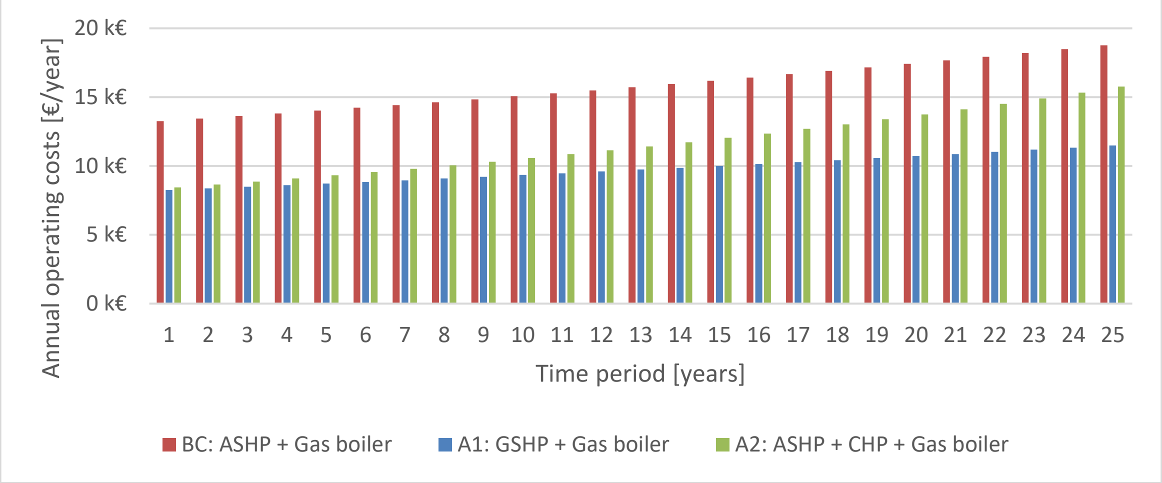


Figure 32: Comparison – Annual operating costs

Concerning the annual accumulated savings taking into account the operating costs of each alternative, the Figure 33 shows the savings between the alternatives and the base case after different time periods, starting with the difference for investment costs as a negative value. Once the graphic shows positive values, the investment costs are compensated by the reduced operating costs. Alternative 1 is more expensive in terms of initial investment, but more economic during operation. Comparing alternative 1 to the base case, the accumulated operating costs savings reach the difference of investment costs after 9 years. Regarding the comparison of alternative 2 and the base case, the threshold of accumulated operating costs savings reaching the difference of investment costs is here gained after 6 years.

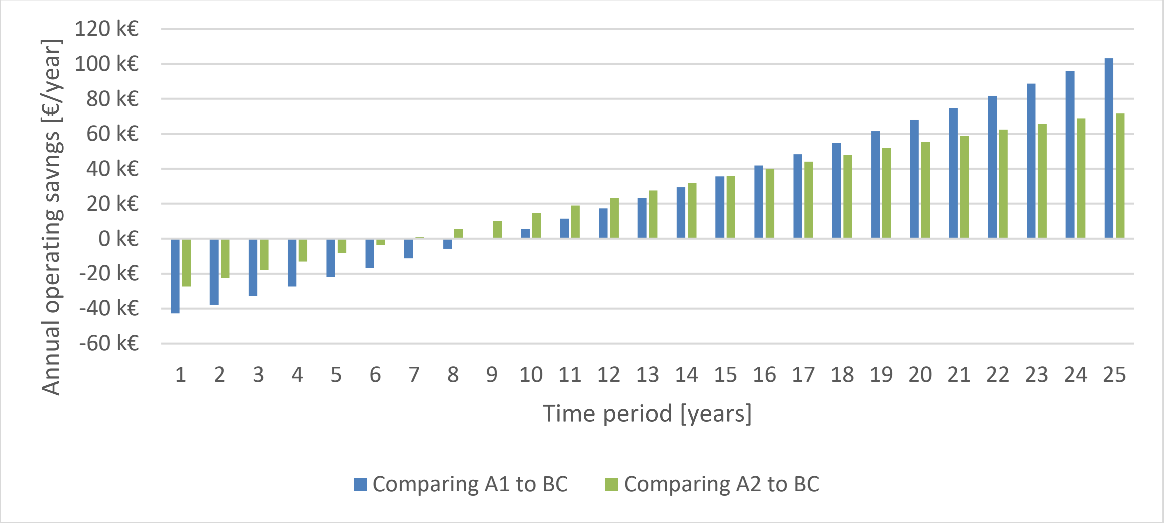


Figure 33: Comparison – Annual accumulated operating costs savings

8.2.2.3.3 Interpretation

Taking into account operating costs, the base case is less suitable. The investment costs are low, but the operating costs are high since this option needs a greater share of electricity which currently is more pricy than natural gas, but also requires a certain share of natural gas which is estimated to get more expensive in the future. Alternative 1 is suitable of an economic point of view, although it represents very high investment costs. The operating costs of this alternative are relatively low because of using an efficient system and being able to generate 100 % of the energy by the heat pump requiring only electricity, which represents a lower inflation rate and hence lower increase of operating costs. Finally, alternative 2 is also economically suitable since the investment is moderate and the operating costs are relatively low. From an economic point of view, the weak point of alternative 2 is the greater dependency on natural gas and its volatile price evolution, while the positive point is the autogenerated electricity by the CHP-system and thus less expensive electricity must be boughed from the market.

Comparing the alternatives 1 and 2 to the base case with the help of Figure 33, the difference of investment costs between the base case to alternatives 1 and 2 are compensated by the savings of the operating costs after 6 (alternative 2) respectively after 9 years (alternative 1). The compensation takes place considerably before the end of lifetime of 25 years which is why the base case is not interesting from an economic point of view. Both alternative 1 and 2 are suitable; alternative 1 can be recommended from a long-term economic point of view, because the savings after 25 years are 44 % higher, while alternative 2 should be considered if the high investment costs of alternative 1 are unbearable for the client.

8.2.3 Justification of selection

The final decision is based on the results regarding energy consumption, environmental impact, and economic impact. The alternative 1 which consists of a hybrid system of a geothermal brine-water heat pump and a condensing gas boiler for peak loads is selected because of the following reasons. First, in terms of energy consumption, the alternative 1 is the best alternative with the lowest annual final and primary energy consumption allowing a reduction of primary energy consumption of 42 % in comparison to the base case, while alternative 2 would only permit a reduction of 3 %. Second, regarding the environmental impact, alternative 1 remains the best alternative with a reduction of the total equivalent warming impact of 38 % in comparison to the base case, while alternative 2 would mean a reduction of only 17 %. Third, concerning the economic impact, alternative 1 is suitable since its high investment costs can be compensated by its low operating costs after 9 years in comparison to the base case, although alternative 2 would be compensated already after 6 years. Finally, alternative 1 convinces by 44 % greater savings after 25 years in comparison to alternative 2.

8.3 Design of the energy generation system

8.3.1 Geothermal heat pump

The design of the geothermal heat pump consists of the determination of the heat pump model, the ground heat exchanger characteristics and the circuit characteristics including pipe selection, pressure drop calculations and pump selection. Regarding the ground heat exchanger characteristics, a detailed calculation of the required ground heat exchanger length is carried out, the configuration and location of the boreholes is determined, the energy balance is calculated, and the material of the heat exchanger is selected.

8.3.1.1 Heat pump model selection

The heat pump model used for the comparison "Vitocal 301.A45 G" as shown in Figure 34 (data sheet in Appendix IV in 11.4.2) with a cooling capacity of 34.2 kW and a heating capacity of 47 kW is planned for the project since it complies with the requirements regarding the building complex considering capacities, size, efficiencies, and noise levels. Furthermore, it meets the requirements regarding the efficiencies determined according to EN 14511 for public funding.

The efficiencies are indicated as mentioned above with EER=3.7 in cooling mode and SCOP=4.5 in heating mode. Regarding the secondary circuit, the supply and return water temperatures are set to 45°C / 37°C in heating mode and to 10°C / 16°C in cooling mode, the operation pressure is 3 bar, the water content is indicated with a volume of 11.5 l, the minimum volume flow rate is 3.7 m³/h with a pressure drop of 65 mbar and the nominal volume flow rate is 7.4 m³/h with a pressure drop of 210 mbar. Concerning the primary

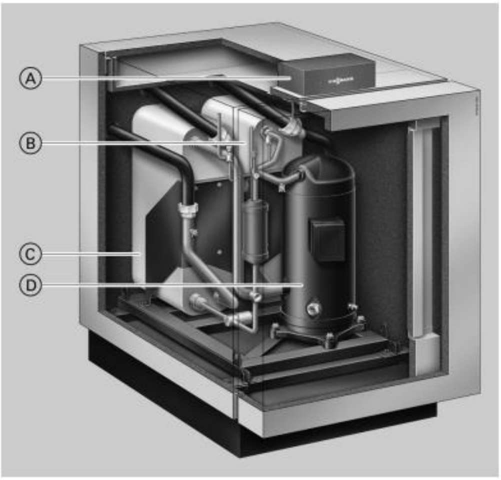


Figure 34: Illustration of chosen heat pump
(Viessmann Climate Solutions SE, 2023a)

circuit, the brine content is indicated with a volume of 11.5 l, with a minimum volume flow rate of 6500 l/h and a pressure drop of 154 mbar and the operation pressure is 3 bar as well. The brine supply temperature must lie between -10 °C and 25 °C. For the electricity supply, a connection to a triphasic power outlet of 400 V must be planned, furthermore a second power outlet of 230 V for the control devices of the heat pump is necessary. The heat pump refrigerant is called R410A with a GWP of 2088 kg of equivalent CO2. Finally, regarding the space requirements, the heat pump shows measurements of 1085mmx780mmx1267mm (length by width by height) and a weight of 298 kg. The heat pump is equipped with connections of type DN50 to the supply and return pipes for both the primary and secondary circuit.

Regarding the brine, the anti-freezing agent “Tyfocor GE” based on ethylene glycol from the manufacturer Tyforop Chemie GmbH will be mixed with water in a ratio of 1:4 (25% anti-freezing agent) to reach a freezing point of -12.3 °C (see (TYFOROP Chemie GmbH, 2024)).

8.3.1.2 Ground heat exchanger

8.3.1.2.1 Required ground heat exchanger length

The required ground heat exchanger length is determined in detail according to recommendations of the International Ground Source Heat Pump Association (IGSHPA) (International Ground Source Heat Pump Association, 1988) using the equations (6), (7) and (8).

$$L_c = \frac{\left(Q_{CAP,c} * \frac{EER+1}{EER} * \left(R_P + R_S * F_{c,07}\right)\right)}{T_{MAX} - T_H} \tag{6}$$

$$L_h = \frac{\left(Q_{CAP,h} * \frac{COP_h - 1}{COP_h} * \left(R_P + R_S * F_{h,01}\right)\right)}{T_L - T_{MIN}} \tag{7}$$

$$L_{required,ground\ exchanger} = \max(L_c; L_h) \tag{8}$$

with
$L_{required,ground\ exchanger}$: *required ground exchanger length*
L_c: *required ground exchanger length for cooling*
L_h: *required ground exchanger length for heating*
$Q_{CAP,c}$: *Cooling capacity of GSHP* $[kW]$
EER: *Energy efficiency ratio in cooling mode*
$Q_{CAP,h}$: *Heating capacity of GSHP* $[kW]$
COP_h: *Coefficient of performance in heating mode*
R_P: *Thermal resistance of tube*
R_S: *Thermal resistance of soil*
$F_{c,07}$: *Run fraction of month July*
$F_{h,01}$: *Run fraction of month January*
T_{MAX}: *maximum entering fluid temperature* $[°C]$
T_{MIN}: *minimum entering fluid temperature* $[°C]$
$T_{soil,H}$: *Maximum annual soil temperature* $[°C]$
$T_{soil,L}$: *Minimum annual soil temperature* $[°C]$

The input data are resumed in Table 28. Detailed calculations are added in Appendix III in 11.3.9.1.

Table 28: Input data for determination of ground exchanger length

Mode	Characteristics	Input value	Unit
Cooling	Cooling capacity of GSHP Q_CAP_c	34.2	kW
	Energy efficiency ratio EER	3.7	-
	Run fraction July F_c_07	20	%
Heating	Heating capacity of GSHP Q_CAP_h	47.0	kW
	Coefficient of performance in heating mode COP_h	4.5	-
	Run fraction January F_h_01	65	%
-	Thermal resistance of tube R_p	0.017	mK/W
-	Thermal resistance of soil R_s	0.304	mK/W
Cooling	Mean maximum fluid temperature (in cooling mode) T_MAX	21.7	°C
Heating	Mean minimum fluid temperature (in heating mode) T_MIN	-1.7	°C
Cooling	Maximum annual soil temperature T_soil,H	10.2	°C
Heating	Minimum annual soil temperature T_soil,L	10.2	°C

Introducing the input data into the equations, the resulting required length of the ground exchanger is 322 m in cooling mode and 1064 m in heating mode. Since the total length of the ground exchanger depends on the utilization factors of the design months (January for heating mode and July for cooling mode) and the utilization factor in heating mode results high, the ground exchanger length with 1064 m in heating mode is higher than estimated beforehand in Chapter 8.2.1.3 increasing the necessary number of boreholes from 9 to 11. Since this also means an increase in investment cost, an analysis is carried out to determine the most economic ground exchanger configuration of the heat pump in heating mode by varying the heating energy satisfaction and the resulting number of boreholes as shown in Figure 35.

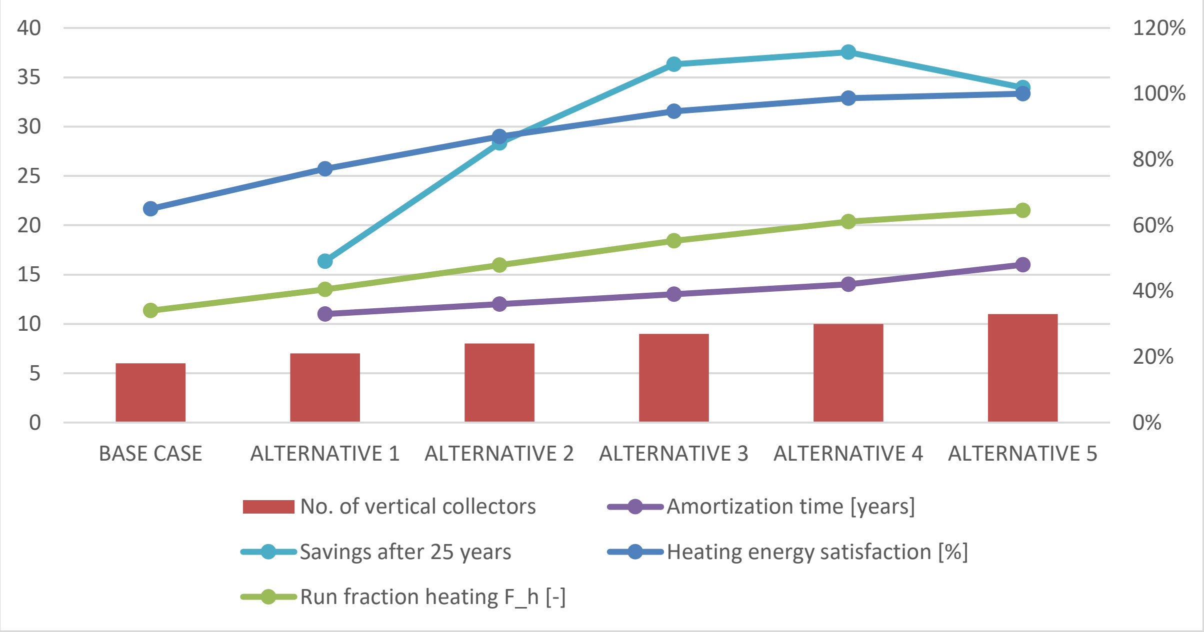


Figure 35: Analysis of most economic ground heat exchanger configuration

The base case consists in the minimum legal case of satisfying 65% of the yearly heating energy resulting in 6 boreholes. 5 alternatives are analyzed, each consisting in one additional borehole until alternative 5 with 11 boreholes and a heating energy satisfaction of 100 %. The run fraction increases in each alternative as well as the heating energy satisfaction, although last increases with less slope between alternatives 3, 4 and 5. The amortization time is between 11 and 16 years and increases with each alternative 1 year, unless for alternative 5, where it increases 2 years. The savings after 25 years lie between 16 k€ (alternative 1) and 38 k€ (alternative 4) and show a peak in alternative 4, although the difference regarding alternative 3 is little with 3 %. Taking into consideration the amortization time and the savings after 25 years, alternative 3 seems to represent a good balance. Therefore, alternative 3 with a heating energy satisfaction of 95% and 9 boreholes is selected as the most economically suitable option and will be further developed. Considering the corresponding run fraction F_h=55%, the total length of the ground heat exchanger is 892 m. Detailed results for each alternative are added in Appendix III in 11.3.9.1.6.

8.3.1.2.2 Definition of distribution field of ground exchangers

Since the depth of the boreholes is limited to 100 m, 9 boreholes of 100 m depth are necessary. The field will be distributed in a configuration of 2x4 boreholes plus 1x1 borehole with a minimum distance of 6 m in between each borehole to avoid an interference between them as recommended in VDI 4640 (VDI, 2019). The total occupied area is around 28m by 8m. The placement of the boreholes is suggested underneath the existing bicycle racks as illustrated in plan 22 in Part III, in a distance of around 10 meters to the heating installation room. The recommended distance to adjacent properties according to VDI 4640 of 3 m is taken into consideration.

8.3.1.2.3 Energy balance

It is important to consider the energy balance to preview if the soil will be cooled down or heated up over the years which implies a change of operating conditions and may reduce the efficiency of the heat pump system and modify the ecosystem of the soil.

The energy balance is determined according to equations (9), (10), (11), (12), and (13).

$$E_{ground,difference} = Q_{ground,heating} - |\mathrm{Q}_{\mathrm{ground,cooling}}| \tag{9}$$

$$E_{ground,cooling} = Q_{ground,cooling} * \sum_{m=5\ldots9} F_{c,m} * days_m \tag{10}$$

$$E_{ground,heating} = Q_{ground,heating} * \sum_{m=1,2,3,4,10,11,12} F_{h,m} * days_m \tag{11}$$

$$Q_{ground,cooling} = Q_{CAP,c} * \frac{EER + 1}{EER} \tag{12}$$

$$Q_{ground,heating} = Q_{CAP,h} * \frac{COP_h - 1}{COP_h} \tag{13}$$

$with$
$E_{ground,difference}$: $Exceeding\ heat\ extraction\ or\ injection\ [kWh]$
$E_{ground,cooling}$: $Heat\ injection\ during\ cooling\ mode\ [kWh]$
$E_{ground,heating}$: $Heat\ extraction\ during\ heating\ mode\ [kWh]$

$F_{c,m}: Run\ fraction\ of\ each\ month\ in\ cooling\ mode\ [-]$
$F_{h,m}: Run\ fraction\ of\ each\ month\ in\ heating\ mode\ [-]$
$Q_{ground,cooling}: Injected\ power\ during\ cooling\ mode\ [kW]$
$Q_{ground,heating}: Extracted\ power\ during\ heating\ mode\ [kW]$
$Q_{CAP,c}: Cooling\ capacity\ of\ GSHP\ [kW]$
$EER: Coefficient\ of\ performance\ in\ cooling\ mode\ [-]$
$Q_{CAP,h}: Heating\ capacity\ of\ GSHP\ [kW]$
$COP_h: Coefficient\ of\ performance\ in\ heating\ mode\ [-]$

The input data are resumed in Table 29.

Table 29: Input data for determination of energy balance

Mode	Characteristics	Input value	Unit
Cooling	Cooling capacity of GSHP Q_CAP_c	34.2	kW
	Energy efficiency ratio EER	3.7	-
	Run fraction May F_c,05	0.2	%
	Run fraction June F_c,06	14	%
	Run fraction July F_c,07	20	%
	Run fraction August F_c,08	18	%
	Run fraction September F_c,09	0	%
Heating	Heating capacity of GSHP Q_CAP_h	47.0	kW
	Coefficient of performance in heating mode COP_h	4.5	-
	Run fraction January F_c,01	55	%
	Run fraction February F_c,02	55	%
	Run fraction March F_c,03	48	%
	Run fraction April F_c,04	32	%
	Run fraction October F_c,10	29	%
	Run fraction November F_c,11	46	%
	Run fraction December F_c,12	55	%

Introducing the input data into the equations, the resulting heat injection during cooling mode is of 16.7 MWh, and the resulting heat extraction during heating mode is of 84.7 MWh. This means that more heat (67.9 MWh) will be extracted than injected.

Possible measures to improve this energy balance are the following options which may be combined. First, the heat pump use may be reduced in heating mode by limiting the energy generation by the GSHP and though satisfying less of the total heating load by the GSHP until 65 %, which is the minimum for meeting the legal requirements. In this case, the surplus of heat extracted is reduced to 41.8 MWh. Second, a thermal solar system could be installed to inject the missing heat during cooling mode to the ground. Finally, it is recommended to realize measurements during at least one year before opting for the described measures, because the reality may differ from the obtained results, since an increase of temperatures is probable due to climate change. This may result in a reduced heating consumption and an increased cooling consumption which would improve the energy balance result. Furthermore, a slightly higher extraction than injection of heat may be desired because ground temperatures have already increased as a consequence of climate change and may be counterbalanced.

8.3.1.3 *Primary circuit design*

The primary circuit design consists of material selection, distribution plan elaboration, pressure drop calculations, and pump selection.

Regarding the material selection, solid materials are chosen from the catalogue of the manufacturer HakaGerodur, including 9 ground heat exchangers, the manifold and the distribution pipes between heat pump and manifold and manifold and ground heat exchangers. Each ground heat exchanger is composed of 4 pipes of DN40, a Y-piece next to the borehole, which introduces the brine into the Doble-U pipes, and a linking U-bend at the deepest point of the borehole with higher pressure resistance until PN 25. The distribution pipes between heat pump and manifold are of DN110 and between manifold and ground heat exchanger of DN50. The manifold itself includes a supply and return connection to the heat pump and 9 connections, one for each borehole. All pipes and connection pieces are of PE100-RC and have the characteristics of SDR11 and PN16. Details about the materials can be found in the corresponding data sheet in Appendix IV in 11.4.7.

Furthermore, the location of the ground heat exchangers, the distribution pipes and the manifold are shown in Figure 36 and in plan 22 of Part III. The area is currently used for bicycle racks and may be reused after the installation of the system for the same purpose.

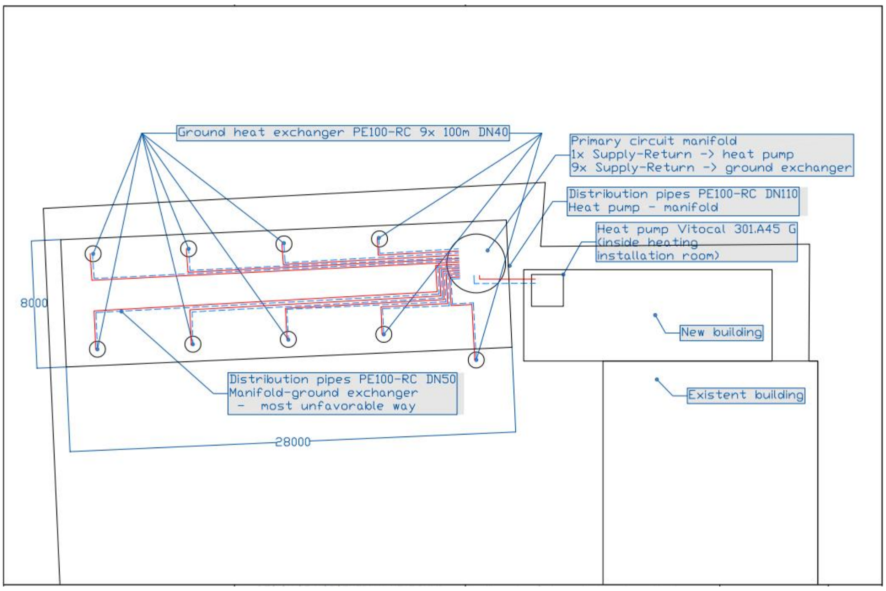


Figure 36: Illustration of primary circuit location and its elements

A pressure drop estimation is carried out for choosing an adequate pump using a pressure drop program published by Software-Factory Schmitz. For the pressure drop estimation, the following elements are taken into account: the distribution pipes from heat pump to the manifold with a length of 10 m both return and supply pipes and a volume flow of 18 m^3/h, the pipes from manifold to the ground exchanger with a length of each 30m and a volume flow of 2 m^3/h, and the ground exchanger pipes of 100 m each and a volume flow of 1 m^3/h. Additionally, two bends of 90° for the pipes between heat pump and manifold both for return and supply pipes, four bends of 90° for the pipes between manifold and ground heat exchangers, one Y-piece for the introduction of the fluid to the ground exchanger and a U-bend of 180° as feet of the ground exchanger are included. Finally, valves both for supply and return pipes between manifold and the heat pump and between manifold and ground exchanger are considered as well as the internal pressure drop inside the heat exchanger of the heat pump extracted from the data sheet. This results in a pressure drop of 74.9 kPa in heating mode and of 70.1 kPa in cooling mode.

The details of the calculations are added in Appendix III in 11.3.9.3.

The design of the pumps is determined by the calculated pressure drop and the mass flow of 18 m³/h and has been realized using the program Wilo-Select 4 from the manufacturer WILO SE. The chosen pumps (Pump 14(H) and (C)) for both heating and cooling mode are the model “Stratos MAXO 100/0,5-12 PN16”. They dispose of a connection diameter of DN100 and a connection pressure of PN16. The corresponding data sheet is added to Appendix IV in 11.4.8.1.4.

8.3.2 Condensing gas boiler

The boiler selection is elaborated according to recommendations of (ASHRAE, 2016, p. 32.5). The chosen condensing gas boiler “Vitocrossal 300” (see Appendix IV in 11.4.5) as shown in Figure 37 has a full load capacity of 35 kW and is able to work until a part load of 7 kW. The supply respectively return water temperature is set to 45°C / 30°C. The standard efficiency is indicated until 98 % resulting in an energy efficiency class A. Part load efficiencies are not indicated in the corresponding data sheet. The total heat transfer surface is 1.8 m², the water content volume is 49 l and the electrical power input is of 56 W_{el}. Regarding space requirements, the boiler is installed on the floor and has a weight of 160 kg. Furthermore, the boiler size is 1707mmx660mmx684mm (height by width by depth). Minimum distances to the surrounding walls must be respected as indicated in the data sheet. The boiler offers a water supply and return connection of DN40, a security connection of DN 40, a drain of DN25, a connection to the expansion valve of DN20, a security valve connection of DN15, a gas connection from the grid of DN20 and finally a siphon for condensation water of DN20. The connection for supply air must be of a diameter of 125 mm and for exhaust gas of a diameter of 80 mm. The pressure drop is determined according to the data sheet considering a temperature difference between supply and return heating water of 15K and a mass flow rate of 2.58 m³/h (proportional value of peak load satisfied by boiler) resulting in a pressure drop of 13.4 mbar. Finally, the chosen condensing gas boiler works independently of room air conditions and suitable to install inside the thermal envelope.

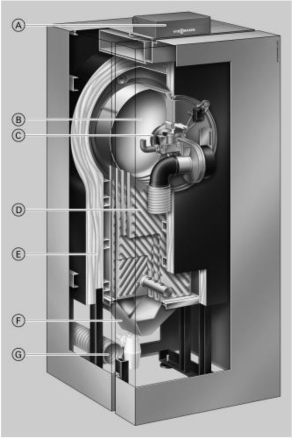


Figure 37: Illustration of chosen condensing gas boiler (Viessmann Climate Solutions SE, 2022)

8.3.3 Buffer tanks

Regarding the buffer tanks, an estimation of the tank volume considering the response time of temperature sensors is carried out, using the design criterion of a maximum deadband of thermostat control of 3 K and a minimum off-time of the compressor of 2 minutes. The calculations detailed in Appendix III in 11.3.9.2 result in a necessary buffer tank volume of 449 l for heating and of 327 l for cooling. The chosen tank models are “Vitocell 140-E Type SEIC” of 600 l for heating and “Vitocell 140-E Type SEIA” of 400 l for cooling as shown in Figure 38 (see Appendix IV in 11.4.6 for more information). These models are designed to be connected to different energy generation systems and provide a high

Figure 38: Illustration of chosen buffer tanks (Viessmann Climate Solutions SE, 2023b)

insulation. The maximum admissible heating water temperature is indicated with 110°C and the maximum operation pressure with 3 bar. Regarding space requirements, the buffer tank for heating shows the measurements 1064mmx1645mm (diameter by height) with a weight of 135 kg and the tank for cooling has the measurements of 859mmx1617mm with a weight of 154 kg.

8.3.4 Additional components

8.3.4.1 Secondary circuit pipes and pump

Concerning the secondary circuit, the pipe materials and sections and the pumps must be selected.

Regarding the material selection, the pipes between heat pump, buffer tanks, condensing gas boiler and manifolds towards the heating distribution system are planned of inox of DN50, with an estimated length of 15 m both return and supply pipes and a pipe roughness of 0.1mm.

A pressure drop estimation is carried out for choosing four adequate pumps using the pressure drop program published by Software-Factory Schmitz. The pumps must be installed between buffer tank and heat pump respectively condensing gas boiler and between buffer tanks and manifolds. For the pressure drop estimation, the following elements are taken into account: the inox pipes between buffer tanks and manifold as mentioned above, six bends of 90° both for supply and return pipes, and the pressure drop due to the chosen microbubble separator and dirt and sludge separator for pumps 10 and 11. Furthermore, the pressure drop inside the heat pump for pump 12 and inside the condensing gas boiler for pump 13 are used. The results are shown in Table 30 and the details of the calculations are added in Appendix III in 11.3.9.4.

The pressure drops and the mass flows are determining the design of the pumps, which has been realized using the program Wilo-Select 4 from the manufacturer WILO SE. The chosen pumps are listed in Table 30. They dispose of a connection diameter of DN50 respectively DN40 and a connection pressure of PN10. The corresponding data sheets are added to Appendix IV in 11.4.8.1.3.

Table 30: Pump selection for secondary circuit

Number	Mode	Loop name	Mass flow [m³/h]	Pressure drop [kPa]	Pump model	Power input [kW]	Diameter
Pump 10	Heating	Secondary pipes	5.11	30.3	Stratos MAXO 50/0,5-6 PN6/10	0.27	DN 50
Pump 12(H)	Heating	Heat pump	5.11	15.4	Stratos MAXO 50/0,5-6 PN6/10	0.27	DN 50
Pump 13	Heating	Condensing gas boiler	2.03	1.9	Stratos MAXO 40/0,5-4 PN6/10	0.13	DN 40
Pump 11	Cooling	Secondary pipes	4.90	30.6	Stratos MAXO 50/0,5-6 PN6/10	0.27	DN 50
Pump 12(C)	Cooling	Heat pump	4.90	16.3	Stratos MAXO 50/0,5-6 PN6/10	0.27	DN 50

8.3.4.2 Pressure maintenance station

The pressure maintenance station has the function to maintain the pressure of the whole installation and is designed with the help of the program Reflex Solutions Pro Version 24.02 from the manufacturer Reflex Winkelmann GmbH and according to VDI 4708 (VDI, 2012). The input data and the results are detailed in Appendix IV in 11.4.8.2. The pressure maintenance is realized by 4 static expansion tanks. First, the expansion tank for sealed heating and cooling water systems "Reflex N

400” of 400 l nominal volume and a maximum permissible operation temperature of 70°C and operation overpressure of 6 bar, connected to the secondary circuit by a pipe of DN25 and showing the measurements of 750 mm x 1102 mm (diameter by height) with a weight of 47 kg. Second, two small expansion tanks directly connected to the energy generation systems: the model “Reflex N8” of 8 l connected to the condensing gas boiler by a pipe of DN20 and the model “Reflex N12” of 12 l connected to the GSHP by a pipe of DN20. Finally, the primary circuit is connected to the expansion tank “Reflex N250” of 250 l nominal volume and a maximum permissible operation temperature of 120°C and operation overpressure of 6 bar, connected by a pipe of DN25 and showing the measurements of 634 mm x 888 mm (diameter by height) with a weight of 25 kg.

8.3.4.3 Refilling station

With the goal to be able to refill heating water with the required quality according to VDI 2035 (VDI, 2021), a refilling station is planned. It is composed of an automatic make-up and filling station “Fillcontrol Plus compact”, a pressure sensor, a water meter, and a cartridge and its housing.

8.3.4.4 Devices for water quality maintenance

To guarantee the water quality, an air and microbubble separator and dirt and sludge separator are introduced into the secondary circuit, both suitable for heating and cooling water systems. Additionally, ventilation fittings with a security valve are installed in the highest locations of the installation to enable air bubbles to exit the circuits.

8.3.4.5 Control devices

Finally, adequate temperature, pressure and flow meters must be installed to be able to monitor and control the installations. The meters must include the possibility to transfer the data to a central monitoring device but also for direct reading for maintenance reasons. Additionally, flow valves and nonreturn valves are added where required.

For switching between heating and cooling mode, the typical local heating and cooling period are taken as base, resulting in a predefined heating mode from October until April and a cooling mode from May until September. A fine-tuning may be interesting to develop, using the outdoor air temperature as leading variable and a defined time-interval, during which the set temperature must overshoot or undercut the outdoor air temperature. A possible set temperature for enabling the heating mode may be an outdoor air temperature of 16°C or less during more than 4 hours and for cooling mode an outdoor air temperature of 22°C or more during 4h. It is important to define heating and cooling set points sufficiently distant to avoid heating and cooling during the same day with the consequence of unnecessary energy consumption.

Regarding the cooling mode, the GSHP allows two operation options, the passive and the active cooling. During passive cooling, the cooled brine transmits the energy with the help of a heat exchanger to the distribution cooling water working only with the circulation pump but without compressor, while during active cooling, the heat pump boosts the cooling process with its compressor increasing therefore the electrical consumption.

8.4 Summary of selected energy generation system

A summary of the selected energy generation system is visualized in the hydraulic plan shown in Figure 39, also added in better resolution in plan 23 in Part III.

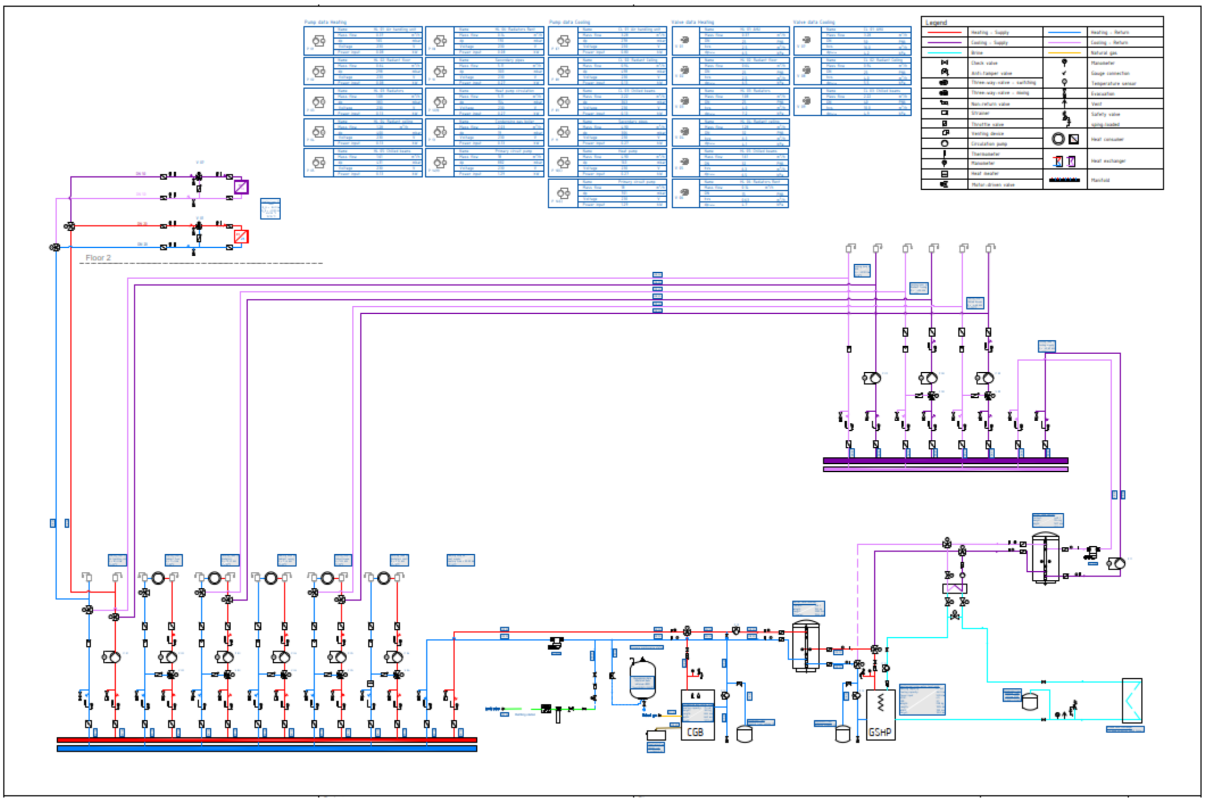


Figure 39: Hydraulic plan of designed energy system

It can be observed that the most important components of the energy generation system are the GSHP with a heating capacity of 47 kW and a cooling capacity of 34.2 kW with its primary brine circuit and the ground heat exchanger with a length of 9x100m, the condensing gas boiler with a heating capacity of 35 kW as an additional energy generator for peak heating loads, the buffer tanks of 500 l respectively 400 l and the secondary water circuit leading to the consumers.

9 CONCLUSIONS

The first conclusion considers that the present work complies with the main objective to design a heating and cooling system of an existing public building complex. The design includes the determination of the heating and cooling loads, the selection and design of the in-room terminal systems and the distribution network as well as the energy generation system.

Regarding the heating and cooling loads, the results have been determined with the help of C.A.T.S. software, taking into consideration the given characteristics of the planned building envelope. They provide a precise basis for the further development of the project. The use of drawing and calculation programs and the consideration of the corresponding standards reinforce the validity of the results of the heating and cooling loads calculated for each room separately. The design heating load with a total value of 39.8 kW and the design cooling load with a total value of -21.4 kW are in the range of expected values and are considered plausible.

In relation to the in-room terminal systems, different systems have been selected to match the expected comfort, to take in account particular requests of the client and to consider singular conditions of each room. This has resulted in a slight up-sizing of the planned air handling unit from 3500 m^3/h to 3950 m^3/h of volume air flow to cover the total latent and part of the sensitive heating and cooling load. The provided additional energy necessary for the AHU is 8.67 kW in heating mode and -22.9 kW in cooling mode. Furthermore, the common rooms with higher comfort expectations are planned to be equipped either with radiant floor heating, radiant ceilings for heating and cooling or chilled beams also both for heating and cooling. The radiant floor is planned in level -2 and -1 where low clear heights impede ceiling-mounted systems and where all sensitive cooling load is already covered by the AHU. The total heating capacity of the radiant floor is of 7.41 kW. The radiant ceilings are planned in level 0, 1 and 2 on demand of the client. This system allows sensitive heating and cooling with a total capacity of 7.45 kW respectively -3.26 kW. The chilled beams are only considered for a single room due to its special equipment and geometry with a heating capacity of 5.61 kW and a cooling capacity of -6.46 kW. For the secondary rooms with less comfort expectations, the opted system is a heating-only solution by means of radiators with a total capacity of 21.14 kW.

Considering the distribution network, a detailed solution of the planned piping and the corresponding control elements has been developed, calculated, and drawn as illustrated in appended plans.

Regarding the energy generation system, a standard solution is selected and designed based on building requirements and legal regulations. In this context, an environmental and techno-economic analysis of a base case and two alternatives has been carried out. For this purpose, the corresponding efficiencies of the different systems, investment and operating costs including the corresponding inflation rates and primary energy and emission factors have been considered. The analysis results in the selected solution, which convinces by its high energy-efficiency, its low GEG emissions during operation and its reduced operating costs making an amortization possible after 9 years in comparison to the base case. It consists in a hybrid system of a geothermal heat pump with a heating capacity of 47 kW and a cooling capacity of 34.2 kW and a condensing gas boiler with a heating capacity of 35 kW. The geothermal heat pump is connected to a ground heat exchanger of 9x100m, dimensioned and drawn in detail. Furthermore, secondary elements as buffer tanks and additional components are designed. Finally, the composition of all elements is illustrated in a hydraulic scheme.

As second conclusion, it should be emphasized that the planned heating and cooling system meets the objectives set at the beginning of the project. First, a technically feasible solution has been planned with a high level of detailed design. Second, this solution meets applicable standards, legal regulations and building requirements. In this context, the compliance of the planned solution with the Gebäudeenergiegesetz 2023 (GEG) must be highlighted, satisfying 95% of the annual heating energy by the geothermal heat pump, what outperforms the legally set regulation of 65% widely. Third, the solution has been chosen considering the economic impact, particularly concerning the choice of the energy generation system. With the help of a secondary analysis, the optimum economic ratio between heat pump capacity and boiler capacity has been found taking into account amortization time and savings after 25 years, resulting in the determination of the best-suited number of boreholes of the ground heat exchanger. Finally, the aim to choose a solution which reduces at its most GHG emissions is achieved by selecting the system with the lowest total equivalent warming impact, with a reduction of 38 % in comparison to the base case.

As last conclusion is to mention that some parts of the project may be used as guideline for the elaboration of similar projects aiming to renew an energy system of refurbished buildings. First, the overview about standards and legal regulations gathered in the state of the art may be applied to further projects. Second, the work includes an example for determining heating and cooling loads in a precise way complying with corresponding standards. Third, the project confirms the challenge of choosing the best-suited in-room terminal system for refurbishment of existing buildings due to their singular geometry and lower insulation grades even after refurbishment. The elaborated selection diagram in Chapter 6 may be a help for choosing the best-suited in-room terminal system for future refurbishment projects. Fourth, the methodology for analyzing different alternatives concerning the energy generation system may be used in future projects as an approach of a first estimation, although it must be mentioned that a more precise calculation of dynamic processes may be achieved when properly using programs modeling energy demand and generation like TRNSYS or Polysun. This last point should be considered as an improvement suggestion for future projects. Finally, the results of the analysis show valuable findings illustrating that hybrid geothermal heat pump systems may be preferable compared to hybrid air-source heat pump systems in terms of energy and environmental impact but even of an economic point of view for further projects of similar size. Furthermore, the second analysis points out the optimum ratio between heat pump capacity and boiler capacity for a most economic result, indicating the best performance when the geothermal heat pump generates 95% of the total annual heating energy.

After the realization of the present work, future research questions may be considered. On the one hand, the impact of the German law Gebäudeenergiegesetz (GEG) entered in force in January 2024 on the advance of the renovation wave may be a question of interest to evaluate political measures of enhancing the energy transition. On the other hand, a review of refurbishment projects which are based on energy generation by hybrid geothermal heat pumps and their optimum economic ratio of heat pump capacity and secondary generation system’s capacity may be another interesting future research question.

10 BIBLIOGRAPHY

ARI Armaturen Albert Richter GmbH & Co. KG. (2019, March). *Data sheet: ARI-Strainer 050 - Y-pattern with flanges with fine screen*. https://www.ari-armaturen.com/_appl/files_tb/files/050001-2.pdf

ASHRAE. (2016). *Handbook: HVAC Systems and Equipment Volume* (M. S. Owen, Ed.). Comshock, W. Stephen. www.ashrae.org.

Ausschuss für Arbeitsstätten. (2023). ASR A3.4: Beleuchtung und Sichtverbindung. *Gemeinsames Ministerialblatt*. www.baua.de

Baunetz_Wissen. (2024). *Pipe network calculation*. https://www.baunetzwissen.de/heizung/fachwissen/heizleitungen-zubehoer/rohrnetzberechnung-161276

Bolles, D. (2024, April 1). *Nasa - What is Climate Change?* https://science.nasa.gov/climate-change/what-is-climate-change/

Buderus GmbH. (2021, February). *Data sheet: EC Power XRGI 6 (CHP)*. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjGpbnj1-eFAxU42wIHHcl8A6QQFnoECBYQAQ&url=https%3A%2F%2Fproductsde.buderus.com%2Fbuderus%2Fproductsde.buderus.com%2Fbroschueren%2Fbuderus-broschuere-bhkw-rz-2021-de.pdf&usg=AOvVaw0tl9ECE91z-utiRwpgi9lm&opi=89978449

Buderus GmbH. (2023). *BHKW Kosten 2023*. https://www.buderus.de/de/bhkw/kosten#:~:text=Pro%20Kilowattstunde%20k%C3%B6nnen%20Sie%20mit,rund%20200%20Euro%20j%C3%A4hrlich%20kosten.

Bundesregierung. (2023). Gebäudeenergiegesetz (GEG). *Bundesgesetzblatt*. https://www.gesetze-im-internet.de/geg/GEG.pdf

Cazorla, A. (2022). *Diseño y dimensionado de instalaciones solares de ACS. Componentes de una instalación solar - Parte A*. https://commons.wikimedia.org/w/index.php?curid=25414023

Daikin N.V. (2024). *Program: Psychrometric diagram viewer 3.2.0* . https://www.daikin.eu/en_us/customers/software-downloads/daikin-psychometrics-diagram-viewer.html

Deutscher Wetterdienst. (2023, July 18). *Meteorological data*. https://opendata.dwd.de/climate_environment/CDC/observations_germany/climate/hourly/

DIN. (1999). DIN 4703-1: Heating appliances - Part 1: Dimensions of sectional radiators. *Beuth Verlag*.

DIN. (2000). DIN 4703-3: Heating appliances - Part 3: Conversion of the standard thermal output. *Beuth Verlag*.

DIN. (2019). DIN 1946-6: Ventilation and air conditioning - Part 6: Ventilation for residential buildings - General requirements, requirements for design, construction, commissioning and handover as well as maintenance. *Beuth Verlag*.

DIN. (2020). DIN/TS 12381-1: German National Annex. *Beuth Verlag*.

DIN. (2021). DIN EN 1264-4. *Beuth Verlag*.

Energieagentur NRW. (2021). *BHKW-Rechner*. https://www.energie-experten.org/heizung/blockheizkraftwerk-bhkw/blockheizkraftwerk-kosten

European Commission. (2023). *Renovation Wave*. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

European Committee for standardization. (2017). *EN 12831-1: Energy performance of buildings - Method for calculation of the design heat load - Part 1: Space heating load, Module M3-3*.

European Environment Agency. (2023a, April 18). *Distribution of greenhouse gas emissions in the European Union (EU-27) in 2021, by sector*. https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

European Environment Agency. (2023b, June 14). *Final energy uses across EU households, with space and water heating disaggregated by fuel (2020)*. https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

European Environment Agency. (2023c, October 24). *Greenhouse gas emissions from energy use in buildings in Europe*. https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-energy?activeAccordion=

European Parliament, & European Council. (2021). Regulation (EU) 2021/1119. *Official Journal of the European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R1119

GoogleMaps. (2024). *Ubication of construction project*. https://www.google.de/maps/place/Hohen+Neuendorf/@52.6722728,13.2828918,16z/data=!4m15!1m8!3m7!1s0x47a9aaf62db0713b:0x42120465b5e4260!2sHohen+Neuendorf!3b1!8m2!3d52.6720645!4d13.2786739!16zL20vMGRsbmNn!3m5!1s0x47a9aae123f643e1:0x41d268cc70952b8c!8m2!3d52.6696911!4d13.2869895!16s%2Fm%2F02pjws9?entry=ttu

HakaGerodur AG. (2021, April 30). *Data sheet: GEROtherm connecting tube for elevated temperatures PN16*. https://www.gerodur.de/en/dnlarchiv/Technisches-Datenblatt-Verbindungsleitungen-RT-PN16_20210430_EN.368.3235.pdf

HakaGerodur AG. (2023a). *Data sheet: GEROtherm Small manhole*. https://www.hakagerodur.ch/de/kleinverteilerschacht-gerotherm-typ-l/

HakaGerodur AG. (2023b, March 1). *Data sheet: GEROtherm DUPLEX Erdwärmesonde PN16*. https://www.hakagerodur.ch/de/gerotherm-duplex/

HakaGerodur AG. (2023c, August 9). *Data sheet: GEROtherm Y piece from the material PE100-RC*. https://www.gerodur.de/en/gerotherm-pieces-and-accessoires/

Harnischmacher, V. (2006). Serielle Durchströmung von Heizkörpern erzeugt mehr thermische Behaglichkeit. *Fachzeitschrift Für Erneuerbare Energien & Technische Gebäudeausrüstung*, 140. https://www.ihks-fachjournal.de/serielle-durchstroemung-von-heizkoerpern-erzeugt-mehr-thermische-behaglichkeit/

International Ground Source Heat Pump Association. (1988). *Closed-Loop/Ground-Source Heat Pump Systems, Installation Guide*.

Jivee Blau. (2012). *Picture: Front view of existent station of Hohen Neuendorf*. https://commons.wikimedia.org/w/index.php?curid=25414023

Kiefer Klimatechnik GmbH. (2024). *Catalog: Chilled beams*. https://www.kieferklima.de/fileadmin/05_Service/Download_Dokumente/Dokumente_English/1-Catalog-Brochures_TI-Flyer/3-INDUCOOL-Chilled%20ceiling%20panel/kieferklima_Technical_Information_INDUCOOL.pdf

Kottek. (2006). *Climate Classification with World Map*. https://koeppen-geiger.vu-wien.ac.at/

Lindner GmbH. (2024). *Catalog: Heated and chilled ceilings*. https://www.lindner-group.com/en/products/ceilings/heated-and-chilled-ceilings/heated-and-chilled-canopy-ceilings/plafotherm-r-ds-320#Brochures

MAGRA Maile + Grammer GmbH. (2024). *Program: MAGplan 6.0.1.28* . https://www.magra-verteiler.de/service/magplan/inhalt.htm

Reflex Winkelmann GmbH. (2024). *Program: Reflex Solutions Pro Version 24.02*. https://rsp.reflex-winkelmann.com/?lang=en#dashboard

Resideo Technologies, Inc. (2021). *Data sheet: Kombi-3-plus V5000 and V5010*. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://homecomfort-techlit.resideo.com/emeadocuments/pim%2520renamed%25202/v5000-v5010-pd-ge0h2300ge25.pdf&ved=2ahUKEwif0qm-5JyGAxWkRfEDHSvFLU0QFnoECBIQAQ&usg=AOvVaw33AD0ggYbqnZc_aVR8xCbE

Senatsverwaltung Berlin. (2024). *Ground water temperatures - North-east Germany*. https://www.berlin.de/sen/uvk/umwelt/wasser-und-geologie/geologie/geothermie/

Spitler, J. D. (2014). *Load calculation applications manual* (Second Edition). American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Stadt Hohen Neuendorf. (2024). *Numbers&Facts - City Hohen Neuendorf*. https://hohen-neuendorf.de/de/stadt-leben/stadt-fakten

Statistisches Bundesamt. (2022). *Verbraucherpreisindex und Inflationsrate*. https://www.destatis.de/DE/Themen/Wirtschaft/Preise/Verbraucherpreisindex/_inhalt.html#_j74s4l38n

Statistisches Bundesamt. (2023). *Daten zur Energiepreisentwicklung*. https://www.destatis.de/DE/Themen/Wirtschaft/Preise/Publikationen/Energiepreise/energiepreisentwicklung-xlsx-5619001.html

TGA Fachplaner. (2024). *Condensing gas boilers and GEG*. https://www.tga-fachplaner.de/gebaeudeenergiegesetz/65-ee-pflicht-wird-das-h2-ready-privileg-die-gas-heizung-abraeumen#:~:text=Mit%20100%2D%25%2DH2%2Dready,H2%2Dready%E2%80%9C%20zu%20erf%C3%BCllen.

Thermondo. (2024). *Heizsysteme: Vergleich & Kosten 2024 im Überblick*. https://www.thermondo.de/info/rat/vergleich/kosten-verschiedener-heizsysteme/

TYFOROP Chemie GmbH. (2024). *Data sheet: Tyfocor GE (Brine)*. https://tyfo.de/downloads/TYFOCOR-GE_en_TI.pdf

UNE. (2017). EN ISO 52016-1. *AENOR*.

UNE. (2020). EN 16798-1. *AENOR*. www.une.org

UNE. (2021). EN ISO 11855-3: Building environment design. Embedded radiant heating and cooling systems. Part 3: Design and dimensioning. *AENOR*. www.une.org

Uponor GmbH. (2024). *Technical Information: Classic underfloor heating and cooling systems*. https://www.uponor.com/en-en/download-centre?query=Technical%20Information%20Classic%20underfloor%20heating%2F%20cooling%20system%20(1141748)

VDI. (2002). VDI 6030 - Part 1: Designing free heating surfaces. Fundamentals - Designing of heating appliances. *VDI Verlag*.

VDI. (2012). VDI 4708 Blatt 1: Pressure maintenance venting, dearation - Pressure maintenance. *VDI Verlag*.

VDI. (2015). VDI 2078: Calculation of thermal loads and room temperatures - Design cooling load and annual simulation. *VDI Verlag*, *1*. www.vdi.de/richtlinien

VDI. (2019). VDI 4640 - Part 2: Thermal use of the underground - Ground source heat pump systems. *VDI Verlag*.

VDI. (2021). VDI 2035 - Part 1: Prevention of damage in water heating installations - Scale formation and waterside corrosion. *VDI Verlag*.

Viessmann Climate Solutions SE. (2022). *Data sheet: VITOCROSSAL 300*. https://www.viessmann.de/de/produkte/gasheizung/vitocrossal-300-cu3a.html#downloads

Viessmann Climate Solutions SE. (2023a). *Data sheet: VITOCAL 300-G/350-G*. https://www.viessmann.de/de/produkte/waermepumpe/vitocal-300-g-42-kw.html#waypoint_downloads

Viessmann Climate Solutions SE. (2023b). *Data sheet: VITOCELL 160-E*. https://www.viessmann.de/de/produkte/warmwasserbereiter/vitocell-140-e.html#waypoint_downloads

Viessmann Climate Solutions SE. (2023c). *Wärmepumpenstrom: Lohnen sich die Sondertarife?* https://www.viessmann.de/de/wissen/infos-und-tipps-zum-kauf/waermepumpenstrom.html#:~:text=Strom%20f%C3%BCr%20W%C3%A4rmepumpen%20ist%20im,bis%2035%20Cent%20pro%20Kilowattstunde.

WILO SE. (2024). *Program: Wilo-Select 4*. https://select4.wilo-select.com/Region.aspx

11 APPENDICES

11.1 Appendix I: CONCERNING CHAPTER 5 – Design heating and cooling load

11.1.1 Interior design temperatures of each room of the building

Level	Number	Name	Temperature heating mode [°C]	Minimum temperature unheated [°C]
2	2.0010	Lift	unheated	15
2	2.0000	Stairs 1	18	-
2	2.0100	ELT-UV	unheated	15
2	2.0200	Technik Lüftung	15	-
2	2.0300	Consulting room	20	-
1	1.0010	Lift	unheated	15
1	1.0000	Stairs 1	18	-
1	1.0100	ELT-UV	unheated	15
1	1.0200	Consulting room	20	-
1	1.0300	Exercise room	20	-
1	1.0400	Exposition	20	-
1	1.0500	Event room	20	-
1	1.0600	Stairs 2	unheated	18
1	1.0700	Tea kitchen	20	-
1	1.0800	Toilettes, handicap	24	-
1	1.0910	Toilettes entrance	20	-
1	1.0920	Mens toilettes	20	-
1	1.0930	Womens toilettes	20	-
1	1.1000	Hall	20	-
1	1.1100	Consulting room	20	-
0	0.0010	Lift	unheated	15
0	0.0000	Stairs 1	18	-
0	0.0100	ELT-UV	unheated	15
0	0.02a0	Library	20	-
0	0.02b0	Porch	15	-
0	0.0400	Bistro	20	-
0	0.0500	Vestibule	20	-
0	0.0600	Secondary room	20	-
0	0.0700	Toilettes	unheated	20
0	0.0800	Stairs 2	18	-

Level	Number	Name	Temperature heating mode [°C]	Minimum temperature unheated [°C]
-1	-1.0010	Lift	unheated	13
-1	-1.0000	Stairs 1	18	-
-1	-1.0100	ELT-UV	unheated	15
-1	-1.0200	Multimedia room	20	-
-1	-1.0300	Staff room library	20	-
-1	-1.04a0	Library	20	-
-1	-1.04b0	Secondary room library	20	-
-1	-1.0500	Cleaning room	20	-
-1	-1.0610	Mens toilettes entrance	20	-
-1	-1.0620	Mens toilettes	20	-
-1	-1.0710	Womens toilettes entrance	20	-
-1	-1.0720	Womens toilettes	20	-
-1	-1.0800	Stairs 2	unheated	18
-1	-1.0900	Toilettes. handicap	24	-
-1	-1.1000	Tea kitchen	20	-
-1	-1.1100	Sanitary installations	unheated	11
-1	-1.1200	Hall	20	-
-1	-1.1300	Heating installations	unheated	12
-2	-2.0010	Lift	unheated	15
-2	-2.0000	Stairs 1	18	-
-2	-2.0100	ELT-UV	unheated	15
-2	-2.0200	Music room 1	20	-
-2	-2.0300	Music room 2	20	-
-2	-2.0400	Small group room	20	-
-2	-2.0500	Big group room	20	-
-2	-2.0600	Stairs 2	18	-
-2	-2.0700	Hall	20	-
-2	-2.0810	ELT installations	unheated	11
-2	-2.0820	HAR installations	unheated	10
-2	-2.0830	Heating installations	unheated	12

11.1.2 Parametrization of rooms introducing floor. ceiling and roof types and corresponding outside conditions

Level	Building	Num-ber	Name	Floor type	Outside condition	Ceiling type	Outside condition	Roof type	Outside condition	Comment
2	New	2.0010	Lift	DE0	Unheated 15°C			DA0	1)	
2	New	2.0000	Stairs 1	DE0	Heated 18°C			DA0	1)	
2	New	2.0100	ELT-UV	DE0	Unheated 15°C			DA0	1)	
2	Old	2.0200	Technik Lüftung	DE1	Heated 20°C			DA2	1)	
2	New	2.0300	Consulting room	DE0b	Heated 20°C			DA0	1)	
1) Exterior temperature										
1	New	1.0010	Lift	DE0	Unheated 15°C	DE0	Unheated 15°C	-		2)
1	New	1.0000	Stairs 1	DE0	Heated 18°C	DE0	Heated 18°C	-		2)
1	New	1.0100	ELT-UV	DE0	Unheated 15°C	DE0	Unheated 15°C	-		2)
1	Old	1.0200	Consulting room 2 (old)	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0300	Exercise room	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0400	Exposition	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0500	Event room	DE1	Heated 20°C	not existend		DA2	1)	3)
1	Old	1.0600	Stairs 2	DE1	Heated 18°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0700	Tea kitchen	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0800	Toilettes. handicap	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0910	Toilettes entrance	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0920	Mens toilettes	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.0930	Womens toilettes	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	Old	1.1000	Hall	DE1	Heated 20°C	DE1	Heated 15°C	DA2	1)	3)
1	New	1.1100	Consulting room 1 (new)	DE0b	Heated 15°C	DE0b	Heated 20°C	-		2)
1) Exterior temperature										
2) not existend (new building)										
3) Inclined roof cut at ceiling height of 3.04m										
0	New	0.0010	Lift	DE0a	Unheated 15°C	DE0	Unheated 15°C			
0	New	0.0000	Stairs 1	DE0a	Heated 18°C	DE0	Heated 18°C			
0	New	0.0100	ELT-UV	DE0a	Unheated 15°C	DE0	Unheated 15°C			
0	Old	0.02a0	Library	DE2	Heated 20°C	DE1	Heated 20°C			
0	Old	0.02b0	Porch	DE2	Heated 20°C	DE1	Heated 20°C			
0	Old	0.0400	Bistro	DE2	Heated 20°C	DE1	Heated 20°C			
0	Old	0.0500	Vestibule	DE2	Heated 20°C	DE1	Heated 20°C			
0	Old	0.0600	Secondary room	DE2	Heated 20°C	DE1	Heated 20°C			
0	Old	0.0700	Toilettes	DE2	Heated 20°C	DE1	Heated 20°C			
0	Old	0.0800	Stairs 2	DE2	Heated 18°C	DE1	Unheated 18°C			

Level	Buil-ding	Num-ber	Name	Floor type	Outside condition	Ceiling type	Outside condition	Roof type	Outside condition	Com-ment
-1	New	-1.0010	Lift	DE0	Unheated 15°C	DE0a	Unheated 15°C			
-1	New	-1.0000	Stairs 1	DE0	Heated 18°C	DE0a	Heated 18°C			
-1	New	-1.0100	ELT-UV	DE0	Unheated 15°C	DE0a	Unheated 15°C			
-1	Old	-1.0200	Multimedia room	DE2a	Heated 20°C	DE2	Heated 20°C			
-1	Old	-1.0300	Staff room library	DE2a	Heated 20°C	DE2	Heated 20°C			
-1	Old	-1.0410	Library	DE2a	Heated 20°C	DE2	Heated 20°C			
-1	Old	-1.0420	Secondary room library	DE2a	Heated 20°C	DE2	Heated 20°C			
-1	Old	-1.0500	Cleaning room	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.0610	Mens toilettes entrance	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.0620	Mens toilettes	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.0710	Womens toilettes entrance	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.0720	Womens toilettes	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.0800	Stairs 2	DE2a	Heated 18°C	DE2	Heated 18°C			
-1	Old	-1.0900	Toilettes. handicap	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.1000	Tea kitchen	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.1100	Sanitary installations	DE2a	Unheated. 8°C	DE2	Heated 20°C			
-1	Old	-1.1200	Hall	DE2a	Heated 20°C	DE2	Heated 20°C			
-1	New	-1.1300	Heating installations	DE0	Unheated 10°C	DE0a	Heated 18°C			
-2	New	-2.0010	Lift	FB0	Unheated. 8°C	DE0	Unheated 15°C			
-2	New	-2.0000	Stairs 1	FB0	Unheated. 8°C	DE0	Heated 18°C			
-2	New	-2.0100	ELT-UV	FB0	Unheated. 8°C	DE0	Unheated 15°C			
-2	Old	-2.0200	Music room 1	FB1	Unheated. 8°C	DE2a	Heated 20°C			
-2	Old	-2.0300	Music room 2	FB1	Unheated. 8°C	DE2a	Heated 20°C			
-2	Old	-2.0400	Small group room	FB1	Unheated. 8°C	DE2a	Heated 20°C			
-2	Old	-2.0500	Big group room	FB1	Unheated. 8°C	DE2a	Heated 20°C			
-2	Old	-2.0600	Stairs 2	FB1	Unheated. 8°C	DE2a	Heated 18°C			
-2	Old	-2.0700	Hall	FB1	Unheated. 8°C	DE2a	Unheated 10°C			
-2	New	-2.0810	ELT installations	FB0	Unheated room. 8°C	DE0	Unheated 10°C			
-2	New	-2.0820	HAR installations	FB0	Unheated. 8°C	DE0	Unheated 10°C			
-2	New	-2.0830	Heating installations	FB0	Unheated. 8°C	DE0	Unheated 10°C			

11.1.3 Ventilation input data: type of ventilation. minimum air changes and exhaust. transfer and supply air flow of each room of the building complex

Level	Building	Number	Name	Type of ventilation	Minimum air changes [1/h]	Exhaust air flow [m^3/h]	Transfer air flow [m^3/h] with T=20°C	Supply air flow [m^3/h] with T=20°C
2	New	2.0010	Lift	Natural	0.0			
2	New	2.0000	Stairs 1	Natural	0.0			
2	New	2.0100	ELT-UV	Natural	0.0			
2	Old	2.0200	Technik Lüftung	Natural	0.0			
2	New	2.0300	Consulting room	Natural	0.5			
1	New	1.0010	Lift	Natural	0.0			
1	New	1.0000	Stairs 1	Natural	0.0			
1	New	1.0100	ELT-UV	Natural	0.0			
1	Old	1.0200	Consulting room 2 (old)	Mechanical	0.5	100		100
1	Old	1.0300	Exercise room	Mechanical	0.5	150		150
1	Old	1.0400	Exposition	Mechanical	0.5	150		150
1	Old	1.0500	Event room	Mechanical	0.5	875		875
1	Old	1.05b	Event room_roof part	Mechanical	0.5	0		0
1	Old	1.0600	Stairs 2	Natural	0.0			
1	Old	1.0700	Tea kitchen	Natural	0.5			
1	Old	1.0800	Toilettes. handicap	Mechanical	0.5	75	75	-
1	Old	1.0910	Toilettes entrance	Mechanical	0.0	0		-
1	Old	1.0920	Mens toilettes	Mechanical	0.5	42.5	42.5	-
1	Old	1.0930	Womens toilettes	Mechanical	0.5	42.5	42.5	-
1	Old	1.1000	Hall	Natural	0.0			
1	New	1.1100	Consulting room 1 (new)	Natural	0.5			
0	New	0.0010	Lift	Natural	0.0			
0	New	0.0000	Stairs 1	Natural	0.0			
0	New	0.0100	ELT-UV	Natural	0.0			
0	Old	0.02a0	Library	Mechanical	0.5	750		750
0	Old	0.02b0	Porch	Natural	0.0			
0	Old	0.0400	Bistro	Mechanical	0.5	30	30	-
0	Old	0.0500	Vestibule	Natural	0.5			
0	Old	0.0600	Secondary room	Natural	0.5			
0	Old	0.0700	Toilettes	Natural	0.5			
0	Old	0.0800	Stairs 2	Natural	0.0			

Level	Building	Number	Name	Type of ventilation	Minimum air changes [1/h]	Exhaust air flow [m³/h]	Transfer air flow [m³/h] with T=20°C	Supply air flow [m³/h] with T=20°C
-1	New	-1.0010	Lift	Natural	0.0			
-1	New	-1.0000	Stairs 1	Natural	0.0			
-1	New	-1.0100	ELT-UV	Natural	0.0			
-1	Old	-1.0200	Multimedia room	Mechanical	0.5	50		50
-1	Old	-1.0300	Staff room library	Mechanical	0.5	50		50
-1	Old	-1.0410	Library	Mechanical	0.5	400		400
-1	Old	-1.0420	Secondary room library	Mechanical	0.5	0		0
-1	Old	-1.0500	Cleaning room	Mechanical	0.0	60	60	0
-1	Old	-1.0610	Mens toilettes entrance	Mechanical	0.0	0		0
-1	Old	-1.0620	Mens toilettes	Mechanical	0.5	160	160	0
-1	Old	-1.0710	Womens toilettes entrance	Mechanical	0.0	0		0
-1	Old	-1.0720	Womens toilettes	Mechanical	0.5	165	165	0
-1	Old	-1.0800	Stairs 2	Natural	0.0			
-1	Old	-1.0900	Toilettes. handicap	Mechanical	0.5	95	95	0
-1	Old	-1.1000	Tea kitchen	Mechanical	0.5	135	135	0
-1	Old	-1.1100	Sanitary installations	Natural	0.0			
-1	Old	-1.1200	Hall	Natural	0.0			
-1	New	-1.1300	Heating installations	Mechanical	0.0	60	60	0
-2	New	-2.0010	Lift	Natural	0.0			
-2	New	-2.0000	Stairs 1	Natural	0.0			
-2	New	-2.0100	ELT-UV	Natural	0.0			
-2	Old	-2.0200	Music room 1	Mechanical	0.5	150		150
-2	Old	-2.0300	Music room 2	Mechanical	0.5	200		200
-2	Old	-2.0400	Small group room	Mechanical	0.5	175		175
-2	Old	-2.0500	Big group room	Mechanical	0.5	450		450
-2	Old	-2.0600	Stairs 2	Natural	0.0			
-2	Old	-2.0700	Hall	Natural	0.0			
-2	New	-2.0810	ELT installations	Mechanical	0.0	30	30	-
-2	New	-2.0820	HAR installations	Mechanical	0.0	20	20	-
-2	New	-2.0830	Heating installations	Mechanical	0.0	15	15	-

11.1.4 External and internal heat gains for calculation of design cooling load

11.1.4.1 External heat gains

			External gains			
				Shades of surrounding		
Building	Number	Name	Sun shadings	Distance between shadowing object and facade [m]	Height above ground level of corresponding floor level [m]	Orientation
Old	-2.050	Big group room	Exterior pale venetian blinds with 45° angle	5	10	East
Old	-2.040	Small group room	Exterior pale venetian blinds with 45° angle	5	10	East
Old	-2.030	Music room 2	Exterior pale venetian blinds with 45° angle	5	3	East
Old	-2.020	Music room 1	Exterior pale venetian blinds with 45° angle	5	3	East
Old	-1.042	Secondary room library	Exterior pale venetian blinds with 45° angle	5	7	East
Old	-1.041	Library	Exterior pale venetian blinds with 45° angle	5	7	East
Old	-1.030	Staff room library	Exterior pale venetian blinds with 45° angle			
Old	-1.020	Multimedia room	Exterior pale venetian blinds with 45° angle			
Old	1.020	Consulting room 2 (old)	No sun shadings (roof windows)			
Old	1.030	Exercise room	No sun shading (dormers window)			
Old	1.040	Exposition	No sun shading (dormers window)			
Old	1.050	Event room	No sun shading (dormers window)			
New	1.110	Consulting room 1 (new)	Exterior pale venetian blinds with 45° angle			
New	2.030	Consulting room	Exterior pale venetian blinds with 45° angle			
Old	0.02a0	Library	Exterior pale venetian blinds with 45° angle	5	4	East
Old	1.05b	Event room_roof part	No sun shadings (roof windows)			

11.1.4.2 Internal heat gains

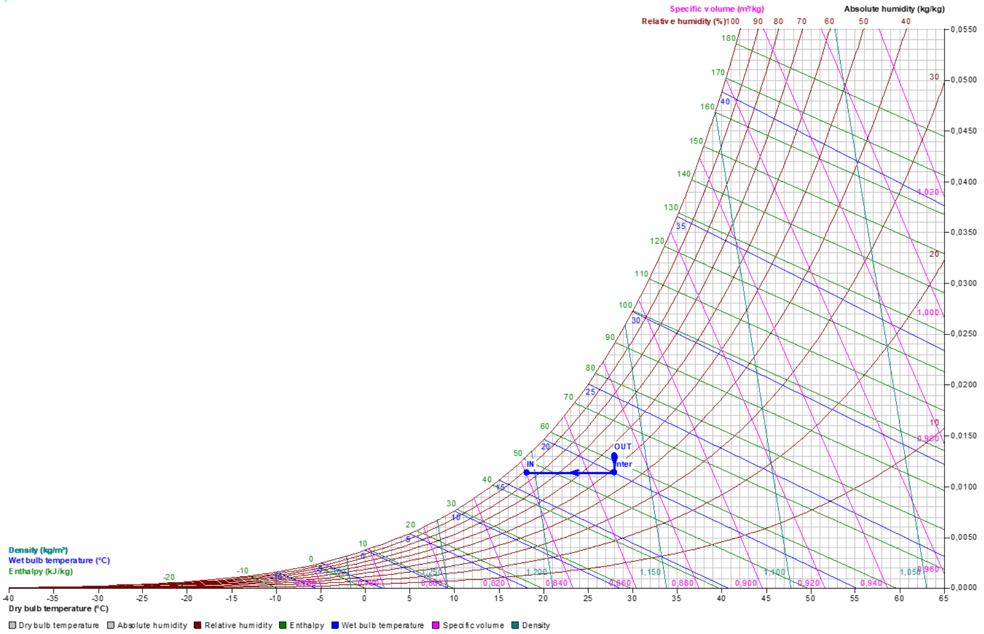
			Internal gains													
			Users				Illumination					Machines				
Building	Number	Name	Start time	End time	No.	Activity	Illumination [lux]	Start time	End time	No	Power [W/m²]	Type	Start time	End time	No.	Power [W]
Old	-2.050	Big group room	8	18	18	2	300	8	18	1	8					
Old	-2.040	Small group room	8	18	7	1	300	8	18	1	8					
Old	-2.030	Music room 2	8	18	8	1	300	8	18	1	8					
Old	-2.020	Music room 1	8	18	6	1	300	8	18	1	8					
Old	-1.042	Secondary room library	8	18	5	1	300	8	18	1	8	PCMulti-media	8	18	1	100
Old	-1.041	Library	8	18	11	1	500	8	18	1	8	PCMulti-media	8	18	5	100
Old	-1.030	Staff room library	8	18	2	1	300	8	18	1	8	PCMulti-media	8	18	2	100
Old	-1.020	Multimedia room	8	18	2	1	300	8	18	1	8	PCMulti-media	8	18	2	100
Old	1.020	Consulting room 2 (old)	8	18	2	1	300	8	18	1	8	PCMulti-media	8	18	2	100
Old	1.030	Exercise room	8	18	6	2	300	8	18	1	8					
Old	1.040	Exposition	8	18	6	2	300	8	18	1	8					
Old	1.050	Event room	18	21	35	1	300	8	21	1	8					
New	1.110	Consulting room 1 (new)	8	18	2	1	300	8	18	1	8	PCMulti-media	8	18	2	100
New	2.030	Consulting room	8	18	2	1	300	8	18	1	8	PCMulti-media	8	18	2	100
Old	0.02a0	Library	8	18	30	1	500	8	18	1	8	PCMulti-media	8	18	9	100
Old	1.05b	Event room_roof part	8	18		-	300	8	18	-						

11.2 Appendix II: Concerning CHAPTER 6 - Selection and design of in-room terminal systems

11.2.1 Results of psychometric calculations

- Program from (Daikin N.V., 2024)

11.2.1.1 Results considering a supply volume air flow of $\dot{V} = 3500\ m^3/h$



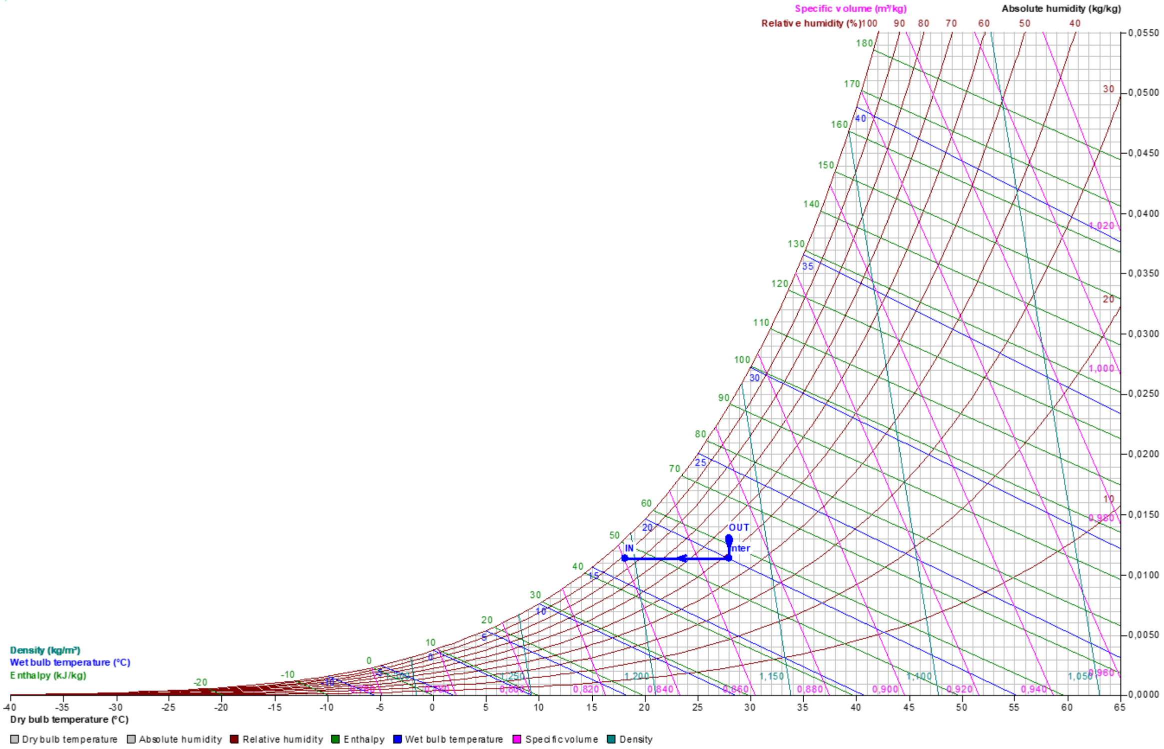
1. Psychrometric points

IN		OUT		Inter	
Dry bulb temperature	18.1°C	Dry bulb temperature	28.0°C	Dry bulb temperature	28.0°C
Wet bulb temperature	16.8°C	Wet bulb temperature	21.2°C	Wet bulb temperature	20.0°C
Dew point	16.1°C	Dew point	18.1°C	Dew point	16.1°C
Relative humidity	87.6%	Relative humidity	55.0%	Relative humidity	48.2%
Absolute humidity	0.0114kg/kg	Absolute humidity	0.0130kg/kg	Absolute humidity	0.0114kg/kg
Enthalpy	47.1kJ/kg	Enthalpy	61.4kJ/kg	Enthalpy	57.3kJ/kg
Density	1.204kg/m³	Density	1.163kg/m³	Density	1.164kg/m³
Specific volume	0.840m³/kg	Specific volume	0.871m³/kg	Specific volume	0.869m³/kg
Pressure	101325.0Pa	Pressure	101325.0Pa	Pressure	101325.0Pa
Airflow	3500m³/h	Airflow	3500m³/h	Airflow	3500m³/h

2. Actions

Cooling: IN. OUT. Inter (Capacities: Total = 16.63kW. Sensible = 11.86kW (71%). Latent = 4.76kW)

11.2.1.2 Results considering a supply volume air flow of $\dot{V} = 3950\ m^3/h$



1. Psychrometric points

IN		OUT		Inter	
Dry bulb temperature	18.1°C	Dry bulb temperature	28.0°C	Dry bulb temperature	28.0°C
Wet bulb temperature	16.8°C	Wet bulb temperature	21.2°C	Wet bulb temperature	20.0°C
Dew point	16.1°C	Dew point	18.1°C	Dew point	16.1°C
Relative humidity	87.6%	Relative humidity	55.0%	Relative humidity	48.2%
Absolute humidity	0.0114kg/kg	Absolute humidity	0.0130kg/kg	Absolute humidity	0.0114kg/kg
Enthalpy	47.1kJ/kg	Enthalpy	61.4kJ/kg	Enthalpy	57.3kJ/kg
Density	1.204kg/m³	Density	1.163kg/m³	Density	1.164kg/m³
Specific volume	0.840m³/kg	Specific volume	0.871m³/kg	Specific volume	0.869m³/kg
Pressure	101325.0Pa	Pressure	101325.0Pa	Pressure	101325.0Pa
Airflow	3950m³/h	Airflow	3950m³/h	Airflow	3950m³/h

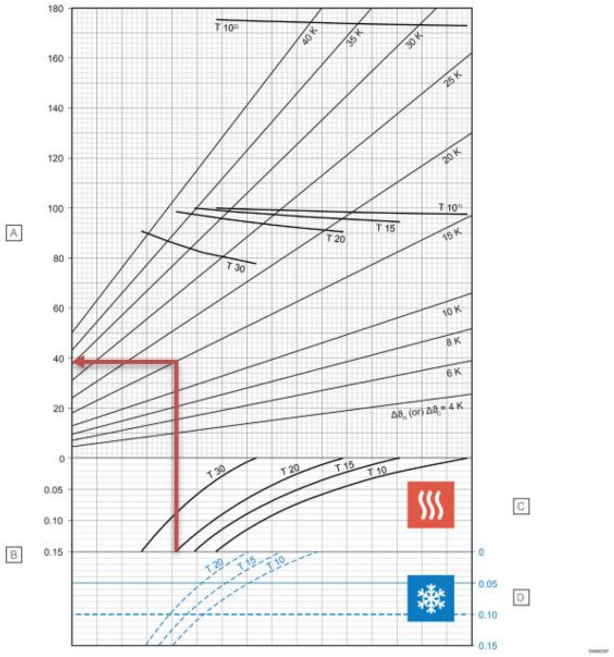
2. Actions

Cooling: IN. OUT. Inter (Capacities: Total = 18.76kW. Sensible = 13.39kW (71%). Latent = 5.38kW)

11.2.2 Determination of the specific heating capacity of the radiant floor

- Input parameters:
    - Radiant floor system type: “Uponor Classic-Comfort Pipe PLUS 17x2,0mm with concrete screed of 45 mm”
    - Pipe spacing T = 20cm
    - Thermal resistance of floor covering $R_{\lambda,B} = 0.15$ m²K/W
- Output parameter:
    - Specific heating capacity $q_H = 38$ W/m²
- Determination diagram provided by manufacturer: (Uponor GmbH, 2024, p. 14)

Uponor Comfort Pipe PLUS 17 x 2,0 mm with screed load distribution layer (su = 45 mm with λu = 1,2 W/mK)



Item	Unit	Description
A	W/m²	Specific thermal heating or cooling output [q_H or q_C]
B	m²K/W	Thermal resistance [$R_{\lambda,B}$]

C - Heating

T (cm)	q_H (W/m²)	$\Delta\vartheta_{H,N}$ (K)
10	97,7	15,1
15	94,6	16,9
20	90,4	18,6
30	76,7	20,9

D - Cooling

T (cm)	q_C (W/m²)	$\Delta\vartheta_{C,N}$ (K)
10	36,0	8
15	32,1	8
20	28,7	8

[1] Limit curve valid for ϑ_i 20 °C and $\vartheta_{F,\,max}$ 29 °C or ϑ_i 24 °C and $\vartheta_{F,\,max}$ 33 °C

[2] Limit curve valid for ϑ_i 20 °C and $\vartheta_{F,\,max}$ 35 °C

11.2.3 Determination of the pressure drop per heating loop of the radiant floor

11.2.3.1 Determination of mass flow rate

- Input parameters:
  - Total heating capacity Q_H [W]
  - Water supply and return temperatures ϑ_S and ϑ_R [°C]
  - Specific heating capacity of water c_P[J/kgK]
  - Number of heating loops n [-]
- Output parameter:
  - Mass flow per heating loop $\dot{m}$ [kg/h]
- Determination by equation:
  - $\dot{m} = Q_H * 3600/((\vartheta_S - \vartheta_R) * c_p * n)$

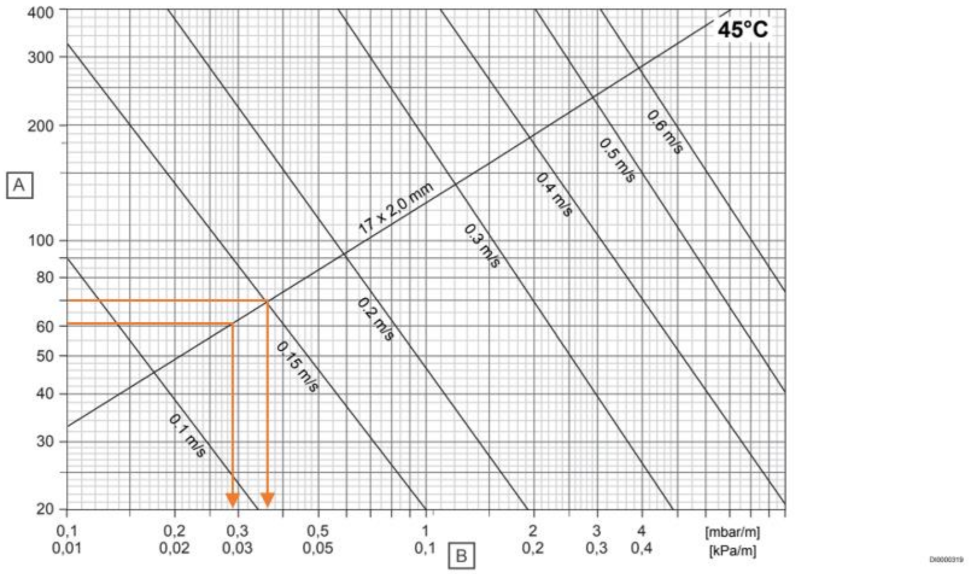
11.2.3.2 Determination of pressure gradient

- Input parameters:
  - Radiant floor system type: “Classic-Comfort Pipe PLUS 17x2,0mm with concrete screed of 45 mm” by Uponor GmbH
  - Mass flow rate $\dot{m}$[kg/h]:
    - Maximum in level -1: $\dot{m}$ = 62 kg/h
    - Maximum in level -2: $\dot{m}$ = 70 kg/h

- Output parameter:
  - Pressure gradient R [kPa/m]:
    - Maximum in level -1: R = 0.029 kPa/m
    - Maximum in level -2: R = 0.036 kPa/m

- Determination diagram provided by manufacturer: (Uponor GmbH, 2024, p. 37)

Pipe dimension 17 x 2,0 mm



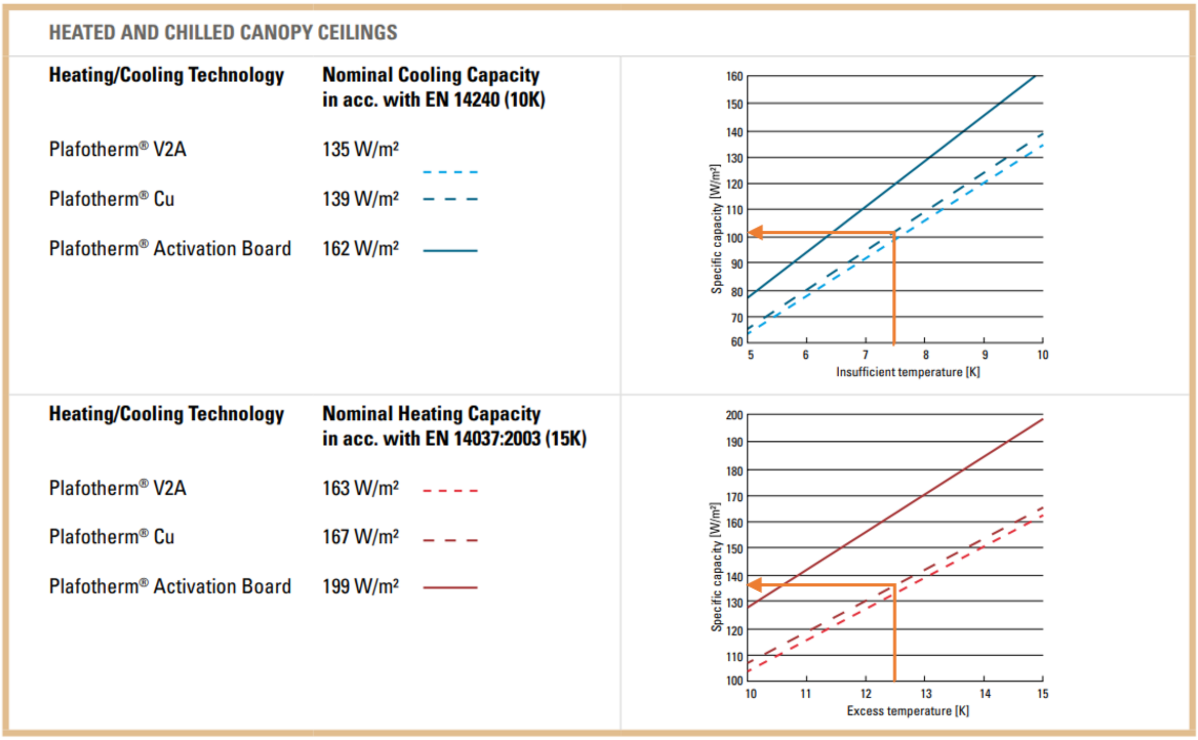
Item	Unit	Description
A	kg/h	Mass flow rate
B	R	Pressure gradient

11.2.3.3 Determination of pressure drop

- Input parameters:
  - Pressure gradient R [kPa/m]
  - Length of heating loop L [m]
- Output parameter:
  - Total pressure drop of heating loop dP [kPa]
- Determination by equation:
  - $dP = R * L$

11.2.4 Determination of the specific heating and cooling capacity of the radiant ceiling panels

- Input parameters:
  - Radiant ceiling system type: “Heated and chilled Canopy Ceilings - Plafotherm DS320 with Plafotherm Cu” by Lindner Group KG
- Output parameter:
  - Specific heating capacity q_H = 137 W/m² → round down to 130 W/m²
  - Specific cooling capacity q_C = 102 W/m² → round down to 95 W/m²
- Determination diagram provided by manufacturer:
  - (Lindner GmbH, 2024, p. 125)



HEATED AND CHILLED CANOPY CEILINGS

Heating/Cooling Technology	Nominal Cooling Capacity in acc. with EN 14240 (10K)	
Plafotherm® V2A	135 W/m²	- - - -
Plafotherm® Cu	139 W/m²	– – –
Plafotherm® Activation Board	162 W/m²	——

Heating/Cooling Technology	Nominal Heating Capacity in acc. with EN 14037:2003 (15K)	
Plafotherm® V2A	163 W/m²	- - - -
Plafotherm® Cu	167 W/m²	– – –
Plafotherm® Activation Board	199 W/m²	——

11.3 Appendix III: Concerning Chapter 8 – Selection and design of energy generation system

11.3.1 Tables of outdoor air temperature based on data of Deutsche Wetterdienst (DWD)

- Input parameter:
    - Hourly outdoor air temperature data of Deutsche Wetterdienst from 2008 to 2022 (both inclusive) (Deutscher Wetterdienst, 2023)
- Output parameters:
    - Hourly outdoor air temperature of each month
        - T_mean,m,j: average
        - T_25,m,j: 25th percentile: for heating mode
        - T_85,m,j: 85th percentile: for cooling mode
- Resulting tables:

Average outdoor air temperature T_mean,m,j [°C]

	Month m											
Hour j	**Janu-ary**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**Octo-ber**	**November**	**December**
1	0.64	1.08	3.06	6.75	10.24	14.21	16.04	15.86	12.05	8.47	5.15	2.11
2	0.52	0.90	2.77	6.33	9.77	13.77	15.63	15.49	11.72	8.30	5.03	2.01
3	0.44	0.74	2.48	5.95	9.36	13.33	15.22	15.17	11.50	8.13	4.91	1.96
4	0.39	0.60	2.27	5.64	9.06	13.02	14.90	14.89	11.25	7.95	4.86	1.95
5	0.33	0.51	2.10	5.37	9.11	13.24	14.96	14.69	11.00	7.83	4.79	1.91
6	0.29	0.41	1.97	5.47	10.05	14.46	15.89	15.07	10.95	7.73	4.71	1.89
7	0.26	0.34	2.09	6.85	12.03	16.43	17.68	16.66	11.58	7.78	4.67	1.87
8	0.24	0.38	2.98	8.58	13.58	17.92	19.14	18.38	13.10	8.42	4.74	1.88
9	0.37	0.94	4.25	10.10	14.95	19.12	20.40	19.96	14.83	9.62	5.18	1.98
10	0.81	1.88	5.58	11.47	16.09	20.20	21.43	21.22	16.49	11.04	5.96	2.36
11	1.40	2.83	6.67	12.57	16.99	21.05	22.22	22.19	17.57	12.15	6.76	2.93
12	1.89	3.60	7.54	13.43	17.67	21.73	22.85	22.94	18.32	12.91	7.32	3.37
13	2.24	4.12	8.17	14.00	18.20	22.18	23.40	23.42	18.80	13.33	7.75	3.67
14	2.40	4.40	8.52	14.41	18.49	22.55	23.76	23.76	19.08	13.54	7.93	3.81
15	2.41	4.55	8.72	14.59	18.62	22.71	23.99	24.00	19.18	13.52	7.84	3.72
16	2.18	4.38	8.70	14.54	18.60	22.77	24.02	23.93	19.04	13.14	7.33	3.39
17	1.78	3.89	8.37	14.22	18.27	22.58	23.78	23.52	18.38	12.00	6.61	3.09
18	1.51	3.11	7.42	13.45	17.67	21.96	23.30	22.68	16.77	10.70	6.20	2.91
19	1.31	2.64	6.18	12.00	16.54	20.98	22.37	21.05	15.01	10.05	5.92	2.79
20	1.15	2.27	5.32	10.36	14.75	19.41	20.53	19.04	14.06	9.69	5.73	2.68
21	1.02	2.00	4.72	9.33	13.23	17.48	18.75	17.96	13.47	9.35	5.56	2.60
22	0.87	1.74	4.24	8.59	12.30	16.29	17.78	17.28	13.00	9.10	5.38	2.48
23	0.75	1.50	3.82	7.99	11.60	15.51	17.10	16.68	12.57	8.83	5.26	2.36
24	0.63	1.32	3.44	7.40	10.97	14.86	16.55	16.17	12.20	8.58	5.11	2.30

Outdoor air temperature - 25th percentile (Heating mode) T_25,m,j [°C]

	Month m											
Hour j	**Janu-ary**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**Octo-ber**	**November**	**December**
1	-2.23	-1.60	0.30	4.00	7.50	11.83	13.80	13.60	9.60	5.80	2.70	-0.20
2	-2.40	-1.70	0.10	3.70	7.00	11.33	13.50	13.20	9.40	5.70	2.50	-0.40
3	-2.40	-1.80	-0.10	3.20	6.70	10.90	13.10	12.90	9.30	5.40	2.30	-0.40
4	-2.40	-1.90	-0.40	3.00	6.50	10.50	12.60	12.70	9.10	5.30	2.10	-0.40
5	-2.50	-2.10	-0.60	2.63	6.60	10.90	12.80	12.50	8.90	5.10	2.10	-0.60
6	-2.40	-2.13	-0.70	3.00	7.50	12.20	13.90	12.90	8.90	5.00	2.10	-0.53
7	-2.50	-2.10	-0.40	4.20	9.60	13.90	15.40	14.40	9.50	5.10	1.83	-0.60
8	-2.60	-2.25	0.50	5.80	11.00	15.00	16.50	16.10	11.10	6.00	1.93	-0.60
9	-2.40	-1.50	1.80	6.83	12.00	16.10	17.50	17.40	12.80	7.40	2.50	-0.60
10	-1.90	-0.43	3.00	7.90	12.80	17.10	18.20	18.30	14.00	8.60	3.40	-0.10
11	-1.10	0.20	3.90	8.50	13.40	17.83	18.90	19.30	15.00	9.60	4.03	0.60
12	-0.60	0.60	4.60	9.40	14.20	18.43	19.40	19.80	15.50	10.18	4.50	0.90
13	-0.40	1.00	5.00	10.20	14.80	18.90	19.80	20.30	15.90	10.60	5.00	1.20
14	-0.20	1.10	5.50	10.40	14.70	19.03	20.30	20.60	16.30	10.70	5.20	1.30
15	0.00	1.10	5.70	10.60	14.90	19.33	20.40	20.90	16.30	10.70	5.13	1.10
16	-0.40	1.00	5.70	10.53	14.80	19.30	20.40	20.60	16.10	10.40	4.63	0.70
17	-0.80	0.68	5.40	10.30	14.70	19.03	20.10	20.40	15.40	9.50	4.00	0.50
18	-1.30	0.08	4.50	9.60	14.00	18.53	19.70	19.60	14.00	8.10	3.60	0.40
19	-1.50	-0.13	3.60	8.43	13.20	17.80	19.30	18.20	12.70	7.40	3.20	0.20
20	-1.80	-0.50	2.80	7.20	11.90	16.73	17.60	16.20	11.70	7.00	3.10	0.10
21	-2.20	-0.80	1.80	6.40	10.50	14.90	16.20	15.50	11.10	6.90	2.93	0.10
22	-2.30	-1.00	1.30	5.90	9.60	13.70	15.30	14.80	10.50	6.60	2.70	0.00
23	-2.30	-1.13	1.00	5.40	9.00	13.00	14.70	14.20	10.10	6.20	2.50	-0.10
24	-2.43	-1.23	0.80	4.73	8.20	12.40	14.20	13.70	9.80	6.00	2.53	-0.10

Outdoor air temperature - 85th percentile (Cooling mode) T_85,m,j [°C]

Hour j	Month m											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1	5.36	5.76	7.24	11.00	14.54	17.90	19.10	19.18	15.48	12.50	9.10	6.50
2	5.40	5.56	6.80	10.67	13.90	17.50	18.80	18.90	15.28	12.38	9.00	6.40
3	5.40	5.46	6.70	10.10	13.50	17.20	18.50	18.50	15.00	12.20	8.90	6.54
4	5.40	5.30	6.40	9.67	13.00	16.60	18.04	18.30	14.80	12.00	8.80	6.64
5	5.20	5.26	6.30	9.40	12.88	16.77	18.20	18.14	14.60	12.00	8.80	6.60
6	5.34	5.40	6.20	9.47	13.74	17.80	18.90	18.40	14.50	11.80	8.80	6.56
7	5.30	5.20	6.20	10.87	15.90	20.10	20.90	19.94	14.88	11.74	8.80	6.44
8	5.20	5.20	6.90	12.70	17.90	21.97	22.70	21.60	16.00	12.30	8.80	6.40
9	5.14	5.40	8.18	14.80	19.64	23.50	24.40	23.84	17.80	13.50	9.20	6.50
10	5.44	6.30	9.80	16.70	21.14	24.97	25.90	25.70	20.00	15.00	10.00	6.80
11	5.90	7.40	10.90	18.17	22.34	25.90	26.78	26.94	21.50	16.30	10.90	7.40
12	6.60	8.36	12.00	19.23	23.10	26.87	27.44	27.90	22.50	17.16	11.50	7.60
13	6.84	8.96	12.84	19.80	23.70	27.30	28.34	28.14	23.38	17.60	12.07	8.10
14	7.30	9.30	13.20	20.50	24.10	27.60	28.80	28.70	23.78	18.00	12.10	8.20
15	7.14	9.56	13.54	20.90	23.80	27.90	29.14	29.00	23.60	18.00	11.80	8.24
16	6.94	9.30	13.40	20.70	24.30	27.70	29.10	29.00	23.50	17.64	11.30	7.70
17	6.54	8.86	13.08	20.30	23.70	27.60	29.00	28.38	22.78	16.00	10.60	7.40
18	6.24	7.86	11.90	19.30	22.90	26.80	27.94	27.28	20.88	14.30	10.20	7.20
19	6.20	7.46	10.18	17.17	21.50	25.60	26.84	25.18	18.68	13.80	9.90	7.00
20	5.94	6.96	9.20	15.00	19.00	23.50	24.34	22.74	17.60	13.50	9.57	7.10
21	5.80	6.56	8.70	13.80	17.44	21.17	22.44	21.90	17.40	13.30	9.50	7.00
22	5.84	6.56	8.30	13.10	16.70	19.90	21.30	21.10	16.70	13.10	9.17	7.00
23	5.80	6.10	7.90	12.30	15.88	19.07	20.44	20.24	16.28	12.90	9.17	6.90
24	5.46	6.00	7.54	11.60	15.30	18.47	19.80	19.70	15.90	12.70	9.07	6.80

11.3.2 Heating and cooling capacities of chosen heat pumps

11.3.2.1 Heating capacity of ASHP modeled depending on outdoor air temperature

- Input parameter:
    - Capacities given by manufacturer (see data sheets in Appendix IV in 11.4.3) at following conditions:
        - Outdoor air temperature as given in table below
        - Heating water temperature: 45°C

ASHP - heat pump capacity		
	A0/W45	**A15/W45**
Outdoor air temperature [°C]	0	15
Heating capacity [kW]	27.2	42.9

- Output parameter:
    - Heating capacity depending on outdoor air temperature [kW]
- Determination by diagram of linear function:
    - With modeled linear equation:

$$Q_{h,ASHP} = a * \vartheta + b$$

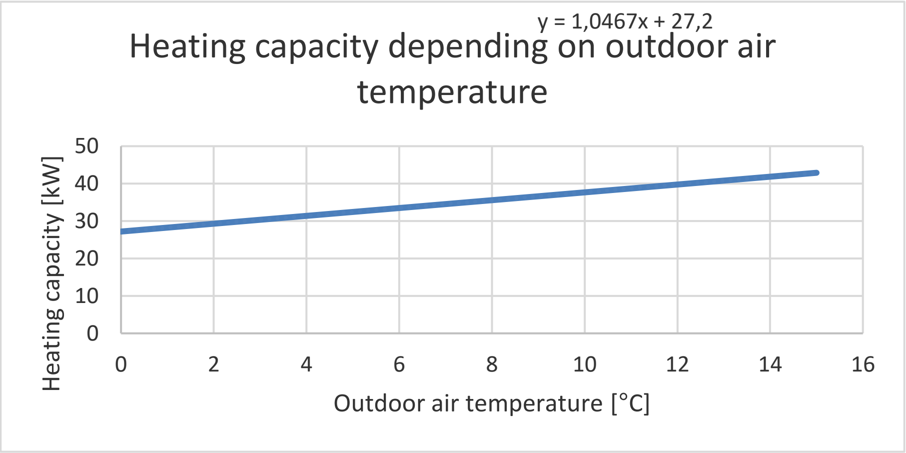
$$with:$$

$$Q_{h,ASHP}: Heating\ capacity\ of\ ASHP\ [kW]$$

$$\vartheta: Outdoor\ air\ temperature\ [°C]$$

$$a: gradient; here\ 1.0467\ \left[\frac{kW}{°C}\right]$$

$$b: offset; here\ 27.2\ [kW]$$



11.3.2.2 Cooling capacity of ASHP

- Capacity given by manufacturer (see data sheets in Appendix IV in 11.4.3) at following conditions:
    - Outdoor air temperature: 35°C
    - Cooling water temperature: 10°C
- Cooling capacity: Q_c_ASHP = 35.6 kW

11.3.2.3 Heating and cooling capacity of GSHP

- Heating mode characteristics given by manufacturer (see data sheets in Appendix IV in 11.4.2) at determined conditions according to European directive 813/2013.

GSHP - heat pump capacity			
	B0/W35	**B0/W55**	**B0/W45 estimated values**
Brine temperature [°C]	0	0	**0**
Heating water temperature [°C]	35	55	**45**
Heating capacity [kW]	49	45	**47**
SCOP	5.2	3.7	**4.5**
Power input [kW_el]	9.4	12.2	**10.5**

  - Conditions and heating capacity:
    - Brine temperature: 0°C
    - Heating water temperature: 45°C
    - Heating capacity: Q_h_GSHP = 47 kW as an intermedium value between data for heating water temperature of 35°C and heating water of 55°C.

- Cooling mode characteristics given by manufacturer (see data sheets in Appendix IV in 11.4.2) determined according to EN 14511:
  - $Q_{c,GSHP} = 34.2\ kW$
  - $Power\ input: P_{input,c} = 9.28\ kW$
  - $Cooling\ efficiency: EER = 3.7 = \frac{Q_{c,GSHP}}{P_{input,c}}$

11.3.2.4 Estimation of number of necessary boreholes for GSHP

- Input parameters:
  - $Estimated\ soil\ heat\ extraction\ rate: q_{soil} = 50\ W/m$
  - $Cooling\ capacity\ of\ GSHP: Q_{c,GSHP} = 34.2\ kW$
  - $Cooling\ efficiency\ EER = 3.7$
  - $Heating\ capacity\ of\ GSHP: Q_{h,GSHP} = 47\ kW$
  - $Heating\ efficiency\ SCOP = 4.5$
  - $Maximum\ depth\ of\ boreholes: X_{s,max} = 100\ m$
- Output parameters:
  - $From\ ground\ extracted\ heat\ in\ heating\ mode: Q_{ground,heating}\ [kW]$
  - $Into\ ground\ injected\ heat\ in\ cooling\ mode: Q_{ground,cooling}\ [kW]$
  - $Estimated\ total\ length\ of\ ground\ heat\ exchanger\ in\ heating\ mode\ L_h\ [m]$
  - $Estimated\ total\ length\ of\ ground\ heat\ exchanger\ in\ cooling\ mode\ L_c\ [m]$
  - $Estimated\ total\ length\ of\ ground\ heat\ exchanger\ L\ [m]$
  - $Estimated\ number\ of\ boreholes\ n$
  - $Estimated\ depth\ of\ each\ borehole\ X_s\ [m]$
- Determination:
  - $L_h = \frac{Q_{ground,heating}}{\mathrm{q_{soil}}}$
  - $L_c = \frac{Q_{ground,cooling}}{\mathrm{q_{soil}}}$
  - $L = \max\,(L_h; L_c)$
  - $Q_{ground,heating} = \mathrm{Q_{h,GSHP}} - \frac{\mathrm{Q_{h,GSHP}}}{\mathrm{SCOP}}$
  - $Q_{ground,cooling} = \mathrm{Q_{c,GSHP}} + \frac{\mathrm{Q_{c,GSHP}}}{\mathrm{EER}}$

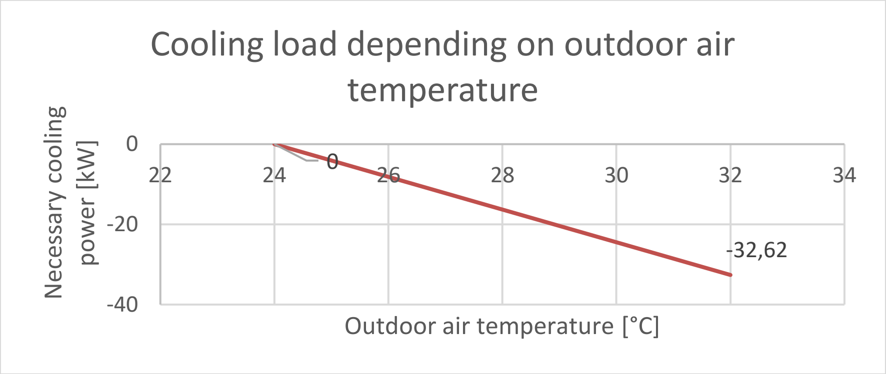
  - $n \geq \frac{L}{X_{s,max}}$
  - $X_s = \frac{L}{n}$
- Table of results:

GSHP - borehole number and depth			
	HEATING MODE	**COOLING MODE**	**SELECTION**
q_soil [W/m]	50	50	
Q_GSHP [kW]	47.0	34.5	
SCOP/EER	4.5	3.7	
Q_ground [kW]	36.6	43.8	
L_h/L_c [m]	731	876	**876**
n	8	9	**9**
X_s [m]	91	97	**97**

11.3.3 Cooling and heating consumption calculations

11.3.3.1 Total cooling consumption

- Input parameters:
  - Maximal cooling load: $Q_{c,load,max} = -32.62\ kW$
  - Cooling load depending on outdoor air temperature with temperature of cooling limit set to $T_{c,limit} = 24°C$ and design outdoor temperature at $T_{c,design} = 32°C$:



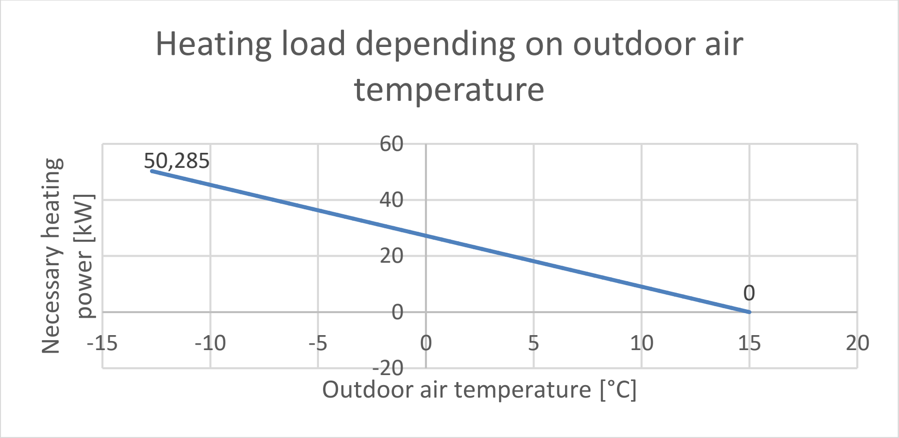
  - 85th percentile of outdoor air temperatures of nearest weather station from 2008-2022 as described in Appendix III in 11.3.1: $T_{85,m,j}$
  - Cooling period: 1 of May until 30th of September
- Output parameters:
  - $Required\ hourly\ cooling\ capacity\ of\ each\ month\ m$: $Q_{c,m,j}\ [kW]$
  - $Required\ monthly\ cooling\ consumption\ E_{c,m}$: $[MWh/month]$
  - $Required\ annual\ cooling\ consumption$: $E_{c,year}\ [MWh/year]$
- Determination:
  - If $T_{85,m,j} \geq T_{c,limit}$:
    - $Q_{c,m,j} = \frac{Q_{c,load,max}}{T_{c,design} - T_{c,limit}} * \left(T_{85,m,j} - T_{c,limit}\right)$
  - If $T_{85,m,j} < T_{c,limit}$:
    - $Q_{c,m,j} = 0\ kW$
  - $E_{c,m} = \left(\sum_{j=1}^{24} Q_{c,m,j}\right) * days_{month}$
  - $E_{c,year} = \sum_{m=5,6,7,8,9} E_{c,m}$

- Table of results:

Required hourly cooling capacity Q_c,m,j [kW]													
Month m		Janu-ary	Febru-ary	March	April	May	June	July	Au-gust	Sep-tem-ber	Octo-ber	Nove-mber	Dece-mber
Days$_{Month}$		31	28	31	30	31	30	31	31	30	31	30	31
Hour j	1	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	2	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	3	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	4	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	5	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	6	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	7	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	8	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	9	0	0	0	0	0.0	0.0	-1.6	0.0	0.0	0	0	0
	10	0	0	0	0	0.0	-3.9	-7.7	-6.9	0.0	0	0	0
	11	0	0	0	0	0.0	-7.7	-11.3	-12.0	0.0	0	0	0
	12	0	0	0	0	0.0	-11.7	-14.0	-15.9	0.0	0	0	0
	13	0	0	0	0	0.0	-13.5	-17.7	-16.9	0.0	0	0	0
	14	0	0	0	0	-0.4	-14.7	-19.6	-19.2	0.0	0	0	0
	15	0	0	0	0	0.0	-15.9	-21.0	-20.4	0.0	0	0	0
	16	0	0	0	0	-1.2	-15.1	-20.8	-20.4	0.0	0	0	0
	17	0	0	0	0	0.0	-14.7	-20.4	-17.9	0.0	0	0	0
	18	0	0	0	0	0.0	-11.4	-16.1	-13.4	0.0	0	0	0
	19	0	0	0	0	0.0	-6.5	-11.6	-4.8	0.0	0	0	0
	20	0	0	0	0	0.0	0.0	-1.4	0.0	0.0	0	0	0
	21	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	22	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	23	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
	24	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0
E_c,m [MWh]		0.00	0.00	0.00	0.00	-0.05	-3.45	-5.06	-4.58	0.00	0.00	0.00	0.00
E_c,year [MWh]		-13.14											

11.3.3.2 Total heating consumption

- Input parameters:
    - Maximal heating load: $Q_{h,load,max} = 50.29\ kW$
    - Heating load depending on outdoor air temperature with temperature of heating limit set to $T_{h,limit} = 15°C$ and design outdoor air temperature at $T_{h,design} = -12.7°C$:



  - 25th percentile of outdoor air temperatures of nearest weather station from 2008-2022 as described in Appendix III in 11.3.1: $T_{25,m,j}$
  - Heating period: 1 of October until 30th of April
- Output parameters:
  - $Required\ hourly\ heating\ capacity\ of\ each\ month\ m$: $Q_{h,m,j}\ [kW]$
  - $Required\ monthly\ heating\ consumption\ E_{h,m}$: $[MWh/month]$
  - $Required\ annual\ heating\ consumption$: $E_{h,year}\ [MWh/year]$
- Determination:
  - If $T_{25,m,j} \leq T_{h,limit}$:
    - $Q_{h,m,j} = \frac{Q_{h,load,max}}{T_{h,limit}-T_{h,design}} * \left(T_{h,limit} - T_{25,m,j}\right)$
  - If $T_{25,m,j} > T_{h,limit}$:
    - $Q_{h,m,j} = 0\ kW$
  - $E_{h,m} = \left(\sum_{j=1}^{24} Q_{h,m,j}\right) * days_{month}$
  - $E_{h,year} = \sum_{m=1,2,3,4,10,11,12} E_{h,m}$
- Table of results:

Required hourly heating capacity Q_h,m,j [kW]													
Month m		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Days$_{Month}$		**31**	**28**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**
Hour j	**1**	31.3	30.1	26.7	20.0	0	0	0	0	0	16.7	22.3	27.6
	2	31.6	30.3	27.0	20.5	0	0	0	0	0	16.9	22.7	28.0
	3	31.6	30.5	27.4	21.4	0	0	0	0	0	17.4	23.1	28.0
	4	31.6	30.7	28.0	21.8	0	0	0	0	0	17.6	23.4	28.0
	5	31.8	31.0	28.3	22.5	0	0	0	0	0	18.0	23.4	28.3
	6	31.6	31.1	28.5	21.8	0	0	0	0	0	18.2	23.4	28.2
	7	31.8	31.0	28.0	19.6	0	0	0	0	0	18.0	23.9	28.3
	8	32.0	31.3	26.3	16.7	0	0	0	0	0	16.3	23.7	28.3
	9	31.6	30.0	24.0	14.8	0	0	0	0	0	13.8	22.7	28.3
	10	30.7	28.0	21.8	12.9	0	0	0	0	0	11.6	21.1	27.4

Required hourly heating capacity Q_h,m,j [kW]													
Month m		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
$\text{Days}_{\text{Month}}$		**31**	**28**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**
	11	29.2	26.9	20.2	11.8	0	0	0	0	0	9.8	19.9	26.1
	12	28.3	26.1	18.9	10.2	0	0	0	0	0	8.8	19.1	25.6
	13	28.0	25.4	18.2	8.7	0	0	0	0	0	8.0	18.2	25.1
	14	27.6	25.2	17.2	8.4	0	0	0	0	0	7.8	17.8	24.9
	15	27.2	25.2	16.9	8.0	0	0	0	0	0	7.8	17.9	25.2
	16	28.0	25.4	16.9	8.1	0	0	0	0	0	8.4	18.8	26.0
	17	28.7	26.0	17.4	8.5	0	0	0	0	0	10.0	20.0	26.3
	18	29.6	27.1	19.1	9.8	0	0	0	0	0	12.5	20.7	26.5
	19	30.0	27.5	20.7	11.9	0	0	0	0	0	13.8	21.4	26.9
	20	30.5	28.1	22.1	14.2	0	0	0	0	0	14.5	21.6	27.0
	21	31.2	28.7	24.0	15.6	0	0	0	0	0	14.7	21.9	27.0
	22	31.4	29.0	24.9	16.5	0	0	0	0	0	15.2	22.3	27.2
	23	31.4	29.3	25.4	17.4	0	0	0	0	0	16.0	22.7	27.4
	24	31.6	29.5	25.8	18.7	0	0	0	0	0	16.3	22.6	27.4
E_h,m [MWh]		22.57	19.14	17.16	10.79	0.00	0.00	0.00	0.00	0.00	10.17	15.44	20.12
E_h,year [MWh]		115.39											

11.3.3.3 A1: Regenerative share of heating consumption generated by ASHP

- Input parameters:
  - Heating capacity of ASHP depending on outdoor air temperature as described in Appendix III in 11.3.2.1: $Q_{h,ASHP}$
  - Required hourly heating capacity of each month m as described in Appendix III in 11.3.2.2: $Q_{h,m,j}$ $[kW]$
  - 25th percentile of outdoor air temperatures of nearest weather station from 2008-2022 as described in Appendix III in 11.3.1: $T_{25,m,j}$
  - Heating period: 1 of October until 30th of April
- Output parameters:
  - $Hourly\ heating\ capacity\ generated\ by\ ASHP\ in\ each\ month\ m$: $Q_{ASHP,m,j}$ $[kW]$
  - $Covered\ monthly\ heating\ consumption\ by\ ASHP$ $E_{ASHP,m}$: $[MWh/month]$
  - $Covered\ annual\ heating\ consumption\ by\ ASHP$ $E_{ASHP,year}$ $[MWh/year]$
- Determination:
  - If $Q_{h,m,j} < Q_{h,ASHP}(T_{25,m,j})$:
    - ▪ $Q_{ASHP,m,j} = \mathrm{Q_{h,m,j}}$
  - If $Q_{h,m,j} \geq Q_{h,ASHP}(T_{25,m,j})$:
    - ▪ $Q_{ASHP,m,j} = \mathrm{Q_{h,ASHP}}(T_{25,m,j})$

- $E_{ASHP,m} = \left(\sum_{j=1}^{24} Q_{ASHP,m,j}\right) * days_{month}$
- $E_{ASHP,year} = \sum_{m=1,2,3,4,10,11,12} E_{ASHP,m}$

- Table of results:

Hourly heating capacity generated by ASHP Q_ASHP,m,j [kW]													
Month m		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Days$_{Month}$		**31**	**28**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**
Hour j	**1**	24.9	25.5	26.7	20.0	0	0	0	0	0	16.7	22.3	27.0
	2	24.7	25.4	27.0	20.5	0	0	0	0	0	16.9	22.7	26.8
	3	24.7	25.3	27.1	21.4	0	0	0	0	0	17.4	23.1	26.8
	4	24.7	25.2	26.8	21.8	0	0	0	0	0	17.6	23.4	26.8
	5	24.6	25.0	26.6	22.5	0	0	0	0	0	18.0	23.4	26.6
	6	24.7	25.0	26.5	21.8	0	0	0	0	0	18.2	23.4	26.7
	7	24.6	25.0	26.8	19.6	0	0	0	0	0	18.0	23.9	26.6
	8	24.5	24.8	26.3	16.7	0	0	0	0	0	16.3	23.7	26.6
	9	24.7	25.6	24.0	14.8	0	0	0	0	0	13.8	22.7	26.6
	10	25.2	26.8	21.8	12.9	0	0	0	0	0	11.6	21.1	27.1
	11	26.0	26.9	20.2	11.8	0	0	0	0	0	9.8	19.9	26.1
	12	26.6	26.1	18.9	10.2	0	0	0	0	0	8.8	19.1	25.6
	13	26.8	25.4	18.2	8.7	0	0	0	0	0	8.0	18.2	25.1
	14	27.0	25.2	17.2	8.4	0	0	0	0	0	7.8	17.8	24.9
	15	27.2	25.2	16.9	8.0	0	0	0	0	0	7.8	17.9	25.2
	16	26.8	25.4	16.9	8.1	0	0	0	0	0	8.4	18.8	26.0
	17	26.4	26.0	17.4	8.5	0	0	0	0	0	10.0	20.0	26.3
	18	25.8	27.1	19.1	9.8	0	0	0	0	0	12.5	20.7	26.5
	19	25.6	27.1	20.7	11.9	0	0	0	0	0	13.8	21.4	26.9
	20	25.3	26.7	22.1	14.2	0	0	0	0	0	14.5	21.6	27.0
	21	24.9	26.4	24.0	15.6	0	0	0	0	0	14.7	21.9	27.0
	22	24.8	26.2	24.9	16.5	0	0	0	0	0	15.2	22.3	27.2
	23	24.8	26.0	25.4	17.4	0	0	0	0	0	16.0	22.7	27.1
	24	24.7	25.9	25.8	18.7	0	0	0	0	0	16.3	22.6	27.1
E_ASHP,m [MWh]		18.90	17.34	16.96	10.79	0.00	0.00	0.00	0.00	0.00	10.17	15.44	19.70
E_ASHP,year [MWh]		109.30											

11.3.3.4 A2: Regenerative share of heating consumption generated by GSHP

- Input parameters:
  - Heating capacity of GSHP as described in Appendix III in 11.3.2.3: $Q_{h,GSHP}$
  - Required hourly heating capacity of each month m as described in Appendix III in 11.3.3.2: $Q_{h,m,j}\ [kW]$
  - Heating period: 1 of October until 30th of April
- Output parameters:
  - $Hourly\ heating\ capacity\ generated\ by\ GSHP\ in\ each\ month\ m$: $Q_{GSHP,m,j}\ [kW]$
  - $Covered\ monthly\ heating\ consumption\ by\ GSHP\ E_{GSHP,m}$: $[MWh/month]$
  - $Covered\ annual\ heating\ consumption\ by\ GSHP\ E_{GSHP,year}\ [MWh/year]$

- Determination:
    - If $Q_{h,m,j} < Q_{h,GSHP}$:
        - $Q_{GSHP,m,j} = \mathrm{Q_{h,m,j}}$
    - If $Q_{h,m,j} \geq Q_{h,GSHP}$:
        - $Q_{GSHP,m,j} = \mathrm{Q_{h,GSHP}}$
    - $E_{GSHP,m} = \left(\sum_{j=1}^{24} Q_{GSHP,m,j}\right) * days_{month}$
    - $E_{GSHP,year} = \sum_{m=1,2,3,4,10,11,12} E_{GSHP,m}$
- Table of results:

Hourly heating capacity generated by GSHP Q_GSHP,m,j [kW]													
Month m		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Days$_{Month}$		**31**	**28**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**
Hour j	**1**	31.3	30.1	26.7	20.0	0	0	0	0	0	16.7	22.3	27.6
	2	31.6	30.3	27.0	20.5	0	0	0	0	0	16.9	22.7	28.0
	3	31.6	30.5	27.4	21.4	0	0	0	0	0	17.4	23.1	28.0
	4	31.6	30.7	28.0	21.8	0	0	0	0	0	17.6	23.4	28.0
	5	31.8	31.0	28.3	22.5	0	0	0	0	0	18.0	23.4	28.3
	6	31.6	31.1	28.5	21.8	0	0	0	0	0	18.2	23.4	28.2
	7	31.8	31.0	28.0	19.6	0	0	0	0	0	18.0	23.9	28.3
	8	32.0	31.3	26.3	16.7	0	0	0	0	0	16.3	23.7	28.3
	9	31.6	30.0	24.0	14.8	0	0	0	0	0	13.8	22.7	28.3
	10	30.7	28.0	21.8	12.9	0	0	0	0	0	11.6	21.1	27.4
	11	29.2	26.9	20.2	11.8	0	0	0	0	0	9.8	19.9	26.1
	12	28.3	26.1	18.9	10.2	0	0	0	0	0	8.8	19.1	25.6
	13	28.0	25.4	18.2	8.7	0	0	0	0	0	8.0	18.2	25.1
	14	27.6	25.2	17.2	8.4	0	0	0	0	0	7.8	17.8	24.9
	15	27.2	25.2	16.9	8.0	0	0	0	0	0	7.8	17.9	25.2
	16	28.0	25.4	16.9	8.1	0	0	0	0	0	8.4	18.8	26.0
	17	28.7	26.0	17.4	8.5	0	0	0	0	0	10.0	20.0	26.3
	18	29.6	27.1	19.1	9.8	0	0	0	0	0	12.5	20.7	26.5
	19	30.0	27.5	20.7	11.9	0	0	0	0	0	13.8	21.4	26.9
	20	30.5	28.1	22.1	14.2	0	0	0	0	0	14.5	21.6	27.0
	21	31.2	28.7	24.0	15.6	0	0	0	0	0	14.7	21.9	27.0
	22	31.4	29.0	24.9	16.5	0	0	0	0	0	15.2	22.3	27.2
	23	31.4	29.3	25.4	17.4	0	0	0	0	0	16.0	22.7	27.4
	24	31.6	29.5	25.8	18.7	0	0	0	0	0	16.3	22.6	27.4
E_GSHP,m [MWh]		22.57	19.14	17.16	10.79	0.00	0.00	0.00	0.00	0.00	10.17	15.44	20.12
E_GSHP,year [MWh]		115.39											

11.3.3.5 A3: Regenerative share of heating consumption generated by ASHP

- Input parameters:
    - Heating capacity of ASHP with a maximum value of $Q_{h,ASHP(A3)} = 15.1\ kW$ set in case of alternative 3, which can be provided by selected ASHP until outdoor design air temperature $T_{h,design} = -12.7°C$
    - Required hourly heating capacity of each month m as described in Appendix III in 11.3.3.2: $Q_{h,m,j}\ [kW]$

  - Heating period: 1 of October until 30th of April
- Output parameters:
  - $Hourly\ heating\ capacity\ generated\ by\ ASHP\ of\ alternative\ 3\ in\ each\ month\ m:$ $$Q_{ASHP(A3),m,j}\ [kW]$$
  - $Covered\ monthly\ heating\ consumption\ by\ ASHP\ E_{ASHP(A3),m}:\ [MWh/month]$
  - $Covered\ annual\ heating\ consumption\ by\ ASHP\ E_{ASHP(A3),year}\ [MWh/year]$
- Determination:
  - If $Q_{h,m,j} < Q_{h,ASHP(A3)}$:
    - $Q_{ASHP(A3),m,j} = \mathrm{Q_{h,m,j}}$
  - If $Q_{h,m,j} \geq Q_{h,ASHP(A3)}$:
    - $Q_{ASHP(A3),m,j} = \mathrm{Q_{h,ASHP(A3)}}$
  - $E_{ASHP(A3),m} = \left(\sum_{j=1}^{24} Q_{ASHP(A3),m,j}\right) * days_{month}$
  - $E_{ASHP(A3),year} = \sum_{m=1,2,3,4,10,11,12} E_{ASHP(A3),m}$
- Table of results:

Hourly heating capacity generated by ASHP in alternative 3 - Q_ASHP(A3),m,j [kW]													
Month m		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Days$_{Month}$		**31**	**28**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**
Hour j	**1**	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	2	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	3	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	4	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	5	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	6	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	7	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	8	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	9	15.1	15.1	15.1	14.8	0	0	0	0	0	13.8	15.1	15.1
	10	15.1	15.1	15.1	12.9	0	0	0	0	0	11.6	15.1	15.1
	11	15.1	15.1	15.1	11.8	0	0	0	0	0	9.8	15.1	15.1
	12	15.1	15.1	15.1	10.2	0	0	0	0	0	8.8	15.1	15.1
	13	15.1	15.1	15.1	8.7	0	0	0	0	0	8.0	15.1	15.1
	14	15.1	15.1	15.1	8.4	0	0	0	0	0	7.8	15.1	15.1
	15	15.1	15.1	15.1	8.0	0	0	0	0	0	7.8	15.1	15.1
	16	15.1	15.1	15.1	8.1	0	0	0	0	0	8.4	15.1	15.1
	17	15.1	15.1	15.1	8.5	0	0	0	0	0	10.0	15.1	15.1
	18	15.1	15.1	15.1	9.8	0	0	0	0	0	12.5	15.1	15.1
	19	15.1	15.1	15.1	11.9	0	0	0	0	0	13.8	15.1	15.1
	20	15.1	15.1	15.1	14.2	0	0	0	0	0	14.5	15.1	15.1
	21	15.1	15.1	15.1	15.1	0	0	0	0	0	14.7	15.1	15.1
	22	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	23	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
	24	15.1	15.1	15.1	15.1	0	0	0	0	0	15.1	15.1	15.1
E_ASHP(A3),m [MWh]		11.23	10.15	11.23	9.26	0.00	0.00	0.00	0.00	0.00	9.53	10.87	11.23
E_ASHP(A3),year [MWh]		73.51											

11.3.3.6 A3: Share of heating consumption and electricity power generated by CHP

- Input parameters:
  - Required hourly heating capacity of each month m as described in Appendix III in 11.3.3.2: $Q_{h,m,j}\ [kW]$
  - $Hourly\ heating\ capacity\ generated\ by\ ASHP\ of\ alternative\ 3\ in\ each\ month\ m$: $$Q_{ASHP(A3),m,j}\ [kW]$$
  - Heating period: 1 of October until 30th of April
  - Heating capacity of CHP-system (see data sheet in Appendix IV in 11.4.4): $$Q_{CHP,max} = 12.4\ kW\ and\ Q_{CHP,min} = 6.2\ kW$$
  - Electrical power generation of CHP-system (see data sheet in Appendix IV in 11.4.4): $$P_{CHP,max} = 6\ kW_{el}\ \left(at\ Q_{CHP,max}\right)\ and\ P_{CHP,min} = 3\ kW_{el}\ (at\ Q_{CHP,min})$$
- Output parameters:
  - $Heating\ capacity\ difference\ between\ total\ heating\ capacity\ and\ ASHP - heating\ capacity\ in\ each\ month\ m$: $$Q_{diff,m,j}\ [kW]$$
  - $Heating\ capacity\ covered\ by\ CHP - system\ in\ each\ month\ m$: $$Q_{CHP,m}\ [kW]$$
  - $Covered\ monthly\ heating\ consumption\ by\ CHP\ E_{CHP,m}$: $[MWh/month]$
  - $Covered\ annual\ heating\ consumption\ by\ CHP\ E_{CHP,year}\ [MWh/year]$
  - $Electrical\ power\ generated\ by\ CHP - system\ in\ each\ month\ m$: $$P_{CHP,m}\ [kW_{el}]$$
  - $Monthly\ generated\ electrical\ power\ by\ CHP\ EP_{CHP,m}$: $[MWh_{el}/month]$
  - $Annualy\ generated\ electrcial\ power\ by\ CHP\ EP_{CHP,year}\ [MWh_{el}/year]$
- Determination:
  - If $Q_{h,m,j} > Q_{ASHP(A3),m,j}$:
    - $Q_{diff,m,j} = \mathrm{Q_{h,m,j}} - Q_{ASHP(A3),m,j}$
  - If $Q_{h,m,j} = Q_{ASHP(A3),m,j}$:
    - $Q_{diff,m,j} = 0\ \mathrm{kW}$
  - $Q_{CHP,m} = \min\limits_{j=1\ldots24}(Q_{diff,m,j})$
  - $E_{CHP,m} = \mathrm{Q_{CHP,m}} * days_{month} * 24h$
  - $E_{CHP,year} = \sum_{m=1,2,3,4,10,11,12} E_{CHP,m}$
  - $P_{CHP,m} = P_{CHP,max} * \left(\frac{Q_{CHP,m}}{Q_{CHP,max}}\right)$
  - $EP_{CHP,m} = \mathrm{P_{CHP,m}} * days_{month} * 24h$
  - $EP_{CHP,year} = \sum_{m=1,2,3,4,10,11,12} EP_{CHP,m}$

- Table of results:

Remaining hourly heating capacity for CHP - Q_diff,m,j [kW]													
Month m		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Days$_{Month}$		**31**	**28**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**
Hour j	**1**	16.2	15.0	11.6	4.9	0	0	0	0	0	1.6	7.2	12.5
	2	16.5	15.2	11.9	5.4	0	0	0	0	0	1.8	7.6	12.9
	3	16.5	15.4	12.3	6.3	0	0	0	0	0	2.3	8.0	12.9
	4	16.5	15.6	12.9	6.7	0	0	0	0	0	2.5	8.3	12.9
	5	16.7	15.9	13.2	7.4	0	0	0	0	0	2.9	8.3	13.2
	6	16.5	16.0	13.4	6.7	0	0	0	0	0	3.1	8.3	13.1
	7	16.7	15.9	12.9	4.5	0	0	0	0	0	2.9	8.8	13.2
	8	16.9	16.2	11.2	1.6	0	0	0	0	0	1.2	8.6	13.2
	9	16.5	14.9	8.9	0.0	0	0	0	0	0	0.0	7.6	13.2
	10	15.6	12.9	6.7	0.0	0	0	0	0	0	0.0	6.0	12.3
	11	14.1	11.8	5.1	0.0	0	0	0	0	0	0.0	4.8	11.0
	12	13.2	11.0	3.8	0.0	0	0	0	0	0	0.0	4.0	10.5
	13	12.9	10.3	3.1	0.0	0	0	0	0	0	0.0	3.1	10.0
	14	12.5	10.1	2.1	0.0	0	0	0	0	0	0.0	2.7	9.8
	15	12.1	10.1	1.8	0.0	0	0	0	0	0	0.0	2.8	10.1
	16	12.9	10.3	1.8	0.0	0	0	0	0	0	0.0	3.7	10.9
	17	13.6	10.9	2.3	0.0	0	0	0	0	0	0.0	4.9	11.2
	18	14.5	12.0	4.0	0.0	0	0	0	0	0	0.0	5.6	11.4
	19	14.9	12.4	5.6	0.0	0	0	0	0	0	0.0	6.3	11.8
	20	15.4	13.0	7.0	0.0	0	0	0	0	0	0.0	6.5	11.9
	21	16.1	13.6	8.9	0.5	0	0	0	0	0	0.0	6.8	11.9
	22	16.3	13.9	9.8	1.4	0	0	0	0	0	0.1	7.2	12.1
	23	16.3	14.2	10.3	2.3	0	0	0	0	0	0.9	7.6	12.3
	24	16.5	14.4	10.7	3.6	0	0	0	0	0	1.2	7.5	12.3
Q_CHP,m [kW]		12.1	10.1	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	9.8
E_CHP,m [MWh]		9.02	6.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.27
E_CHP,year [MWh]		23.10											
P_CHP,m [kW_el]		5.9	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7
EP_CHP,m [MWh_el]		4.37	3.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.52
EP_CHP,year [MWh_el]		11.18											

11.3.4 Summary of occupied efficiencies of the different energy generation systems

- Source: data sheets of manufacturers (see data sheets in Appendix IV)

ASHP - heat pump capacity		
Efficiency	**Value**	**Conditions**
Efficiency of condensing gas boiler: η_boiler	98%	T_supply=40°C; T_return=30°C
Efficiency of CHP: η_CHP	92%	At full load; with fuel input Q_fuel=20kW, heating capacity Q_heat=12.4 kW_th,electricity power Q_el=6 kW_el; η_CHP = (Q_heat + Q_el)/Q_fuel
GSHP - SCOP W45	4.5	SCOP W35 = 5.23, SCOP W55 = 3.7, SCOP W45 estimated as average of SCOP W35 and SCOP W55
GSHP - EER	3.7	With cooling capacity Q_c = 34.2 kW, and electrical power input Q_el_in_ = 9.28 kW; EER = Q_c/Q_el_in
ASHP - COP A2.5/W45	2.6	COP A0/W45 = 2.4 COP A15/W45 = 3.6 COP A2.5/W45 as interpoled result between COP A0/W45 and COP A15/W45 with 2.5 °C air temperature chosen since it is the average outdoor air temperature during heating period
ASHP - EER A35/W7	2.9	With outdoor air temperature T_air=35°C, cooling water temperature T_water=7°C

11.3.5 Primary energy and emission factors of energy sources

- Source: Annex 4 and annex 9, GEG (Bundesregierung, 2023)

Primary energy and emission factors depending on energy source

Energy source	**Primary energy factor [-]**	**Emission factor [eq. kg CO2/kWh]**
Network electricity	1.8	0.24
Natural gas	1.1	0.56

11.3.6 Investment and maintenance costs

Investment costs

System	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Source**
ASHP "ZETA SKY Hi HP R7 3.1" from Swegon	41,152 €	-	41,152 €	Quote of manufacturer
GSHP "Vitocal 300-G 301.A45" from Viessmann	-	27,940 €	-	Quote of manufacturer
Installation of GSHP	-	91,700 €	-	
Condensing gas boiler "Vitocrossal 300 - 60kW" from Viessmann	13,459 €	13,459 €	13,459 €	Quote of manufacturer
CHP-system "XRGI 6" from Buderus	-	-	32,182 €	Estimation based on (Energieagentur NRW, 2021)
TOTAL INVESTMENT COSTS	**54.6 k€**	**133.1 k€**	**86.8 k€**	

Maintenance costs

System	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Source**
Air source heat pumps	250 €	-	250 €	Estimation based on (Thermondo, 2024)
Geothermal heat pumps	-	250 €	-	Estimation based on (Thermondo, 2024)
Condensing gas boilers	300 €	300 €	300 €	Estimation based on (Thermondo, 2024)
CHP-systems	-	-	268 €	Estimation based on (Buderus GmbH, 2023): providing values of C_maintenance=2 €ct/kWh_el; here E_el_out = 13.4 kWh_el
TOTAL INVESTMENT COSTS	**550 €**	**550 €**	**818 €**	

11.3.7 Table of results of economic and environmental calculations

Table of results of economic and environmental calculations

1. Building data

		Heating	Cooling
Conditioned area [m]	1,283.20 m^2		
Thermal load [kW]		50.29 kW	-32.62 kW
Annual energy consumption [MWh/a]		115 MWh/a	-13 MWh/a

2. Energy prices and indexes

Price base:	**Price [€ct/kWh]**	**Inflation index [%]**
Electricity price for heat pumps	26.232 €ct/kWh	1.25%
Electricity price general	32.79 €ct/kWh	1.25%
Gas price	8.06 €ct/kWh	3.77%
Consumer price		2.94%

3. Comparison

Alternatives	**A1: ASHP + Gas boiler**	**A2: GSHP + Gas boiler**	**A3: ASHP + CHP + Gas boiler**	**Determi-nation**
Investment costs	54.6 k€	105.1 k€	86.8 k€	
Determination of final energy consumption				
Heating				
Annual heating consumption	115 MWh/a	115 MWh/a	115 MWh/a	
Share HP	94.7%	100.0%	63.7%	
Share Boiler	5.3%	0.0%	16.3%	
Share CHP	0.0%	0.0%	20.0%	
COP HP	2.6	4.5	2.6	
Efficiency Boiler [%]	98%	98%	98%	
Efficiency CHP [%]	92%	92%	92%	
Final energy consumption - HP	42.0 MWh/a	25.8 MWh/a	28.3 MWh/a	A
Final energy consumption - Boiler	6.2 MWh/a	0.0 MWh/a	19.2 MWh/a	B
Final energy consumption - CHP	0.0 MWh/a	0.0 MWh/a	25.1 MWh/a	C
Cooling				
Annual cooling consumption	-13 MWh/a	-13 MWh/a	-13 MWh/a	
Generation by ASHP or GSHP ?	ASHP	GSHP	ASHP	
EER HP	2.9	3.7	2.9	
Final energy consumption - HP	-4.5 MWh/a	-3.6 MWh/a	-4.5 MWh/a	D
Electricity generation				
CHP power generation			11.2 MWh	E
Final energy consumption - electricity	46.5 MWh/a	29.4 MWh/a	21.6 MWh/a	F=((A-E)-D)
Final energy consumption - gas	6.2 MWh/a	0.0 MWh/a	44.3 MWh/a	G=(B+C)
Annual final energy consumption	**52.73 MWh/a**	**29.41 MWh/a**	**65.85 MWh/a**	H=((A-E)+B+C-D)

Table of results of economic and environmental calculations				
3. Comparison (continuation)				
Alternatives	**A1: ASHP + Gas boiler**	**A2: GSHP + Gas boiler**	**A3: ASHP + CHP + Gas boiler**	**Determi-nation**
Determination of primary energy consumption				
Primary energy factors				
Network electricity	1.8	1.8	1.8	J
Natural gas	1.1	1.1	1.1	K
Annual primary energy consumption	**90.57 MWh/a**	**52.94 MWh/a**	**87.54 MWh/a**	=(F*J+G*K)
Determination of indirect emissions				
Emission factors				
Network electricity	0.56 kg/ kWh	0.56 kg/ kWh	0.56 kg/ kWh	L
Natural gas	0.24 kg/ kWh	0.24 kg/ kWh	0.24 kg/ kWh	M
Annual equivalent CO2 emissions	**27.54 eq.t of CO2/a**	**16.47 eq.t of CO2/a**	**22.71 eq.t of CO2/a**	=(F*L+G*M)
Determination of annual operating costs				
Heating				
Electricity HP	11,027.93 €	6,778.35 €	7,418.41 €	
Gas Boiler	500.53 €	0.00 €	1,544.30 €	
Gas CHP	0.00 €	0.00 €	2,023.87 €	
Annual heating operating costs	12,078.46 €	7,328.35 €	11,760.15 €	N
Cooling				
Electricity HP	1,175.19 €	936.48 €	1,175.19 €	
Annual cooling operating costs	1,175.19 €	936.48 €	1,175.19 €	O
Electricity generation				
Electricity savings due to power of CHP	0.00 €	0.00 €	-4,485.92 €	
Annual savings due to electricity generation	0.00 €	0.00 €	-4,485.92 €	P
Maintenance				
Annual maintenance costs	550.00 €	550.00 €	773.58 €	Q
Annual operating costs	**13,254 €**	**8,265 €**	**8,449 €**	**=N+O+P+Q**

11.3.8 Evolution of operating costs for 25 years and savings between alternatives

Evolution of operating costs and savings between alternatives									
1. Evolution of annual operating costs									
Alternative		**A1: ASHP + Gas boiler**				**A2: GSHP + Gas boiler**			
Year		Electricity costs	Gas costs	Maintenance costs	TOTAL	Electricity costs	Gas costs	Maintenance costs	TOTAL
1	2025	12,203 €	501 €	550 €	13 k€	7,715 €	0 €	550 €	8 k€
2	2026	12,356 €	519 €	566 €	13 k€	7,811 €	0 €	566 €	8 k€
3	2027	12,510 €	539 €	583 €	14 k€	7,909 €	0 €	583 €	8 k€
4	2028	12,666 €	559 €	600 €	14 k€	8,008 €	0 €	600 €	9 k€
5	2029	12,825 €	580 €	618 €	14 k€	8,108 €	0 €	618 €	9 k€
6	2030	12,985 €	602 €	636 €	14 k€	8,209 €	0 €	636 €	9 k€
7	2031	13,147 €	625 €	654 €	14 k€	8,312 €	0 €	654 €	9 k€
8	2032	13,312 €	649 €	674 €	15 k€	8,416 €	0 €	674 €	9 k€
9	2033	13,478 €	673 €	693 €	15 k€	8,521 €	0 €	693 €	9 k€
10	2034	13,647 €	698 €	714 €	15 k€	8,627 €	0 €	714 €	9 k€
11	2035	13,817 €	725 €	735 €	15 k€	8,735 €	0 €	735 €	9 k€
12	2036	13,990 €	752 €	756 €	15 k€	8,844 €	0 €	756 €	10 k€
13	2037	14,165 €	780 €	779 €	16 k€	8,955 €	0 €	779 €	10 k€
14	2038	14,342 €	810 €	802 €	16 k€	9,067 €	0 €	802 €	10 k€
15	2039	14,521 €	840 €	825 €	16 k€	9,180 €	0 €	825 €	10 k€
16	2040	14,703 €	872 €	849 €	16 k€	9,295 €	0 €	849 €	10 k€
17	2041	14,886 €	905 €	874 €	17 k€	9,411 €	0 €	874 €	10 k€
18	2042	15,073 €	939 €	900 €	17 k€	9,529 €	0 €	900 €	10 k€
19	2043	15,261 €	974 €	927 €	17 k€	9,648 €	0 €	927 €	11 k€
20	2044	15,452 €	1,011 €	954 €	17 k€	9,769 €	0 €	954 €	11 k€
21	2045	15,645 €	1,049 €	982 €	18 k€	9,891 €	0 €	982 €	11 k€
22	2046	15,840 €	1,089 €	1,011 €	18 k€	10,014 €	0 €	1,011 €	11 k€
23	2047	16,038 €	1,130 €	1,040 €	18 k€	10,140 €	0 €	1,040 €	11 k€
24	2048	16,239 €	1,172 €	1,071 €	18 k€	10,266 €	0 €	1,071 €	11 k€
25	2049	16,442 €	1,217 €	1,103 €	19 k€	10,395 €	0 €	1,103 €	11 k€

Alternative		**A3: ASHP + CHP + Gas boiler**			
Year		Electricity costs	Gas costs	Maintenance costs	TOTAL
1	2025	4,108 €	3,568 €	774 €	8 k€
2	2026	4,159 €	3,703 €	796 €	9 k€
3	2027	4,211 €	3,842 €	820 €	9 k€
4	2028	4,264 €	3,987 €	844 €	9 k€
5	2029	4,317 €	4,137 €	869 €	9 k€
6	2030	4,371 €	4,293 €	894 €	10 k€
7	2031	4,426 €	4,455 €	920 €	10 k€
8	2032	4,481 €	4,623 €	948 €	10 k€
9	2033	4,537 €	4,798 €	975 €	10 k€
10	2034	4,594 €	4,978 €	1,004 €	11 k€
11	2035	4,651 €	5,166 €	1,034 €	11 k€
12	2036	4,709 €	5,361 €	1,064 €	11 k€
13	2037	4,768 €	5,563 €	1,095 €	11 k€
14	2038	4,828 €	5,773 €	1,127 €	12 k€

Alternative		**A3: ASHP + CHP + Gas boiler (continuation)**			
Year		Electricity costs	Gas costs	Maintenance costs	TOTAL
15	2039	4,888 €	5,990 €	1,161 €	12 k€
16	2040	4,949 €	6,216 €	1,195 €	12 k€
17	2041	5,011 €	6,451 €	1,230 €	13 k€
18	2042	5,074 €	6,694 €	1,266 €	13 k€
19	2043	5,137 €	6,946 €	1,303 €	13 k€
20	2044	5,201 €	7,208 €	1,342 €	14 k€
21	2045	5,266 €	7,480 €	1,381 €	14 k€
22	2046	5,332 €	7,762 €	1,422 €	15 k€
23	2047	5,399 €	8,054 €	1,463 €	15 k€
24	2048	5,466 €	8,358 €	1,506 €	15 k€
25	2049	5,534 €	8,673 €	1,551 €	16 k€

2. Savings between alternatives				
Year		**Comparing A1 - A2**	**Comparing A1 - A3**	**Comparing A2 - A3**
1	2025	5 k€	5 k€	0 k€
2	2026	10 k€	10 k€	0 k€
3	2027	15 k€	14 k€	1 k€
4	2028	20 k€	19 k€	1 k€
5	2029	26 k€	24 k€	2 k€
6	2030	31 k€	28 k€	3 k€
7	2031	37 k€	33 k€	3 k€
8	2032	42 k€	38 k€	4 k€
9	2033	48 k€	42 k€	6 k€
10	2034	53 k€	47 k€	7 k€
11	2035	59 k€	51 k€	8 k€
12	2036	65 k€	55 k€	10 k€
13	2037	71 k€	60 k€	11 k€
14	2038	77 k€	64 k€	13 k€
15	2039	83 k€	68 k€	15 k€
16	2040	90 k€	72 k€	17 k€
17	2041	96 k€	76 k€	20 k€
18	2042	103 k€	80 k€	22 k€
19	2043	109 k€	84 k€	25 k€
20	2044	116 k€	87 k€	28 k€
21	2045	123 k€	91 k€	32 k€
22	2046	130 k€	94 k€	35 k€
23	2047	137 k€	98 k€	39 k€
24	2048	144 k€	101 k€	43 k€
25	2049	151 k€	104 k€	47 k€

🟩 Amortization time

11.3.9 Design of GSHP

11.3.9.1 Determination of required ground exchanger length according to IGSHPA

- Calculation according to (International Ground Source Heat Pump Association, 1988)

11.3.9.1.1 Determination of soil temperatures

- Input parameters:
  - $\text{Mean annual outdoor air temperature}$
    $T_{amb,mean}\ [°C] = 10.22\ °C = \sum_{m=1\ldots12;j=1\ldots24}(T_{mean,m,j})$ (see Appendix III in 11.3.1)
  - $\text{Depth of ground exchanger } X_s = 100\ m$
- Output parameters:
  - $\text{Mean annual soil temperature}: T_{soil,mean}\ [°C]$
  - $\text{Maximum annual soil temperature}: T_{soil,H}\ [°C]$
  - $\text{Minimum annual soil temperature}: T_{soil,L}\ [°C]$
- Determination:
  - $T_{soil,mean} = T_{amb,mean}$
  - $T_{soil,H} = T_{soil,L} = T_{soil,mean}\quad (\text{if } X_s \gg)$

11.3.9.1.2 Determination of maximum and minimum brine temperatures

- Input parameters:
  - $\text{Cooling capacity of GSHP}: Q_{CAP,c}\ [kW] = -34.2\ kW$
  - $\text{Heating capacity of GSHP}: Q_{CAP,h}\ [kW] = 47.0\ kW$
  - $EER: \text{Energy efficiency ratio in cooling mode } [-] = 3.7$
  - $COP_h: \text{Coefficient of performance in heating mode } [-] = 4.5$
  - $\text{Volume flow rate of fluid}:\ \dot{V}_{fluid}\left[\frac{m^3}{h}\right] = 18\ m^3/h$ (see data sheet in Appendix IV in 11.4.2)
  - $\text{Specific heat capacity of fluid}: c_{p,fluid}\left[\frac{kJ}{kgK}\right] = 3.92\ kJ/kgK$ ((TYFOROP Chemie GmbH, 2024))
  - $\text{Mean annual outdoor air temperature}: T_{amb,mean}[°C] = 10.22°C$
- Output parameters:
  - $\text{Entering fluid temperature (towards ground heat exchanger)}$
    $\text{in cooling mode}: T_{IN,cooling}\ [°C]$
  - $\text{Entering fluid temperature (towards ground heat exchanger)}$
    $\text{in heating mode}: T_{IN,heating}\ [°C]$
  - $\text{Injected power into the ground in cooling mode}: Q_{ground,cooling}\ [kW]$
  - $\text{Extracted power from the ground in heating mode}: Q_{ground,heating}\ [kW]$
  - $\text{Leaving fluid temperature (from ground heat exchanger) in summer } T_{OUT,cooling}[°C]$
  - $\text{Leaving fluid temperature (from ground heat exchanger) in winter } T_{OUT,heating}[°C]$
  - $\text{Mean maximum fluid temperature (in cooling mode)} T_{MAX}\ [°C]$
  - $\text{Mean minimum fluid temperature (in heating mode)} T_{MIN}\ [°C]$
- Determination:
  - $T_{IN,cooling} = T_{amb,mean} + [11K \ldots 17K] = 10.22 + [11K \ldots 17K]$
    $\rightarrow \text{Chosen}: T_{IN,cooling} = 22°C$
  - $T_{IN,heating} = T_{amb,mean} - [6K \ldots 11K] = 10.22 - [6K \ldots 13K]$
    $\rightarrow \text{Chosen}: T_{IN,heating} = -2°C$
  - $Q_{ground,cooling} = Q_{CAP,c} * \left(1 + \frac{1}{EER}\right) = -43.5\ kW$

  - $Q_{ground,heating} = Q_{CAP,h} * \left(1 - \frac{1}{COP}\right) = 36.5\ kW$
  - $T_{OUT,cooling} = T_{IN,cooling} + \frac{Q_{ground,cooling}}{\dot{V}_{fluid} * c_{p,fluid}} = 21.38\ °C$
  - $T_{OUT,heating} = T_{IN,heating} - \frac{Q_{ground,heating}}{\dot{V}_{fluid} * c_{p,fluid}} = -1.38\ °C$
  - $T_{MAX} = \frac{T_{IN,cooling} + T_{OUT,cooling}}{2} = 21.69\ °C$
  - $T_{MIN} = \frac{T_{IN,heating} + T_{OUT,heating}}{2} = -1.69\ °C$

11.3.9.1.3 Determination of pipe resistance to heat flow

- Input parameters:
  - $Number\ of\ tubes\ inside\ heat\ exchanger: n\ [-] = 4\ (Doble - U)$
  - $Exterior\ diameter\ of\ ground\ exchanger\ pipe: D_e [m] = 0.04\ m$ (see data sheet in Appendix IV in 11.4.7.1)
  - $Interior\ diameter\ of\ ground\ exchanger\ pipe: D_i [m] = 0.0326\ m$ (see data sheet in Appendix IV in 11.4.7.1)
  - $Thermal\ conductivity\ of\ ground\ exchanger\ pipes: k_p \left[\frac{W}{mK}\right] = 0.4 \frac{W}{mK}$ (see data sheet in Appendix IV in 11.4.7.1)
- Output parameter:
  - $Thermal\ resistance\ of\ ground\ exchanger\ pipes: R_p \left[\frac{mK}{W}\right]$
- Determination:
  - $R_p = \frac{1}{2 * \pi * k_p} * \ln\left(\frac{\sqrt{n} * D_e}{\sqrt{n} * D_e - (D_e - D_i)}\right) = 0.017 \frac{mk}{W}$

11.3.9.1.4 Determination of soil resistance to heat flow

- Input parameters:
  - $Type\ of\ ground\ heat\ exchanger: Double - U, Vertical$
  - $Days\ of\ use: 120\ days$
- Output parameter:
  - $Soil\ resistance\ to\ heat\ flow\ R_s \left[\frac{mK}{W}\right]$
- Determination:
  - According to(International Ground Source Heat Pump Association, 1988): $R_s = 0.304 \frac{mK}{W}$

11.3.9.1.5 Calculation of monthly heating and cooling run fractions

- Input parameters:
  - $Monthly\ energy\ consumption\ for\ cooling\ E_{m,c,HP} \left[\frac{kWh}{month}\right]$
  - $Monthly\ energy\ consumption\ for\ heating\ E_{m,h,HP} \left[\frac{kWh}{month}\right]$
  - $Cooling\ capacity\ of\ GSHP: Q_{CAP,c}\ [kW] = -34.2\ kW$
  - $Heating\ capacity\ of\ GSHP: Q_{CAP,h}\ [kW] = 47.0\ kW$
  - $Days\ of\ each\ month: days_m\ [d]$
- Output parameters:
  - $Monthly\ run\ fractions\ of\ HP\ for\ cooling\ F_{c,m}\ [-]$
  - $Monthly\ run\ fractions\ of\ HP\ for\ heating\ F_{h,m}\ [-]$
- Determination:

  - $F_{c,m} = \frac{E_{m,c,HP}}{Q_{CAP,c} * 24h * days_m}$
  - $F_{h,m} = \frac{E_{m,h,HP}}{Q_{CAP,h} * 24h * days_m}$
- Table of results of heating and run fractions for July and January (design months) depending on alternatives varying heating energy satisfaction (compare Chapter 8.4.1.2)

Results of heating and cooling run fractions						
Variable	**Base case**	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
Run fraction July F_c_07	20%	20%	20%	20%	20%	20%
Run fraction January F_h_01	34%	40%	48%	55%	61%	65%

11.3.9.1.6 Detailed results concerning the analysis of most economic ground heat exchanger configuration

Results concerning the analysis of most economic ground heat exchanger configuration							
CATEGORY	**Variable**	**Base case**	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
GENERAL INFOS	Design criteria	6 boreholes	7 boreholes	8 boreholes	9 boreholes	10 boreholes	100% heating energy satisfaction
	Average heating capacity GSHP [kW]	15.5 kW	19 kW	22.5 kW	26 kW	29 kW	32 kW
	Heating energy satisfaction [%]	65%	77%	87%	95%	99%	100%
COOLING MODE	Cooling consumption July [kWh]	-5059	-5059	-5059	-5059	-5059	-5059
	Q_CAP_cooling [kW]	-34.2	-34.2	-34.2	-34.2	-34.2	-34.2
	Utilization hours of GSHP in July [h]	148	148	148	148	148	148
	Run fraction cooling F_c [-]	20%	20%	20%	20%	20%	20%
HEATING MODE	Heating consumption January [kWh]	11900	14140	16740	19340	21380	22570
	Q_CAP_heating [kW]	47	47	47	47	47	47
	Utilization hours of GSHP in January [h]	253	301	356	411	455	480
	Run fraction heating F_h [-]	34%	40%	48%	55%	61%	65%
HEAT EXCHANGER LENGTH	L_c [m]	292	292	292	292	292	292
	L_h [m]	580	674	783	892	978	1028
BOREHOLE CONFIGURATION	No. of vertical collectors [-]	6	7	8	9	10	11
	Depth of collectors [m]	97	97	98	100	98	94
INVESTMENT COSTS	HP Vitocal 300G	28000	28000	28000	28000	28000	28000
	Condensing gas boiler	13500	13500	13500	13500	13500	13500
	Installation Boreholes	42373	48590	54808	61025	67242	73459
	Total investment costs [€]	83873	90090	96308	102525	108742	114959
RATING	Amortization time [years]	-	14	14	13	14	16

11.3.9.2 Buffer tank sizing

- Input parameters:
  - $Cooling\ capacity\ of\ GSHP: Q_{c,GSHP}\ [kW] = -34.2\ kW$
  - $Heating\ capacity\ of\ GSHP: Q_{h,GSHP}\ [kW] = 47.0\ kW$
  - $Heating\ capacity\ of\ condensing\ gas\ boiler: Q_{h,boiler}[kW] = 35\ kW$
  - $Design\ criterion: max\left(\frac{dT}{dt}\right) = 1.5 \frac{K}{minute}$
  - $Density\ of\ water: \rho_{water} = 1000\ kg/m^3$
  - $Specific\ heat\ capacity\ of\ water: 4.184\ kJ/kgK$

- Output parameters:
    - $Cooling\ buffer\ tank\ volume: V_{tank,c}\ [m3]$
    - $Heating\ buffer\ tank\ volume: V_{tank,h}\ [m3]$
- Determination:
    - $V_{tank,c} = \frac{Q_{c,max}}{\rho_{water} * c_{p,water} * \left(\frac{dT}{dt}\right)} = 0.327\ m^3 \Rightarrow V_{tank,c} = 400\ l$
    - $V_{tank,h} = \frac{Q_{h,max}}{\rho_{water} * c_{p,water} * \left(\frac{dT}{dt}\right)} = 0.449\ m^3 \Rightarrow V_{tank,h} = 500\ l$

11.3.9.3 Determination of pressure drop in primary circuit

Results of pressure drop calculations for primary circuit in heating mode											
	Description	**Ground Exchanger 2U H DN40**	**Pipes Ground-Manifold H DN50**	**Pipes Manifold-HP H DN110**	**Bends Ground-Manifold H DN50**	**Bends Manifold-HP H DN110**	**Y Ground H DN50-DN40**	**Valve Manifdold - HP H DN110**	**U-bend H**	**Valve Ground-Manifold H DN50**	**Heat pump pressure drop**
Element charac-teristics	Element of pipe	circular	circular	circular	Circular bend	Circular bend	Y-pipe bent	Globe valve Y-pattern	U-bend	Globe valve Y-pattern	-
	Number	2	2	2	8	4	2	2	1	2	-
	Diameter [mm]	32.6	40.8	90	40.8	90	40.8	90	32.6	40.8	-
	Length [m]	100	30	10	-	-	-	-	100	-	-
	Radius [mm] / Angle [°]	-	-	-	2500 / 90	5500 / 90	30 / -	-	-	-	-
Flow charac-teristics	Flow medium	Water/Ethylene glycol 25%									-
	Condition	liquid									-
	Volume flow [m³/h]	1	2	18	2	18	2	18	1	2	-
	Mass flow [kg/h]	1042	2084	18756	2084	18756	2084	18756	1042	2084	-
	Density [kg/m³]	1042	1042	1042	1042	1042	1042	1042	1042	1042	-
	Dyn. Viscos. [10^-6kg/ms]	4032.5	4032.5	4032.5	4032.5	4032.5	4032.5	4032.5	4032.5	4032.5	-
	Kin. Viscos. [10^-6 m²/s]	3.87	3.87	3.87	3.87	3.87	3.87	3.87	3.87	3.87	-
Results	Veloc. of flow [m/s]	0.33	0.42	0.79	0.42	0.79	0.42	0.79	0.33	0.42	-
	Reynolds number	2803	4480	18278	4480	18278	4480	18278	2803	4480	-
	Flow	turbulent									-
	Absolute roughness [mm]	0.03	0.03	0.03	0.03	0.03	-	-	-	-	-
	Pipe friction number	0.045	0.039	0.027	0.039	0.027	-	-	-	-	-
	Resistance coefficient	138.75	28.95	3.02	3.91	2.67	0.63	2.62	0.21	3.47	-
	Pressure drop [Pa]	0.16013	0.05447	0.01941	0.02946	0.03442	0.00118	0.01686	0.00012	0.00653	0.42646
	Total pressure drop [Pa]	**74904**									
	Head [m]	**7.64**									
	Pump number and model	**P14(H): Stratos MAXO 100/0,5-12 PN16**									

Results of pressure drop calculations for primary circuit in cooling mode

	Description	**Ground Exchanger 2U C DN40**	**Pipes Ground-Manifold C DN50**	**Pipes Manifold-HP C DN110**	**Bends Ground-Manifold C DN50**	**Bends Manifold-HP C DN110**	**Y Ground C DN50-DN40**	**Valve Manifdold - HP C DN110**	**U-bend-C**	**Valve Ground-Manifold C DN50**	**Heat pump pressure drop**
Element charac-teristics	Element of pipe	circular	circular	circular	Circular bend	Circular bend	Y-pipe bent	Globe valve Y-pattern	U-bend	Globe valve Y-pattern	-
	Number	2	2	2	8	4	2	2	1	2	-
	Diameter [mm]	32.6	40.8	90	40.8	90	40.8	90	32.6	40.8	-
	Length [m]	100	30	10	-	-	-	-	100	-	-
	Radius [mm] / Angle [°]	-	-	-	2500 / 90	5500 / 90	30 / -	-	-	-	-
Flow charac-teristics	Flow medium	Water/Ethylene glycol 25%									-
	Condition	liquid									-
	Volume flow [m^3/h]	1	2	18	2	18	2	18	1	2	-
	Mass flow [kg/h]	1035	2070	18630	2070	18630	2070	18630	1035	2070	-
	Density [kg/m^3]	1035	1035	1035	1035	1035	1035	1035	1035	1035	-
	Dyn. Viscos. [10^-6kg/ms]	2142.5	2142.5	2142.5	2142.5	2142.5	2142.5	2142.5	2142.5	2142.5	-
	Kin. Viscos. [10^-6 m^2/s]	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	-
Results	Veloc. of flow [m/s]	0.33	0.42	0.79	0.42	0.79	0.42	0.79	0.33	0.42	-
	Reynolds number	5241	8375	34172	8375	34172	8375	34172	5241	8375	-
	Flow	turbulent									-
	Absolute roughness [mm]	0.03	0.03	0.03	0.03	0.03	-	-	-	-	-
	Pipe friction number	0.038	0.033	0.024	0.033	0.024	-	-	-	-	-
	Resistance coefficient	116.33	24.56	2.64	3.32	2.33	0.63	2.59	0.21	3.36	-
	Pressure drop [Pa]	0.13334	0.04590	0.01685	0.02482	0.02986	0.00118	0.01658	0.00012	0.00629	0.42646
	Total pressure drop [Pa]	**70140**									
	Head [m]	**7.15**									
	Pump number and model	**P14(C): Stratos MAXO 100/0,5-12 PN16**									

11.3.9.4 Determination of pressure drop in secondary circuit

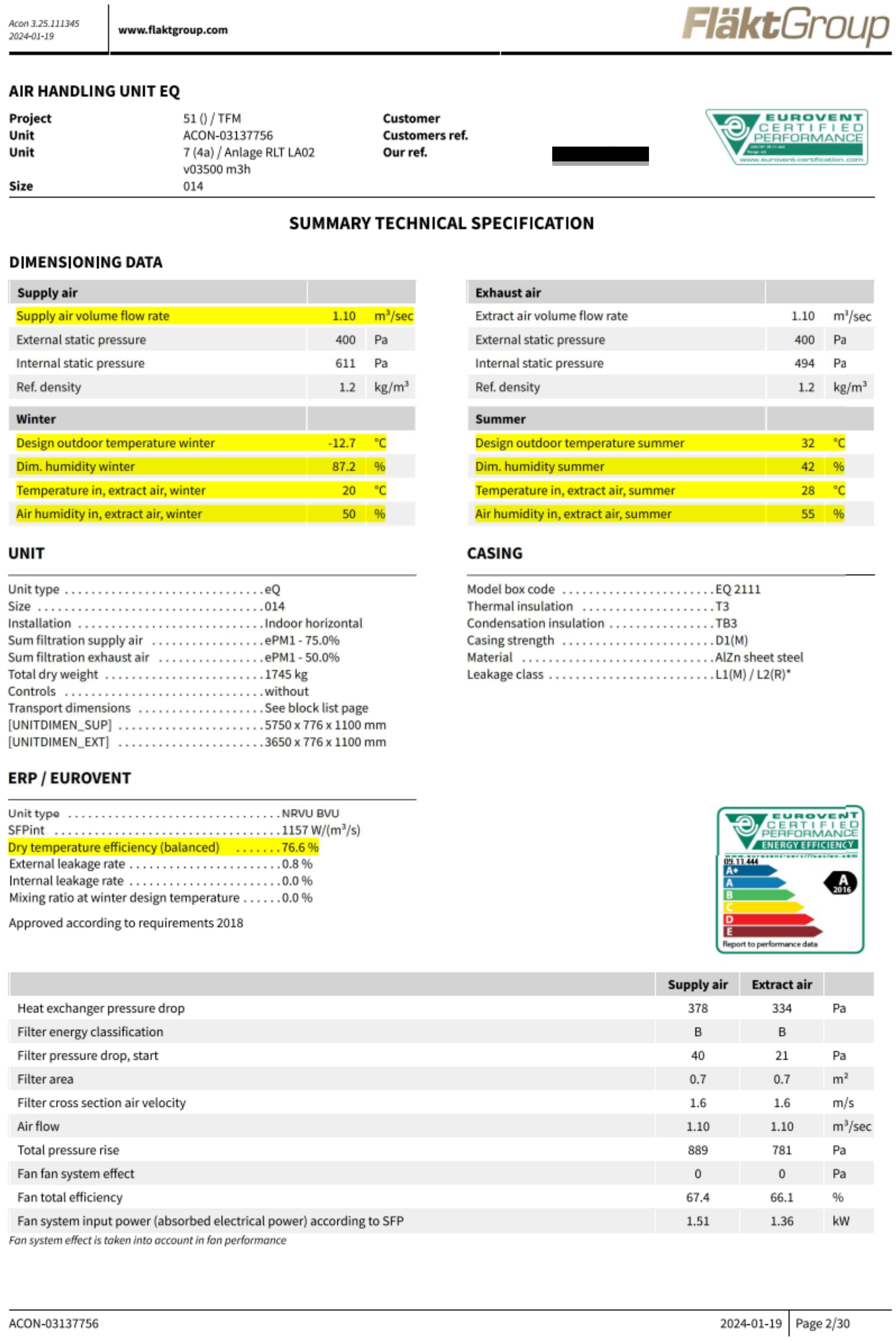
Results of pressure drop calculations for secondary circuit in heating mode							
	Description	**Pipes Secondary H**	**Bends Secondary H**	**Microbubble separator H**	**Dirt separator H**	**Heat pump H**	**Condensing gas boiler**
Element charac-teristics	Element of pipe	circular	Circular bend	Reflex Exvoid A2	Reflex Exdirt D2		
	Number	2	12	until 7.5 m^3/h	until 7.5 m^3/h		
	Dimensions of element	Diameter of pipe D: 53.00 mm	Diameter of pipe D: 53.00 mm	Flow rate characteristic value kvs [m^3/h]	Flow rate characteristic value kvs [m^3/h]		
		Length of pipe L: 15.00 m	Radius R: 3000.00 mm	56.1	56.1		
		---	Angle w: 90.00 Grad				
Flow charac-teristics	Flow medium	Water 45 °C	Water 45 °C	Water 45°C	Water 45°C	Water 45°C	Water 45°C
	Condition	liquid	liquid	liquid	liquid	liquid	liquid
	Volume flow [m^3/h]	6.0	6.0	5.1	5.1	5.1	2.0
	Mass flow [kg/h]	5942	5942	5060	5060	5060	2010
	Density [kg/m^3]	990.3	999.7	990.3	990.3	990.3	990.3
	Dyn.Visvos. [10^-6kg/ms]	600.0	600.0				
	Kin.Viscos. [10^-6 m^2/s]	0.61	0.61				
	Temperature (inlet) [°C]			45	45	45	45
	Temperature (outlet) [°C]			37	37	37	30
	Specific heat capacity [J/kgK]			4180	4180	4180	4180
	Capacity [W]			47000	47000	47000	35000
Results	Veloc.of flow [m/s]	0.76	0.76				
	Reynolds number	66084	66084				
	Flow	turbulent	turbulent				
	Absolute roughness [mm]	0.10	0.10				
	Pipe friction number	0.026	0.026				
	Resistance coefficient	7.23	2.35				
	Pressure drop [Pa]	0.04088	0.07964	0.09108	0.09108	0.15416	0.01890
	Total pressure drop [Pa]	**30266**				**15416**	**1890**
	Head [m]	**3.09**				**1.57**	**0.19**
	Pump number and model	**P10: Stratos MAXO 50/0,5-6 PN6/10**				**P12(H): Stratos MAXO 50/0,5-6 PN6/10**	**P13: Stratos MAXO 40/0,5-4 PN6/10**

Results of pressure drop calculations for secondary circuit in cooling mode						
	Description	**Pipes Secondary C**	**Bends Secondary C**	**Microbubble separator C**	**Dirt separator C**	**Heat pump C**
Element charac-teristics	Element of pipe	circular	Circular bend	Reflex Exvoid A2	Reflex Exdirt D2	
	Number	2	12	until 7.5 m^3/h	until 7.5 m^3/h	
	Dimensions of element	Diameter of pipe D: 53.00 mm	Diameter of pipe D: 53.00 mm	Flow rate characteristic value kvs [m^3/h]	Flow rate characteristic value kvs [m^3/h]	
		Length of pipe L: 15.00 m	Radius R: 3000.00 mm	56.1	56.1	
		---	Angle w: 90.00 Grad			
Flow charac-teristics	Flow medium	Water 10 °C	Water 10 °C	Water 10°C	Water 10°C	Water 10°C
	Condition	liquid	liquid	liquid	liquid	liquid
	Volume flow [m^3/h]	6.0	6.0	4.9	4.9	4.9
	Mass flow [kg/h]	5944	5944	4897	4897	4897
	Density [kg/m^3]	999.7	990.7	999.7	999.7	999.7
	Dyn.Visvos. [10^-6kg/ms]	1310.0	1310.0			
	Kin.Viscos. [10^-6 m^2/s]	1.32	1.32			
	Temperature (inlet) [°C]			10	10	10
	Temperature (outlet) [°C]			16	16	16
	Specific heat capacity [J/kgK]			4190	4190	4190
	Capacity [W]			34200	34200	34200
Results	Veloc.of flow [m/s]	0.76	0.76			
	Reynolds number	30280	30280			
	Flow	turbulent	turbulent			
	Absolute roughness [mm]	0.10	0.10			
	Pipe friction number	0.028	0.028			
	Resistance coefficient	7.87	2.56			
	Pressure drop [Pa]	0.04451	0.08696	0.08732	0.08732	0.16250
	Total pressure drop [Pa]	**30612**				**16250**
	Head [m]	**3.12**				**1.66**
	Pump number and model	**P11: Stratos MAXO 50/0,5-6 PN6/10**				**P12(C): Stratos MAXO 50/0,5-6 PN6/10**

11.4 Appendix IV: Data sheets

11.4.1 Data sheet: Air handling unit (AHU) -

- 19/01/2024: Facilitated by B2B Customer Service Program Fläkt (extract)



Acon 3.25.111345
2024-01-19

www.flaktgroup.com

FläktGroup

AIR HANDLING UNIT EQ

Project	51 () / TFM	**Customer**	
Unit	ACON-03137756	**Customers ref.**	
Unit	7 (4a) / Anlage RLT LA02 v03500 m3h	**Our ref.**	[redacted]
Size	014		

SUMMARY TECHNICAL SPECIFICATION

DIMENSIONING DATA

Supply air		
Supply air volume flow rate	1.10	m³/sec
External static pressure	400	Pa
Internal static pressure	611	Pa
Ref. density	1.2	kg/m³
Winter		
Design outdoor temperature winter	-12.7	°C
Dim. humidity winter	87.2	%
Temperature in, extract air, winter	20	°C
Air humidity in, extract air, winter	50	%

Exhaust air		
Extract air volume flow rate	1.10	m³/sec
External static pressure	400	Pa
Internal static pressure	494	Pa
Ref. density	1.2	kg/m³
Summer		
Design outdoor temperature summer	32	°C
Dim. humidity summer	42	%
Temperature in, extract air, summer	28	°C
Air humidity in, extract air, summer	55	%

UNIT

Unit type ....eQ
Size 014
Installation ....Indoor horizontal
Sum filtration supply air ....ePM1 - 75.0%
Sum filtration exhaust air ....ePM1 - 50.0%
Total dry weight ....1745 kg
Controls ....without
Transport dimensions ....See block list page
[UNITDIMEN_SUP] ....5750 x 776 x 1100 mm
[UNITDIMEN_EXT] ....3650 x 776 x 1100 mm

CASING

Model box code ....EQ 2111
Thermal insulation T3
Condensation insulation TB3
Casing strength ....D1(M)
Material ....AlZn sheet steel
Leakage class ....L1(M) / L2(R)*

ERP / EUROVENT

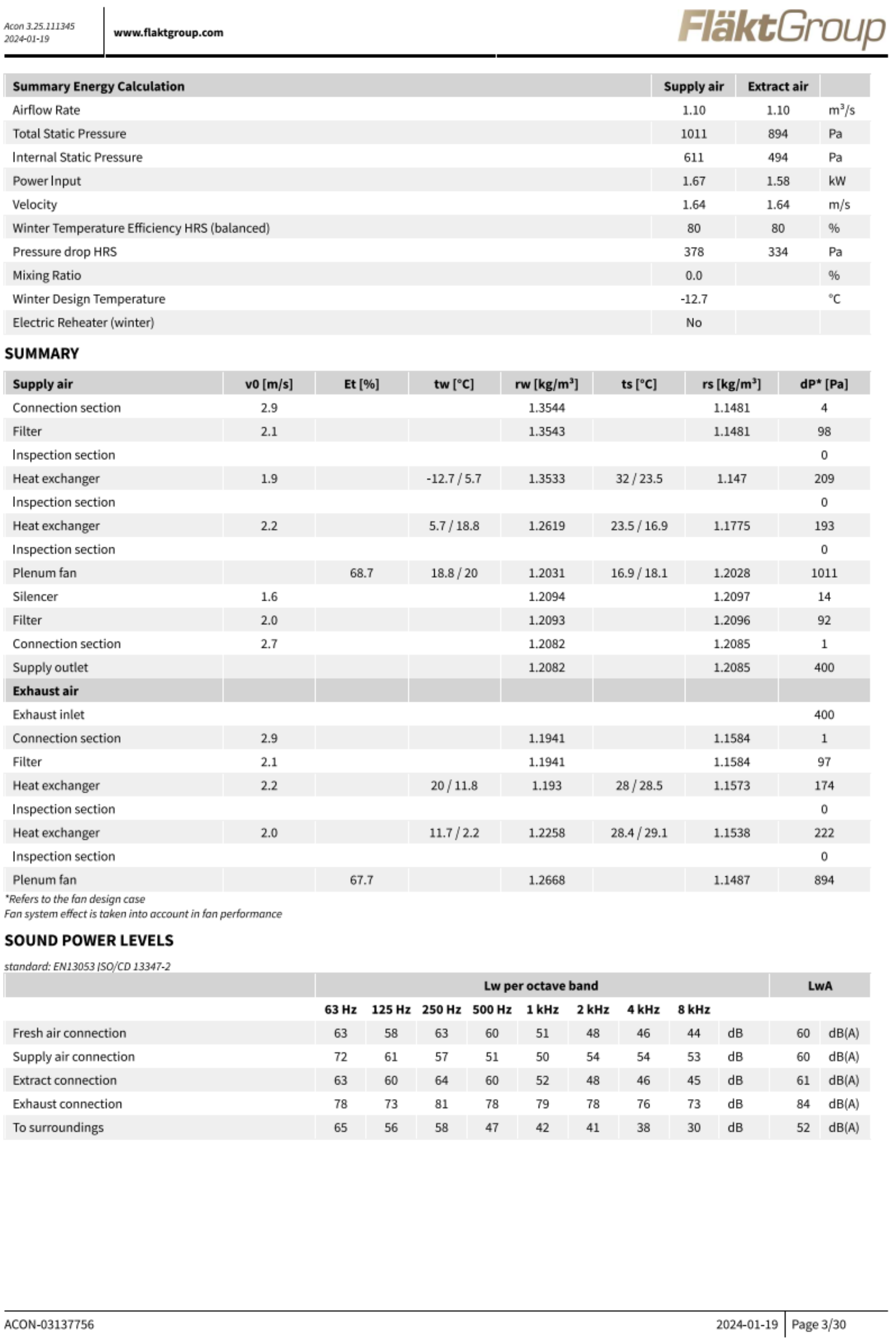
Unit type ....NRVU BVU
SFPint ....1157 W/(m³/s)
Dry temperature efficiency (balanced) ....76.6 %
External leakage rate ....0.8 %
Internal leakage rate ....0.0 %
Mixing ratio at winter design temperature ......0.0 %

Approved according to requirements 2018

	Supply air	Extract air	
Heat exchanger pressure drop	378	334	Pa
Filter energy classification	B	B	
Filter pressure drop, start	40	21	Pa
Filter area	0.7	0.7	m²
Filter cross section air velocity	1.6	1.6	m/s
Air flow	1.10	1.10	m³/sec
Total pressure rise	889	781	Pa
Fan fan system effect	0	0	Pa
Fan total efficiency	67.4	66.1	%
Fan system input power (absorbed electrical power) according to SFP	1.51	1.36	kW

Fan system effect is taken into account in fan performance

ACON-03137756 2024-01-19 Page 2/30



Acon 3.25.111345
2024-01-19

www.flaktgroup.com

Summary Energy Calculation	Supply air	Extract air	
Airflow Rate	1.10	1.10	m^3/s
Total Static Pressure	1011	894	Pa
Internal Static Pressure	611	494	Pa
Power Input	1.67	1.58	kW
Velocity	1.64	1.64	m/s
Winter Temperature Efficiency HRS (balanced)	80	80	%
Pressure drop HRS	378	334	Pa
Mixing Ratio	0.0		%
Winter Design Temperature	-12.7		°C
Electric Reheater (winter)	No		

SUMMARY

Supply air	v0 [m/s]	Et [%]	tw [°C]	rw [kg/m³]	ts [°C]	rs [kg/m³]	dP* [Pa]
Connection section	2.9			1.3544		1.1481	4
Filter	2.1			1.3543		1.1481	98
Inspection section							0
Heat exchanger	1.9		-12.7 / 5.7	1.3533	32 / 23.5	1.147	209
Inspection section							0
Heat exchanger	2.2		5.7 / 18.8	1.2619	23.5 / 16.9	1.1775	193
Inspection section							0
Plenum fan		68.7	18.8 / 20	1.2031	16.9 / 18.1	1.2028	1011
Silencer	1.6			1.2094		1.2097	14
Filter	2.0			1.2093		1.2096	92
Connection section	2.7			1.2082		1.2085	1
Supply outlet				1.2082		1.2085	400
Exhaust air							
Exhaust inlet							400
Connection section	2.9			1.1941		1.1584	1
Filter	2.1			1.1941		1.1584	97
Heat exchanger	2.2		20 / 11.8	1.193	28 / 28.5	1.1573	174
Inspection section							0
Heat exchanger	2.0		11.7 / 2.2	1.2258	28.4 / 29.1	1.1538	222
Inspection section							0
Plenum fan		67.7		1.2668		1.1487	894

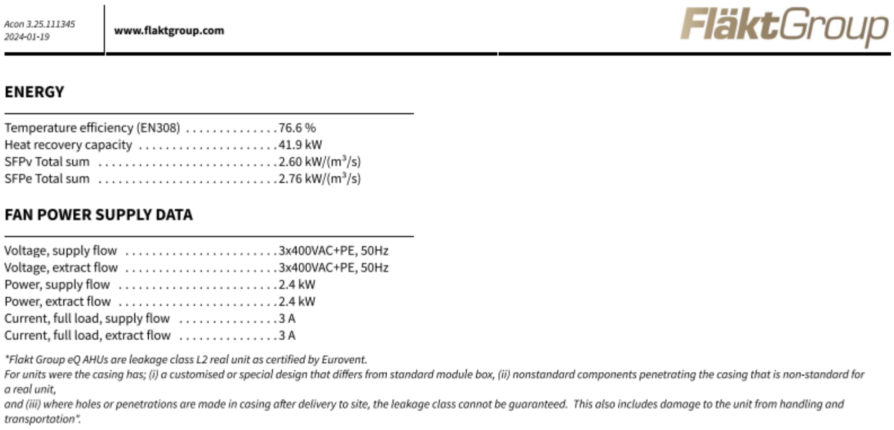
**Refers to the fan design case*
Fan system effect is taken into account in fan performance

SOUND POWER LEVELS

standard: EN13053 ISO/CD 13347-2

	Lw per octave band									LwA	
	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz			
Fresh air connection	63	58	63	60	51	48	46	44	dB	60	dB(A)
Supply air connection	72	61	57	51	50	54	54	53	dB	60	dB(A)
Extract connection	63	60	64	60	52	48	46	45	dB	61	dB(A)
Exhaust connection	78	73	81	78	79	78	76	73	dB	84	dB(A)
To surroundings	65	56	58	47	42	41	38	30	dB	52	dB(A)

ACON-03137756 2024-01-19 | Page 3/30



Acon 3.25.111345
2024-01-19

www.flaktgroup.com

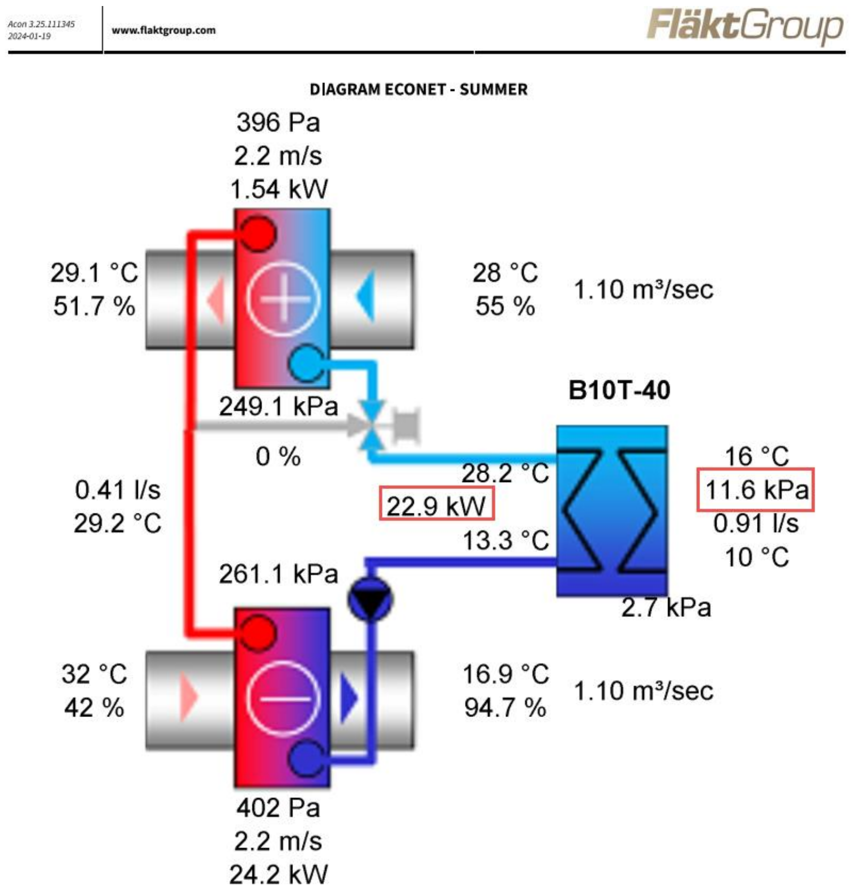
ENERGY

Temperature efficiency (EN308) ....76.6 %
Heat recovery capacity ....41.9 kW
SFPv Total sum ....2.60 kW/(m³/s)
SFPe Total sum ....2.76 kW/(m³/s)

FAN POWER SUPPLY DATA

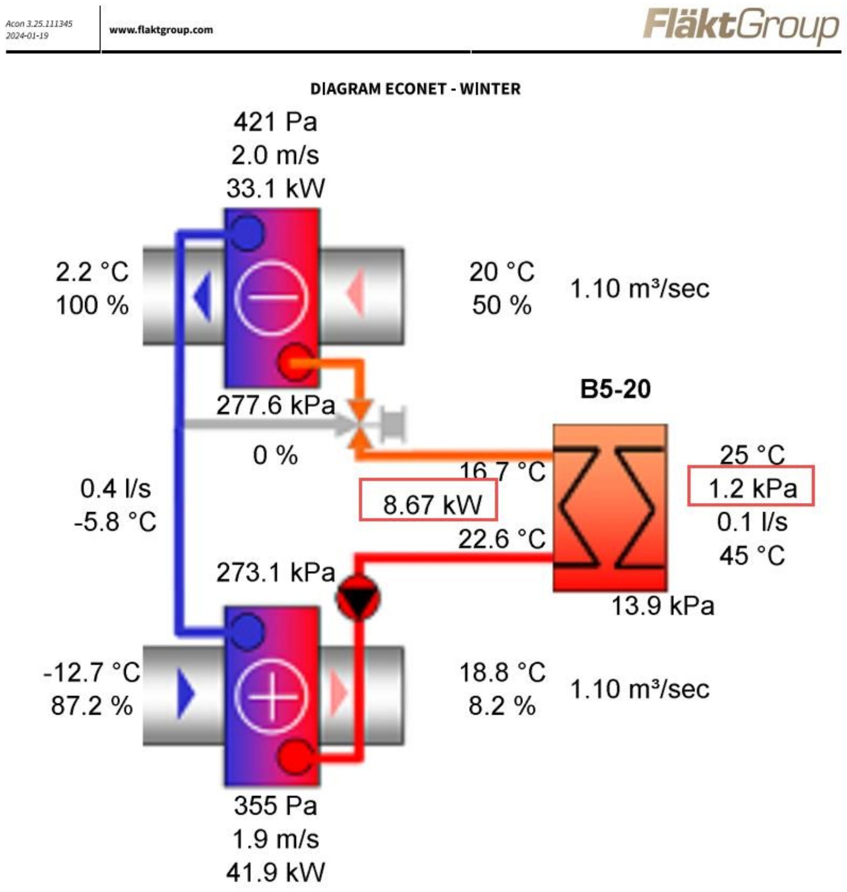
Voltage, supply flow ....3x400VAC+PE, 50Hz
Voltage, extract flow ....3x400VAC+PE, 50Hz
Power, supply flow ....2.4 kW
Power, extract flow ....2.4 kW
Current, full load, supply flow ....3 A
Current, full load, extract flow ....3 A

"Flakt Group eQ AHUs are leakage class L2 real unit as certified by Eurovent.
For units were the casing has; (i) a customised or special design that differs from standard module box, (ii) nonstandard components penetrating the casing that is non-standard for a real unit,
and (iii) where holes or penetrations are made in casing after delivery to site, the leakage class cannot be guaranteed. This also includes damage to the unit from handling and transportation".



Acon 3.25.111345
2024-01-19
www.flaktgroup.com
FläktGroup

DIAGRAM ECONET - SUMMER



Acon 3.25.111345
2024-01-19
www.flaktgroup.com
FläktGroup

DIAGRAM ECONET - WINTER

11.4.2 Data sheet: Ground source heat pump (GSHP) – Vitocal 300-G 301.A45 (Viessmann)

- 20/12/2023: Extracted from (Viessmann Climate Solutions SE, 2023a)

VIESSMANN

VITOCAL 300-G/350-G
Sole/Wasser-Wärmepumpen 20,5 bis 85,6 kW
Wasser/Wasser-Wärmepumpen 25,4 bis 117,8 kW
1- und 2-stufig

Datenblatt

Best.-Nr. und Preise: siehe Preisliste

Wärmepumpen mit elektrischem Antrieb für Beheizung und Trinkwassererwärmung in monovalenten oder bivalenten Heizungsanlagen

VITOCAL 300-G

Bis 60 °C Vorlauftemperatur

- **Typ BW 301.A21 bis A45**
  1-stufige Wärmepumpe ohne eingebaute Umwälzpumpen, auch als 1. Stufe (Master) einer 2-stufigen Wärmepumpe
- **Typ BWS 301.A21 bis A45**
  2. Stufe (Slave) einer 2-stufigen Wärmepumpe, ohne eigene Regelung

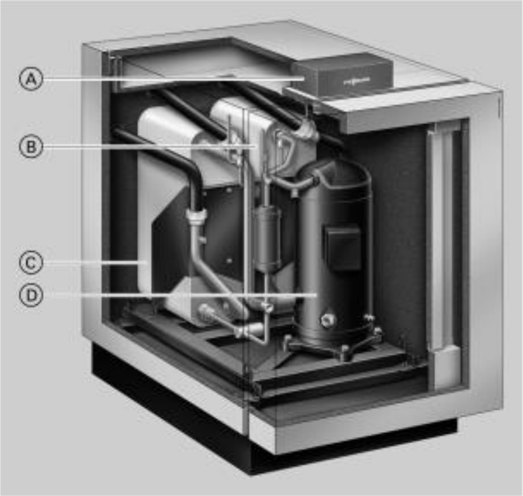
VITOCAL 350-G

Bis 70 °C Vorlauftemperatur

- **Typ BW 351.B20 bis B42**
  1-stufige Wärmepumpe ohne eingebaute Umwälzpumpen, auch als 1. Stufe (Master) einer 2-stufigen Wärmepumpe
- **Typ BWS 351.B20 bis B42**
  2. Stufe (Slave) einer 2-stufigen Wärmepumpe, ohne eigene Regelung

5811552 DE 4/2023

Vorteile Vitocal 300-G



Ⓐ Witterungsgeführte, digitale Wärmepumpenregelung Vitotronic 200
Ⓑ Verflüssiger
Ⓒ Verdampfer
Ⓓ Hermetischer Compliant Scroll-Verdichter

- Geringe Betriebskosten durch hohen COP (Coefficient of Performance) nach EN 14511: Bis 4,8 bei B0/W35
- Monovalenter Betrieb für Raumbeheizung und Trinkwassererwärmung
- Maximale Vorlauftemperaturen für hohen Trinkwasserkomfort bis 60 °C
- Geräusch- und schwingungsarm durch schalloptimierte Gerätekonstruktion
- Geringe Betriebskosten bei höchster Effizienz in jedem Betriebspunkt durch innovatives RCD-System (Refrigerant Cycle Diagnostic System) mit elektronischem Expansionsventil (EEV)
- Bei 2-stufiger Ausführung (Typ BW+BWS):
  Höchste Variabilität durch Kombination von Modulen auch mit unterschiedlicher Leistung
  Einfachere Einbringung durch kleinere und leichtere Module

Nur Typ BW:

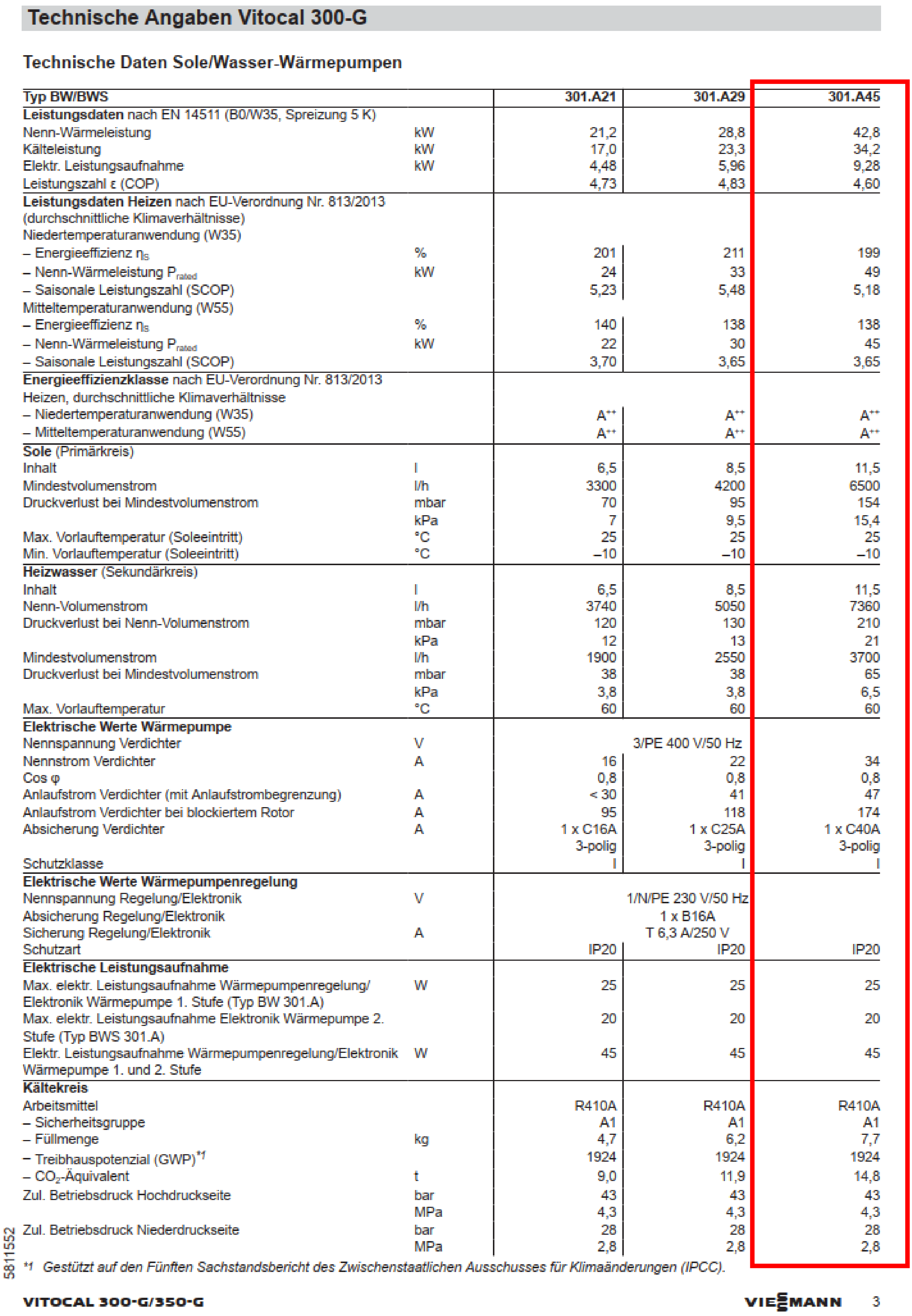
- Einfach zu bedienende Vitotronic Regelung mit Klartext- und Grafikanzeige für witterungsgeführten Heizbetrieb, mit Kühlfunktionen „natural cooling“ und „active cooling“
- Leistungserweiterung durch Kaskadierung möglich:
  21,2 bis 428,0 kW
- Optimierte Nutzung des selbsterzeugten Stroms von Photovoltaikanlagen
- Internetfähig durch Vitoconnect (Zubehör) für Bedienung und Service über Viessmann Apps

Auslieferungszustand Typ BW

- Komplette Wärmepumpe in Kompaktbauweise als 1-stufige Wärmepumpe oder als 1. Stufe (Master) einer 2-stufigen Wärmepumpe
- Schallabsorbierende Stellfüße
- Witterungsgeführte Wärmepumpenregelung Vitotronic 200 mit Außentemperatursensor
- Elektronische Anlaufstrombegrenzung und integrierte Phasenüberwachung

Auslieferungszustand Typ BWS

- Wärmepumpe in Kompaktbauweise als 2. Stufe (Slave)
- Schallabsorbierende Stellfüße
- Elektrische Anschlussleitung zur 1. Stufe (Master)
- Elektronische Anlaufstrombegrenzung



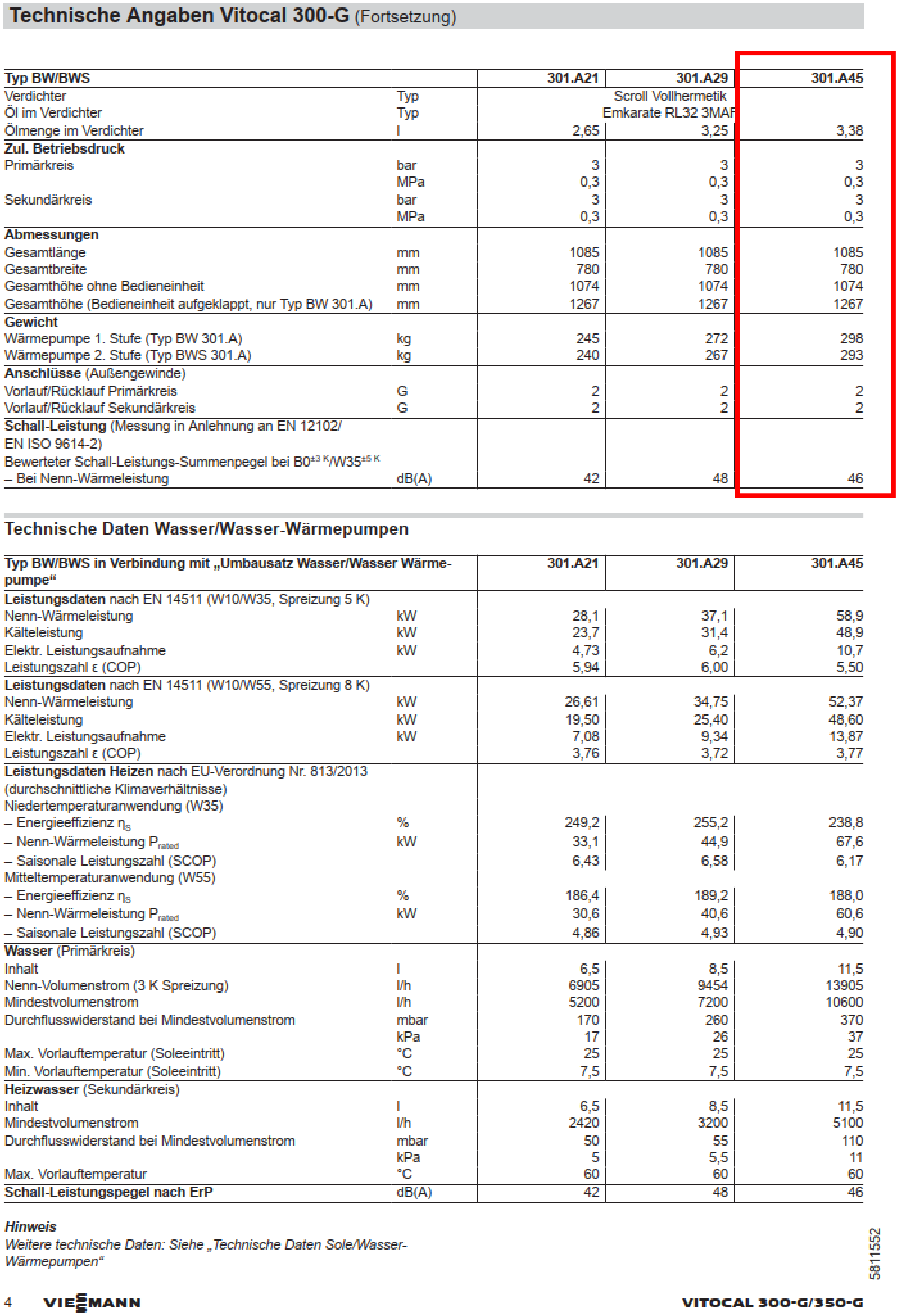
Technische Angaben Vitocal 300-G

Technische Daten Sole/Wasser-Wärmepumpen

Typ BW/BWS		**301.A21**	**301.A29**	**301.A45**
Leistungsdaten nach EN 14511 (B0/W35, Spreizung 5 K)				
Nenn-Wärmeleistung	kW	21,2	28,8	42,8
Kälteleistung	kW	17,0	23,3	34,2
Elektr. Leistungsaufnahme	kW	4,48	5,96	9,28
Leistungszahl ε (COP)		4,73	4,83	4,60
Leistungsdaten Heizen nach EU-Verordnung Nr. 813/2013 (durchschnittliche Klimaverhältnisse)				
Niedertemperaturanwendung (W35)				
– Energieeffizienz η_S	%	201	211	199
– Nenn-Wärmeleistung P_{rated}	kW	24	33	49
– Saisonale Leistungszahl (SCOP)		5,23	5,48	5,18
Mitteltemperaturanwendung (W55)				
– Energieeffizienz η_S	%	140	138	138
– Nenn-Wärmeleistung P_{rated}	kW	22	30	45
– Saisonale Leistungszahl (SCOP)		3,70	3,65	3,65
Energieeffizienzklasse nach EU-Verordnung Nr. 813/2013				
Heizen, durchschnittliche Klimaverhältnisse				
– Niedertemperaturanwendung (W35)		A^{++}	A^{++}	A^{++}
– Mitteltemperaturanwendung (W55)		A^{++}	A^{++}	A^{++}
Sole (Primärkreis)				
Inhalt	l	6,5	8,5	11,5
Mindestvolumenstrom	l/h	3300	4200	6500
Druckverlust bei Mindestvolumenstrom	mbar	70	95	154
	kPa	7	9,5	15,4
Max. Vorlauftemperatur (Soleeintritt)	°C	25	25	25
Min. Vorlauftemperatur (Soleeintritt)	°C	–10	–10	–10
Heizwasser (Sekundärkreis)				
Inhalt	l	6,5	8,5	11,5
Nenn-Volumenstrom	l/h	3740	5050	7360
Druckverlust bei Nenn-Volumenstrom	mbar	120	130	210
	kPa	12	13	21
Mindestvolumenstrom	l/h	1900	2550	3700
Druckverlust bei Mindestvolumenstrom	mbar	38	38	65
	kPa	3,8	3,8	6,5
Max. Vorlauftemperatur	°C	60	60	60
Elektrische Werte Wärmepumpe				
Nennspannung Verdichter	V	3/PE 400 V/50 Hz		
Nennstrom Verdichter	A	16	22	34
Cos φ		0,8	0,8	0,8
Anlaufstrom Verdichter (mit Anlaufstrombegrenzung)	A	< 30	41	47
Anlaufstrom Verdichter bei blockiertem Rotor	A	95	118	174
Absicherung Verdichter	A	1 x C16A 3-polig	1 x C25A 3-polig	1 x C40A 3-polig
Schutzklasse		I	I	I
Elektrische Werte Wärmepumpenregelung				
Nennspannung Regelung/Elektronik	V	1/N/PE 230 V/50 Hz		
Absicherung Regelung/Elektronik		1 x B16A		
Sicherung Regelung/Elektronik	A	T 6,3 A/250 V		
Schutzart		IP20	IP20	IP20
Elektrische Leistungsaufnahme				
Max. elektr. Leistungsaufnahme Wärmepumpenregelung/ Elektronik Wärmepumpe 1. Stufe (Typ BW 301.A)	W	25	25	25
Max. elektr. Leistungsaufnahme Elektronik Wärmepumpe 2. Stufe (Typ BWS 301.A)		20	20	20
Elektr. Leistungsaufnahme Wärmepumpenregelung/Elektronik Wärmepumpe 1. und 2. Stufe	W	45	45	45
Kältekreis				
Arbeitsmittel		R410A	R410A	R410A
– Sicherheitsgruppe		A1	A1	A1
– Füllmenge	kg	4,7	6,2	7,7
– Treibhauspotenzial (GWP)*1		1924	1924	1924
– CO_2-Äquivalent	t	9,0	11,9	14,8
Zul. Betriebsdruck Hochdruckseite	bar	43	43	43
	MPa	4,3	4,3	4,3
Zul. Betriebsdruck Niederdruckseite	bar	28	28	28
	MPa	2,8	2,8	2,8

*1 *Gestützt auf den Fünften Sachstandsbericht des Zwischenstaatlichen Ausschusses für Klimaänderungen (IPCC).*

5811552



Technische Angaben Vitocal 300-G (Fortsetzung)

Typ BW/BWS		301.A21	301.A29	301.A45
Verdichter	Typ	Scroll Vollhermetik		
Öl im Verdichter	Typ	Emkarate RL32 3MAF		
Ölmenge im Verdichter	l	2,65	3,25	3,38
Zul. Betriebsdruck				
Primärkreis	bar	3	3	3
	MPa	0,3	0,3	0,3
Sekundärkreis	bar	3	3	3
	MPa	0,3	0,3	0,3
Abmessungen				
Gesamtlänge	mm	1085	1085	1085
Gesamtbreite	mm	780	780	780
Gesamthöhe ohne Bedieneinheit	mm	1074	1074	1074
Gesamthöhe (Bedieneinheit aufgeklappt, nur Typ BW 301.A)	mm	1267	1267	1267
Gewicht				
Wärmepumpe 1. Stufe (Typ BW 301.A)	kg	245	272	298
Wärmepumpe 2. Stufe (Typ BWS 301.A)	kg	240	267	293
Anschlüsse (Außengewinde)				
Vorlauf/Rücklauf Primärkreis	G	2	2	2
Vorlauf/Rücklauf Sekundärkreis	G	2	2	2
Schall-Leistung (Messung in Anlehnung an EN 12102/ EN ISO 9614-2)				
Bewerteter Schall-Leistungs-Summenpegel bei $B0^{\pm 3\,K}/W35^{\pm 5\,K}$				
– Bei Nenn-Wärmeleistung	dB(A)	42	48	46

Technische Daten Wasser/Wasser-Wärmepumpen

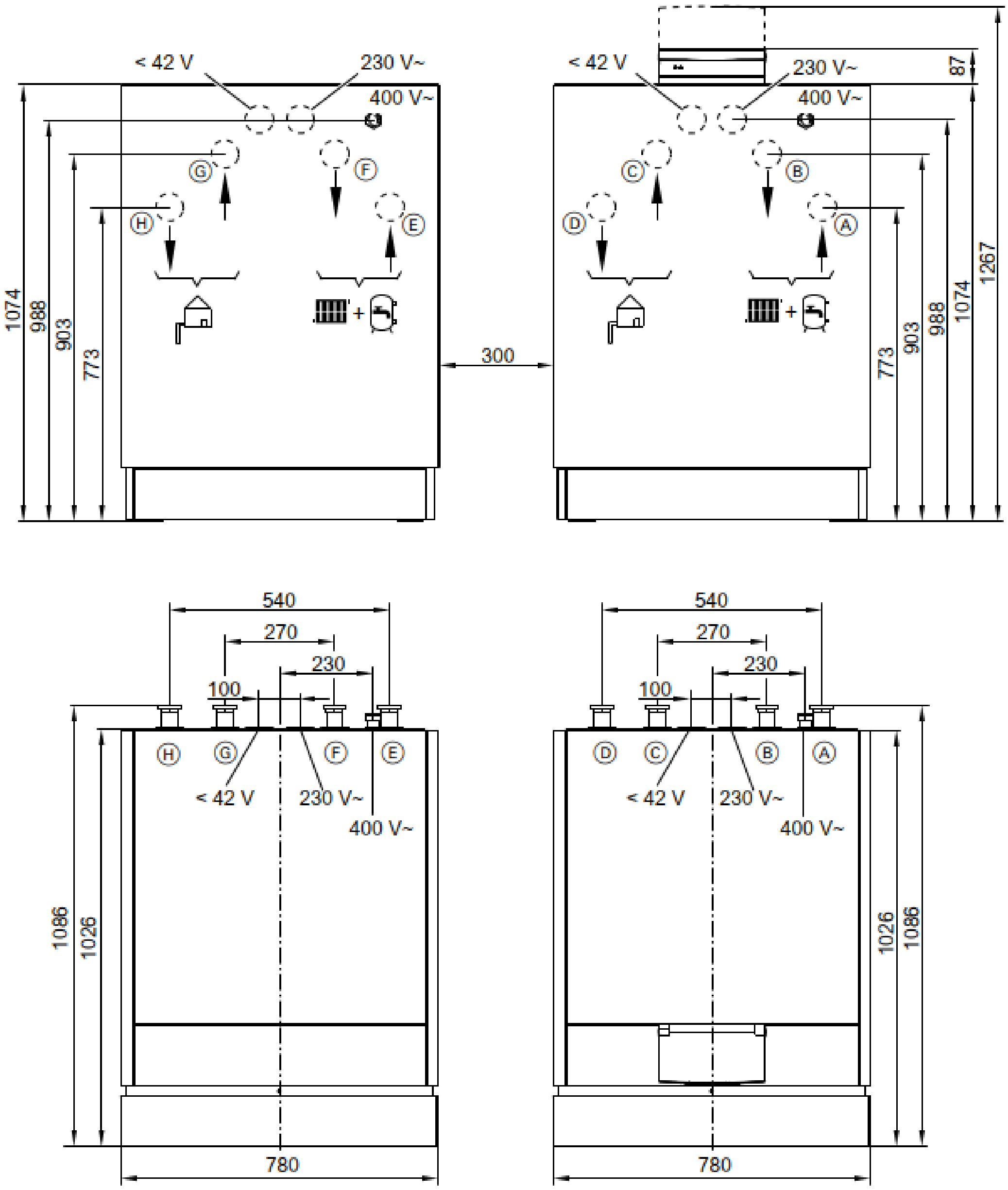
Typ BW/BWS in Verbindung mit „Umbausatz Wasser/Wasser Wärmepumpe“		301.A21	301.A29	301.A45
Leistungsdaten nach EN 14511 (W10/W35, Spreizung 5 K)				
Nenn-Wärmeleistung	kW	28,1	37,1	58,9
Kälteleistung	kW	23,7	31,4	48,9
Elektr. Leistungsaufnahme	kW	4,73	6,2	10,7
Leistungszahl ε (COP)		5,94	6,00	5,50
Leistungsdaten nach EN 14511 (W10/W55, Spreizung 8 K)				
Nenn-Wärmeleistung	kW	26,61	34,75	52,37
Kälteleistung	kW	19,50	25,40	48,60
Elektr. Leistungsaufnahme	kW	7,08	9,34	13,87
Leistungszahl ε (COP)		3,76	3,72	3,77
Leistungsdaten Heizen nach EU-Verordnung Nr. 813/2013 (durchschnittliche Klimaverhältnisse)				
Niedertemperaturanwendung (W35)				
– Energieeffizienz η_S	%	249,2	255,2	238,8
– Nenn-Wärmeleistung P_{rated}	kW	33,1	44,9	67,6
– Saisonale Leistungszahl (SCOP)		6,43	6,58	6,17
Mitteltemperaturanwendung (W55)				
– Energieeffizienz η_S	%	186,4	189,2	188,0
– Nenn-Wärmeleistung P_{rated}	kW	30,6	40,6	60,6
– Saisonale Leistungszahl (SCOP)		4,86	4,93	4,90
Wasser (Primärkreis)				
Inhalt	l	6,5	8,5	11,5
Nenn-Volumenstrom (3 K Spreizung)	l/h	6905	9454	13905
Mindestvolumenstrom	l/h	5200	7200	10600
Durchflusswiderstand bei Mindestvolumenstrom	mbar	170	260	370
	kPa	17	26	37
Max. Vorlauftemperatur (Soleeintritt)	°C	25	25	25
Min. Vorlauftemperatur (Soleeintritt)	°C	7,5	7,5	7,5
Heizwasser (Sekundärkreis)				
Inhalt	l	6,5	8,5	11,5
Mindestvolumenstrom	l/h	2420	3200	5100
Durchflusswiderstand bei Mindestvolumenstrom	mbar	50	55	110
	kPa	5	5,5	11
Max. Vorlauftemperatur	°C	60	60	60
Schall-Leistungspegel nach ErP	dB(A)	42	48	46

Hinweis

Weitere technische Daten: Siehe „Technische Daten Sole/Wasser-Wärmepumpen“

Technische Angaben Vitocal 300-G (Fortsetzung)

Abmessungen Typ BW 301.A21 bis A45, BWS 301.A21 bis A45



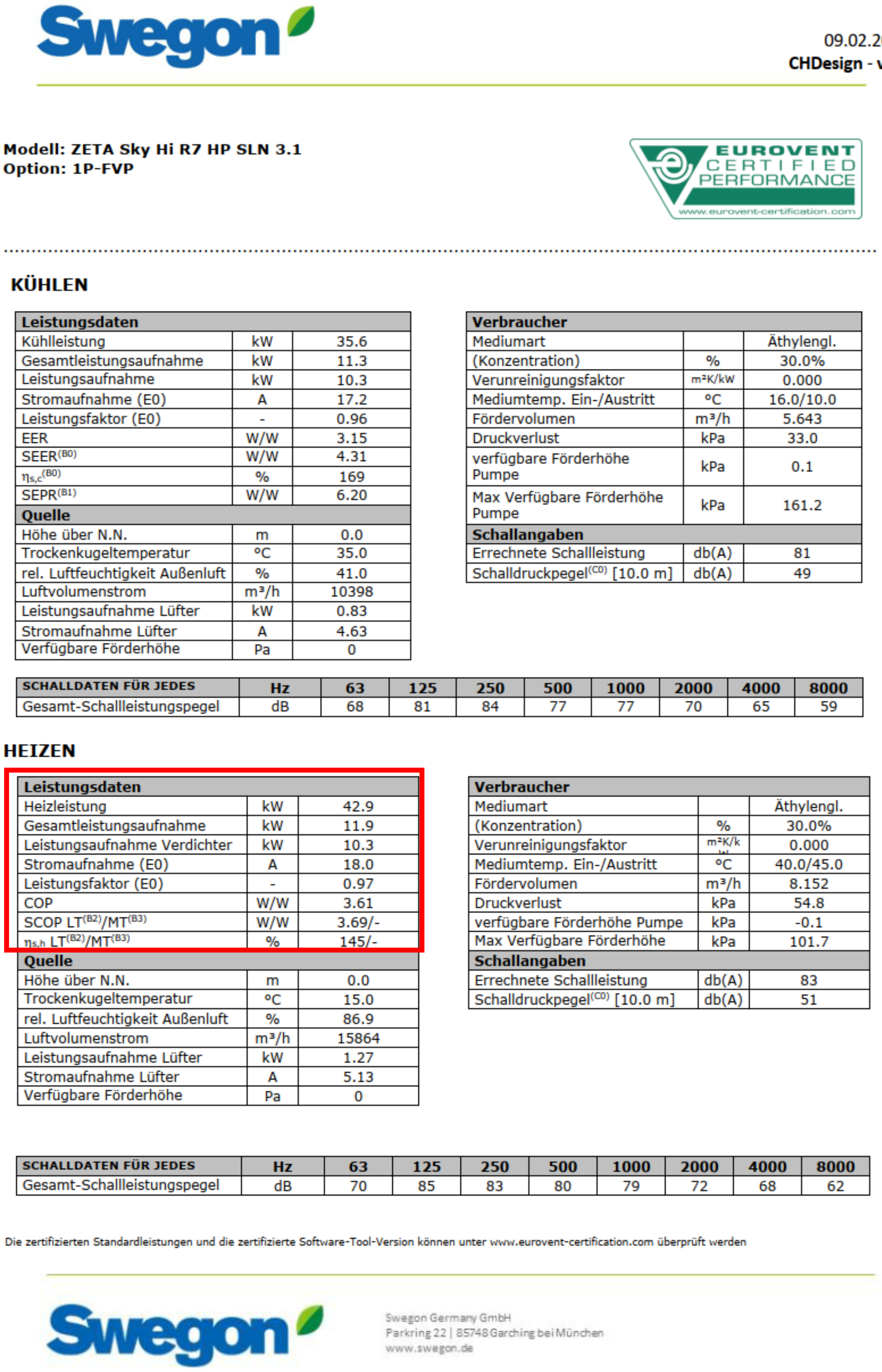
Links Typ BWS, rechts Typ BW

Ⓐ/Ⓔ	Rücklauf Sekundärkreis
Ⓑ/Ⓕ	Vorlauf Sekundärkreis
Ⓒ/Ⓖ	Vorlauf Primärkreis (Soleeintritt Wärmepumpe)
Ⓓ/Ⓗ	Rücklauf Primärkreis (Soleaustritt Wärmepumpe)

11.4.3 Data sheet: Air source heat pump (ASHP) - ZETA Sky Hi R7 HP SLN 3.1 (Swegon)

- 09/02/2024: Facilitated by B2B Customer Service Swegon

11.4.3.1 Design point 1: Outdoor air temperature at 15°C, Heating water at 45°C



Swegon

09.02.2024
CHDesign - v2.4

Modell: ZETA Sky Hi R7 HP SLN 3.1
Option: 1P-FVP

EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com

KÜHLEN

Leistungsdaten		
Kühlleistung	kW	35.6
Gesamtleistungsaufnahme	kW	11.3
Leistungsaufnahme	kW	10.3
Stromaufnahme (E0)	A	17.2
Leistungsfaktor (E0)	-	0.96
EER	W/W	3.15
SEER$^{(B0)}$	W/W	4.31
$\eta_{s,c}^{(B0)}$	%	169
SEPR$^{(B1)}$	W/W	6.20
Quelle		
Höhe über N.N.	m	0.0
Trockenkugeltemperatur	°C	35.0
rel. Luftfeuchtigkeit Außenluft	%	41.0
Luftvolumenstrom	m³/h	10398
Leistungsaufnahme Lüfter	kW	0.83
Stromaufnahme Lüfter	A	4.63
Verfügbare Förderhöhe	Pa	0

Verbraucher		
Mediumart		Äthylengl.
(Konzentration)	%	30.0%
Verunreinigungsfaktor	m²K/kW	0.000
Mediumtemp. Ein-/Austritt	°C	16.0/10.0
Fördervolumen	m³/h	5.643
Druckverlust	kPa	33.0
verfügbare Förderhöhe Pumpe	kPa	0.1
Max Verfügbare Förderhöhe Pumpe	kPa	161.2
Schallangaben		
Errechnete Schallleistung	db(A)	81
Schalldruckpegel$^{(C0)}$ [10.0 m]	db(A)	49

SCHALLDATEN FÜR JEDES	**Hz**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Gesamt-Schallleistungspegel	dB	68	81	84	77	77	70	65	59

HEIZEN

Leistungsdaten		
Heizleistung	kW	42.9
Gesamtleistungsaufnahme	kW	11.9
Leistungsaufnahme Verdichter	kW	10.3
Stromaufnahme (E0)	A	18.0
Leistungsfaktor (E0)	-	0.97
COP	W/W	3.61
SCOP LT$^{(B2)}$/MT$^{(B3)}$	W/W	3.69/-
$\eta_{s,h}$ LT$^{(B2)}$/MT$^{(B3)}$	%	145/-
Quelle		
Höhe über N.N.	m	0.0
Trockenkugeltemperatur	°C	15.0
rel. Luftfeuchtigkeit Außenluft	%	86.9
Luftvolumenstrom	m³/h	15864
Leistungsaufnahme Lüfter	kW	1.27
Stromaufnahme Lüfter	A	5.13
Verfügbare Förderhöhe	Pa	0

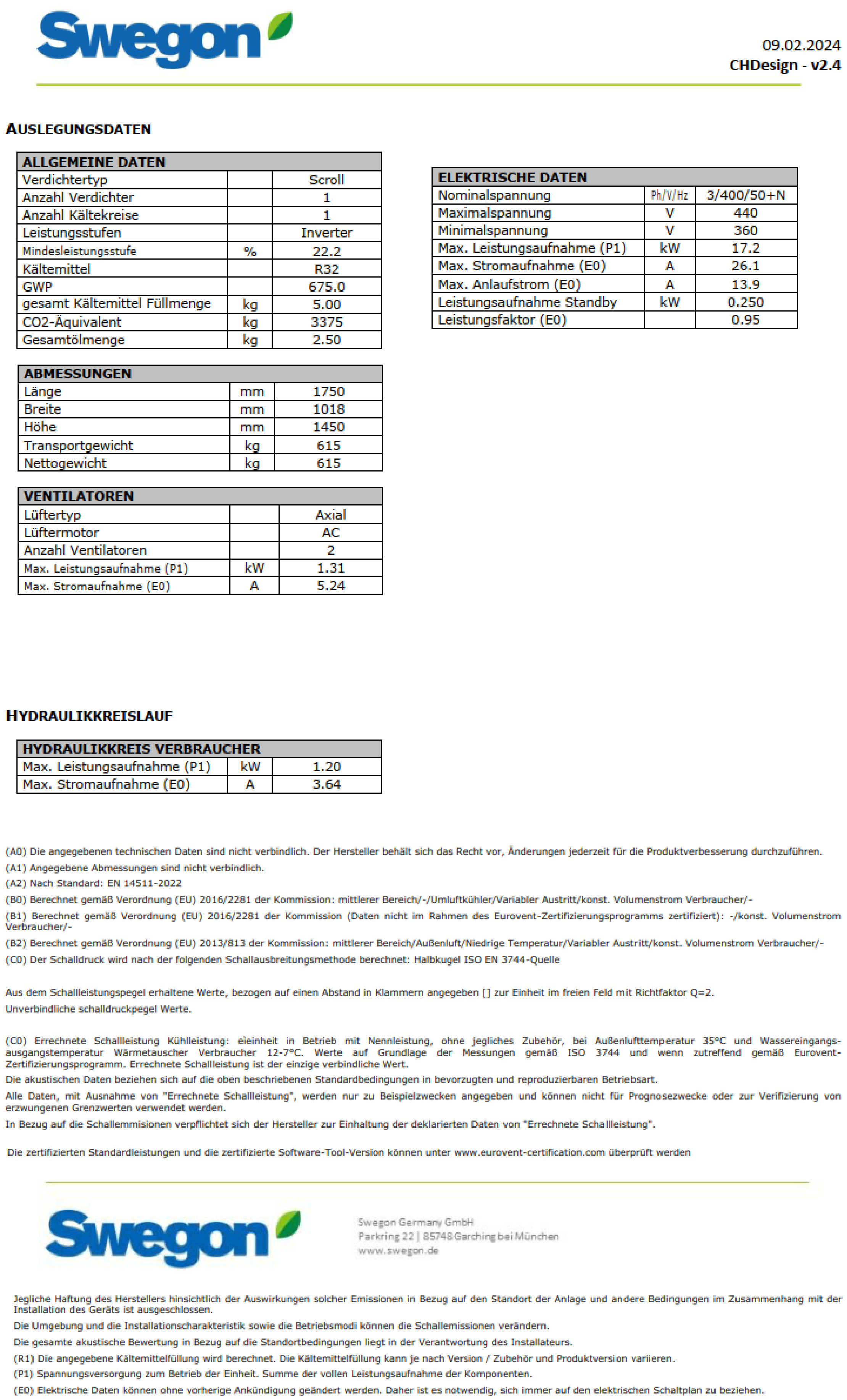
Verbraucher		
Mediumart		Äthylengl.
(Konzentration)	%	30.0%
Verunreinigungsfaktor	m²K/kW	0.000
Mediumtemp. Ein-/Austritt	°C	40.0/45.0
Fördervolumen	m³/h	8.152
Druckverlust	kPa	54.8
verfügbare Förderhöhe Pumpe	kPa	-0.1
Max Verfügbare Förderhöhe	kPa	101.7
Schallangaben		
Errechnete Schallleistung	db(A)	83
Schalldruckpegel$^{(C0)}$ [10.0 m]	db(A)	51

SCHALLDATEN FÜR JEDES	**Hz**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Gesamt-Schallleistungspegel	dB	70	85	83	80	79	72	68	62

Die zertifizierten Standardleistungen und die zertifizierte Software-Tool-Version können unter www.eurovent-certification.com überprüft werden

Swegon

Swegon Germany GmbH
Parkring 22 | 85748 Garching bei München
www.swegon.de



09.02.2024
CHDesign - v2.4

AUSLEGUNGSDATEN

ALLGEMEINE DATEN		
Verdichtertyp		Scroll
Anzahl Verdichter		1
Anzahl Kältekreise		1
Leistungsstufen		Inverter
Mindesleistungsstufe	%	22.2
Kältemittel		R32
GWP		675.0
gesamt Kältemittel Füllmenge	kg	5.00
CO2-Äquivalent	kg	3375
Gesamtölmenge	kg	2.50

ELEKTRISCHE DATEN		
Nominalspannung	Ph/V/Hz	3/400/50+N
Maximalspannung	V	440
Minimalspannung	V	360
Max. Leistungsaufnahme (P1)	kW	17.2
Max. Stromaufnahme (E0)	A	26.1
Max. Anlaufstrom (E0)	A	13.9
Leistungsaufnahme Standby	kW	0.250
Leistungsfaktor (E0)		0.95

ABMESSUNGEN		
Länge	mm	1750
Breite	mm	1018
Höhe	mm	1450
Transportgewicht	kg	615
Nettogewicht	kg	615

VENTILATOREN		
Lüftertyp		Axial
Lüftermotor		AC
Anzahl Ventilatoren		2
Max. Leistungsaufnahme (P1)	kW	1.31
Max. Stromaufnahme (E0)	A	5.24

HYDRAULIKKREISLAUF

HYDRAULIKKREIS VERBRAUCHER		
Max. Leistungsaufnahme (P1)	kW	1.20
Max. Stromaufnahme (E0)	A	3.64

(A0) Die angegebenen technischen Daten sind nicht verbindlich. Der Hersteller behält sich das Recht vor, Änderungen jederzeit für die Produktverbesserung durchzuführen.

(A1) Angegebene Abmessungen sind nicht verbindlich.

(A2) Nach Standard: EN 14511-2022

(B0) Berechnet gemäß Verordnung (EU) 2016/2281 der Kommission: mittlerer Bereich/-/Umluftkühler/Variabler Austritt/konst. Volumenstrom Verbraucher/-

(B1) Berechnet gemäß Verordnung (EU) 2016/2281 der Kommission (Daten nicht im Rahmen des Eurovent-Zertifizierungsprogramms zertifiziert): -/konst. Volumenstrom Verbraucher/-

(B2) Berechnet gemäß Verordnung (EU) 2013/813 der Kommission: mittlerer Bereich/Außenluft/Niedrige Temperatur/Variabler Austritt/konst. Volumenstrom Verbraucher/-

(C0) Der Schalldruck wird nach der folgenden Schallausbreitungsmethode berechnet: Halbkugel ISO EN 3744-Quelle

Aus dem Schallleistungspegel erhaltene Werte, bezogen auf einen Abstand in Klammern angegeben [] zur Einheit im freien Feld mit Richtfaktor Q=2.

Unverbindliche schalldruckpegel Werte.

(C0) Errechnete Schallleistung Kühlleistung: eieinheit in Betrieb mit Nennleistung, ohne jegliches Zubehör, bei Außenlufttemperatur 35°C und Wassereingangs-ausgangstemperatur Wärmetauscher Verbraucher 12-7°C. Werte auf Grundlage der Messungen gemäß ISO 3744 und wenn zutreffend gemäß Eurovent-Zertifizierungsprogramm. Errechnete Schallleistung ist der einzige verbindliche Wert.

Die akustischen Daten beziehen sich auf die oben beschriebenen Standardbedingungen in bevorzugten und reproduzierbaren Betriebsart.

Alle Daten, mit Ausnahme von "Errechnete Schallleistung", werden nur zu Beispielzwecken angegeben und können nicht für Prognosezwecke oder zur Verifizierung von erzwungenen Grenzwerten verwendet werden.

In Bezug auf die Schallemmisionen verpflichtet sich der Hersteller zur Einhaltung der deklarierten Daten von "Errechnete Schallleistung".

Die zertifizierten Standardleistungen und die zertifizierte Software-Tool-Version können unter www.eurovent-certification.com überprüft werden

Swegon Germany GmbH
Parkring 22 | 85748 Garching bei München
www.swegon.de

Jegliche Haftung des Herstellers hinsichtlich der Auswirkungen solcher Emissionen in Bezug auf den Standort der Anlage und andere Bedingungen im Zusammenhang mit der Installation des Geräts ist ausgeschlossen.

Die Umgebung und die Installationscharakteristik sowie die Betriebsmodi können die Schallemissionen verändern.

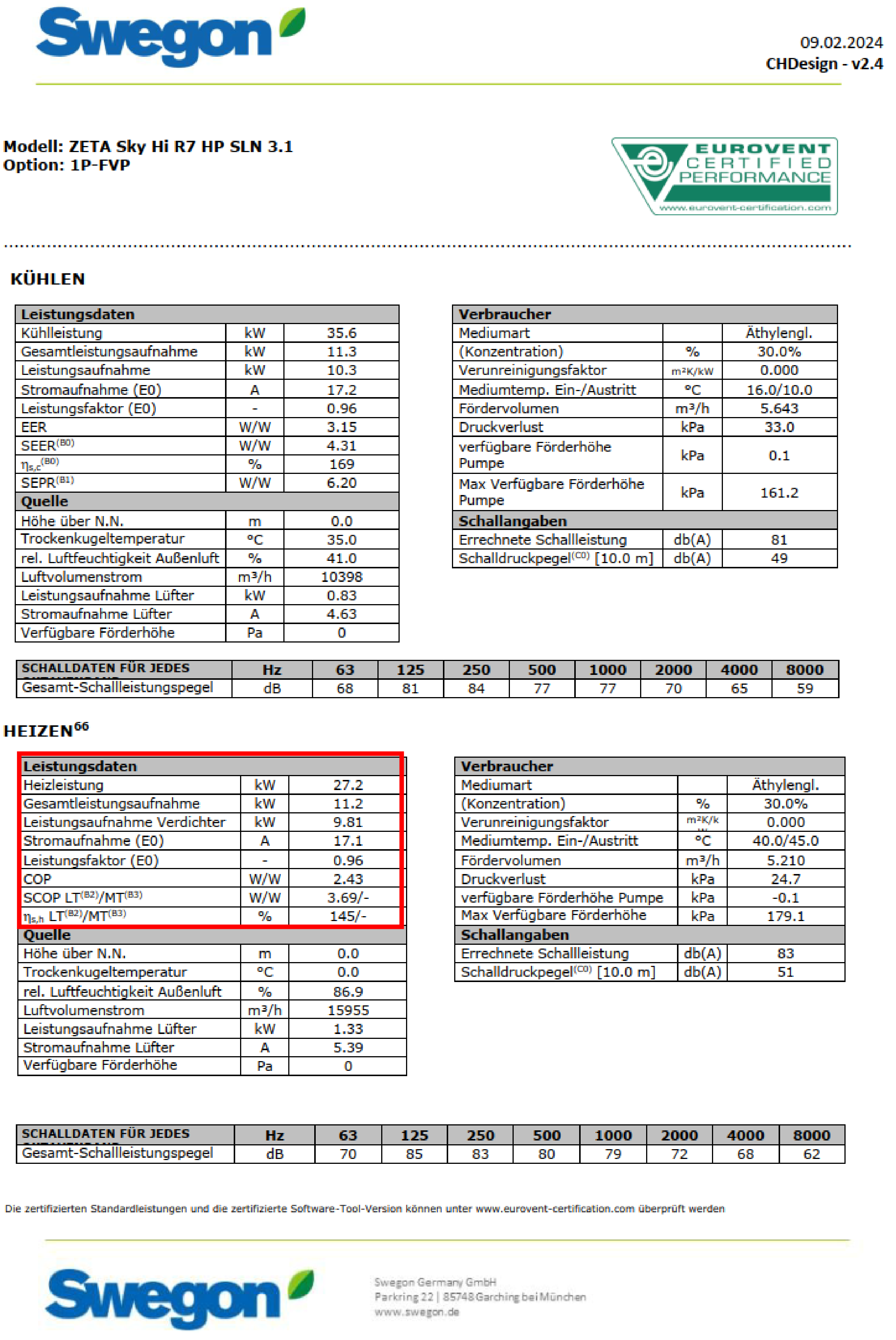
Die gesamte akustische Bewertung in Bezug auf die Standortbedingungen liegt in der Verantwortung des Installateurs.

(R1) Die angegebene Kältemittelfüllung wird berechnet. Die Kältemittelfüllung kann je nach Version / Zubehör und Produktversion variieren.

(P1) Spannungsversorgung zum Betrieb der Einheit. Summe der vollen Leistungsaufnahme der Komponenten.

(E0) Elektrische Daten können ohne vorherige Ankündigung geändert werden. Daher ist es notwendig, sich immer auf den elektrischen Schaltplan zu beziehen.

11.4.3.2 Design point 2: Outdoor air temperature at 0°C, Heating water at 45°C



09.02.2024
CHDesign - v2.4

Modell: ZETA Sky Hi R7 HP SLN 3.1
Option: 1P-FVP

EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com

KÜHLEN

Leistungsdaten		
Kühlleistung	kW	35.6
Gesamtleistungsaufnahme	kW	11.3
Leistungsaufnahme	kW	10.3
Stromaufnahme (E0)	A	17.2
Leistungsfaktor (E0)	-	0.96
EER	W/W	3.15
SEER(B0)	W/W	4.31
$\eta_{s,c}$(B0)	%	169
SEPR(B1)	W/W	6.20
Quelle		
Höhe über N.N.	m	0.0
Trockenkugeltemperatur	°C	35.0
rel. Luftfeuchtigkeit Außenluft	%	41.0
Luftvolumenstrom	m³/h	10398
Leistungsaufnahme Lüfter	kW	0.83
Stromaufnahme Lüfter	A	4.63
Verfügbare Förderhöhe	Pa	0

Verbraucher		
Mediumart		Äthylengl.
(Konzentration)	%	30.0%
Verunreinigungsfaktor	m²K/kW	0.000
Mediumtemp. Ein-/Austritt	°C	16.0/10.0
Fördervolumen	m³/h	5.643
Druckverlust	kPa	33.0
verfügbare Förderhöhe Pumpe	kPa	0.1
Max Verfügbare Förderhöhe Pumpe	kPa	161.2
Schallangaben		
Errechnete Schallleistung	db(A)	81
Schalldruckpegel(C0) [10.0 m]	db(A)	49

SCHALLDATEN FÜR JEDES	Hz	63	125	250	500	1000	2000	4000	8000
Gesamt-Schallleistungspegel	dB	68	81	84	77	77	70	65	59

HEIZEN[66]

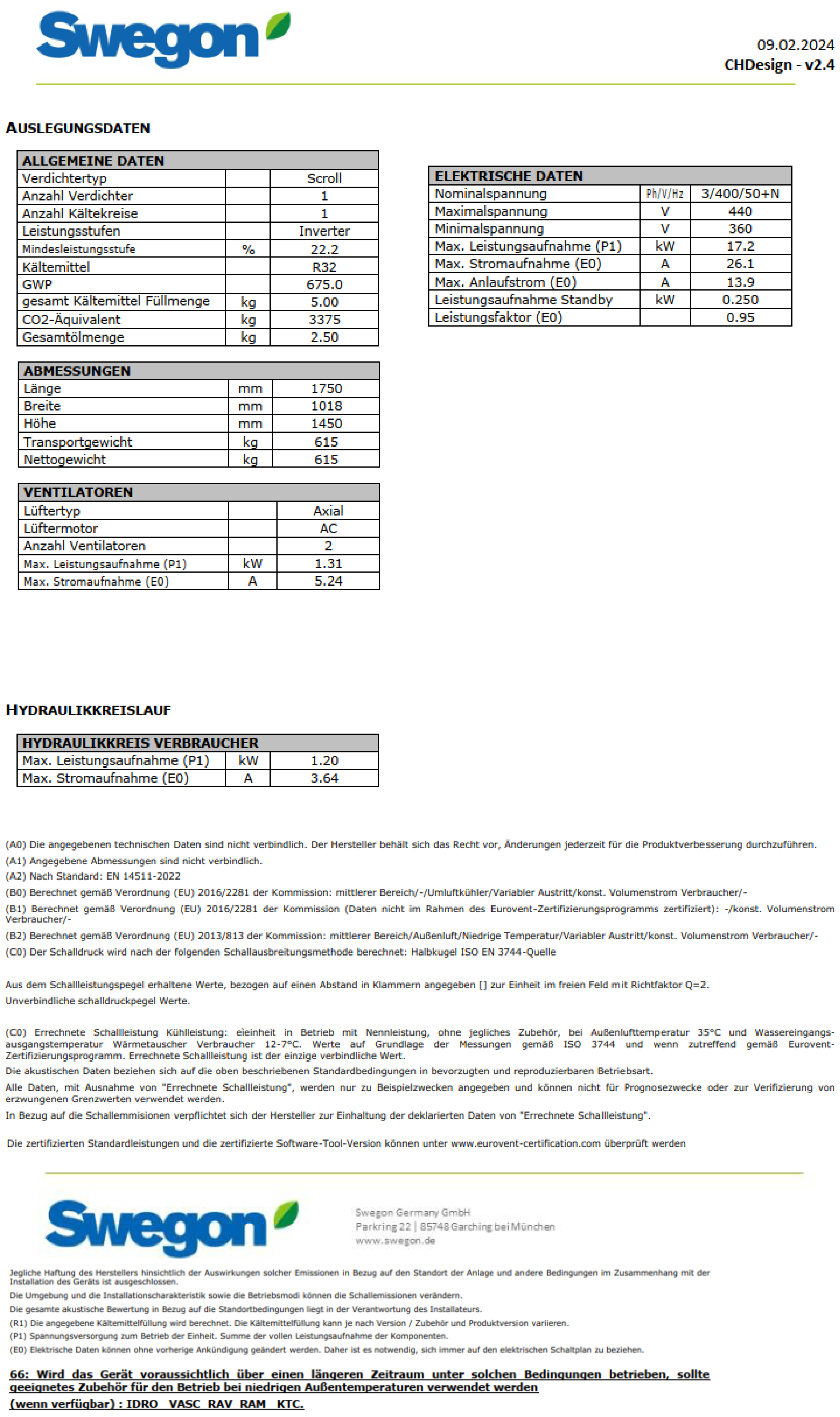
Leistungsdaten		
Heizleistung	kW	27.2
Gesamtleistungsaufnahme	kW	11.2
Leistungsaufnahme Verdichter	kW	9.81
Stromaufnahme (E0)	A	17.1
Leistungsfaktor (E0)	-	0.96
COP	W/W	2.43
SCOP LT(B2)/MT(B3)	W/W	3.69/-
$\eta_{s,h}$ LT(B2)/MT(B3)	%	145/-
Quelle		
Höhe über N.N.	m	0.0
Trockenkugeltemperatur	°C	0.0
rel. Luftfeuchtigkeit Außenluft	%	86.9
Luftvolumenstrom	m³/h	15955
Leistungsaufnahme Lüfter	kW	1.33
Stromaufnahme Lüfter	A	5.39
Verfügbare Förderhöhe	Pa	0

Verbraucher		
Mediumart		Äthylengl.
(Konzentration)	%	30.0%
Verunreinigungsfaktor	m²K/k	0.000
Mediumtemp. Ein-/Austritt	°C	40.0/45.0
Fördervolumen	m³/h	5.210
Druckverlust	kPa	24.7
verfügbare Förderhöhe Pumpe	kPa	-0.1
Max Verfügbare Förderhöhe	kPa	179.1
Schallangaben		
Errechnete Schallleistung	db(A)	83
Schalldruckpegel(C0) [10.0 m]	db(A)	51

SCHALLDATEN FÜR JEDES	Hz	63	125	250	500	1000	2000	4000	8000
Gesamt-Schallleistungspegel	dB	70	85	83	80	79	72	68	62

Die zertifizierten Standardleistungen und die zertifizierte Software-Tool-Version können unter www.eurovent-certification.com überprüft werden

Swegon Germany GmbH
Parkring 22 | 85748 Garching bei München
www.swegon.de



09.02.2024
CHDesign - v2.4

AUSLEGUNGSDATEN

ALLGEMEINE DATEN		
Verdichtertyp		Scroll
Anzahl Verdichter		1
Anzahl Kältekreise		1
Leistungsstufen		Inverter
Mindesleistungsstufe	%	22.2
Kältemittel		R32
GWP		675.0
gesamt Kältemittel Füllmenge	kg	5.00
CO2-Äquivalent	kg	3375
Gesamtölmenge	kg	2.50

ELEKTRISCHE DATEN		
Nominalspannung	Ph/V/Hz	3/400/50+N
Maximalspannung	V	440
Minimalspannung	V	360
Max. Leistungsaufnahme (P1)	kW	17.2
Max. Stromaufnahme (E0)	A	26.1
Max. Anlaufstrom (E0)	A	13.9
Leistungsaufnahme Standby	kW	0.250
Leistungsfaktor (E0)		0.95

ABMESSUNGEN		
Länge	mm	1750
Breite	mm	1018
Höhe	mm	1450
Transportgewicht	kg	615
Nettogewicht	kg	615

VENTILATOREN		
Lüftertyp		Axial
Lüftermotor		AC
Anzahl Ventilatoren		2
Max. Leistungsaufnahme (P1)	kW	1.31
Max. Stromaufnahme (E0)	A	5.24

HYDRAULIKKREISLAUF

HYDRAULIKKREIS VERBRAUCHER		
Max. Leistungsaufnahme (P1)	kW	1.20
Max. Stromaufnahme (E0)	A	3.64

(A0) Die angegebenen technischen Daten sind nicht verbindlich. Der Hersteller behält sich das Recht vor, Änderungen jederzeit für die Produktverbesserung durchzuführen.

(A1) Angegebene Abmessungen sind nicht verbindlich.

(A2) Nach Standard: EN 14511-2022

(B0) Berechnet gemäß Verordnung (EU) 2016/2281 der Kommission: mittlerer Bereich/-/Umluftkühler/Variabler Austritt/konst. Volumenstrom Verbraucher/-

(B1) Berechnet gemäß Verordnung (EU) 2016/2281 der Kommission (Daten nicht im Rahmen des Eurovent-Zertifizierungsprogramms zertifiziert): -/konst. Volumenstrom Verbraucher/-

(B2) Berechnet gemäß Verordnung (EU) 2013/813 der Kommission: mittlerer Bereich/Außenluft/Niedrige Temperatur/Variabler Austritt/konst. Volumenstrom Verbraucher/-

(C0) Der Schalldruck wird nach der folgenden Schallausbreitungsmethode berechnet: Halbkugel ISO EN 3744-Quelle

Aus dem Schallleistungspegel erhaltene Werte, bezogen auf einen Abstand in Klammern angegeben [] zur Einheit im freien Feld mit Richtfaktor Q=2.

Unverbindliche schalldruckpegel Werte.

(C0) Errechnete Schallleistung Kühlleistung: eieinheit in Betrieb mit Nennleistung, ohne jegliches Zubehör, bei Außenlufttemperatur 35°C und Wassereingangs-ausgangstemperatur Wärmetauscher Verbraucher 12-7°C. Werte auf Grundlage der Messungen gemäß ISO 3744 und wenn zutreffend gemäß Eurovent-Zertifizierungsprogramm. Errechnete Schallleistung ist der einzige verbindliche Wert.

Die akustischen Daten beziehen sich auf die oben beschriebenen Standardbedingungen in bevorzugten und reproduzierbaren Betriebsart.

Alle Daten, mit Ausnahme von "Errechnete Schallleistung", werden nur zu Beispielzwecken angegeben und können nicht für Prognosezwecke oder zur Verifizierung von erzwungenen Grenzwerten verwendet werden.

In Bezug auf die Schallemmisionen verpflichtet sich der Hersteller zur Einhaltung der deklarierten Daten von "Errechnete Schallleistung".

Die zertifizierten Standardleistungen und die zertifizierte Software-Tool-Version können unter www.eurovent-certification.com überprüft werden

Swegon Germany GmbH
Parkring 22 | 85748 Garching bei München
www.swegon.de

Jegliche Haftung des Herstellers hinsichtlich der Auswirkungen solcher Emissionen in Bezug auf den Standort der Anlage und andere Bedingungen im Zusammenhang mit der Installation des Geräts ist ausgeschlossen.

Die Umgebung und die Installationscharakteristik sowie die Betriebsmodi können die Schallemissionen verändern.

Die gesamte akustische Bewertung in Bezug auf die Standortbedingungen liegt in der Verantwortung des Installateurs.

(R1) Die angegebene Kältemittelfüllung wird berechnet. Die Kältemittelfüllung kann je nach Version / Zubehör und Produktversion variieren.

(P1) Spannungsversorgung zum Betrieb der Einheit. Summe der vollen Leistungsaufnahme der Komponenten.

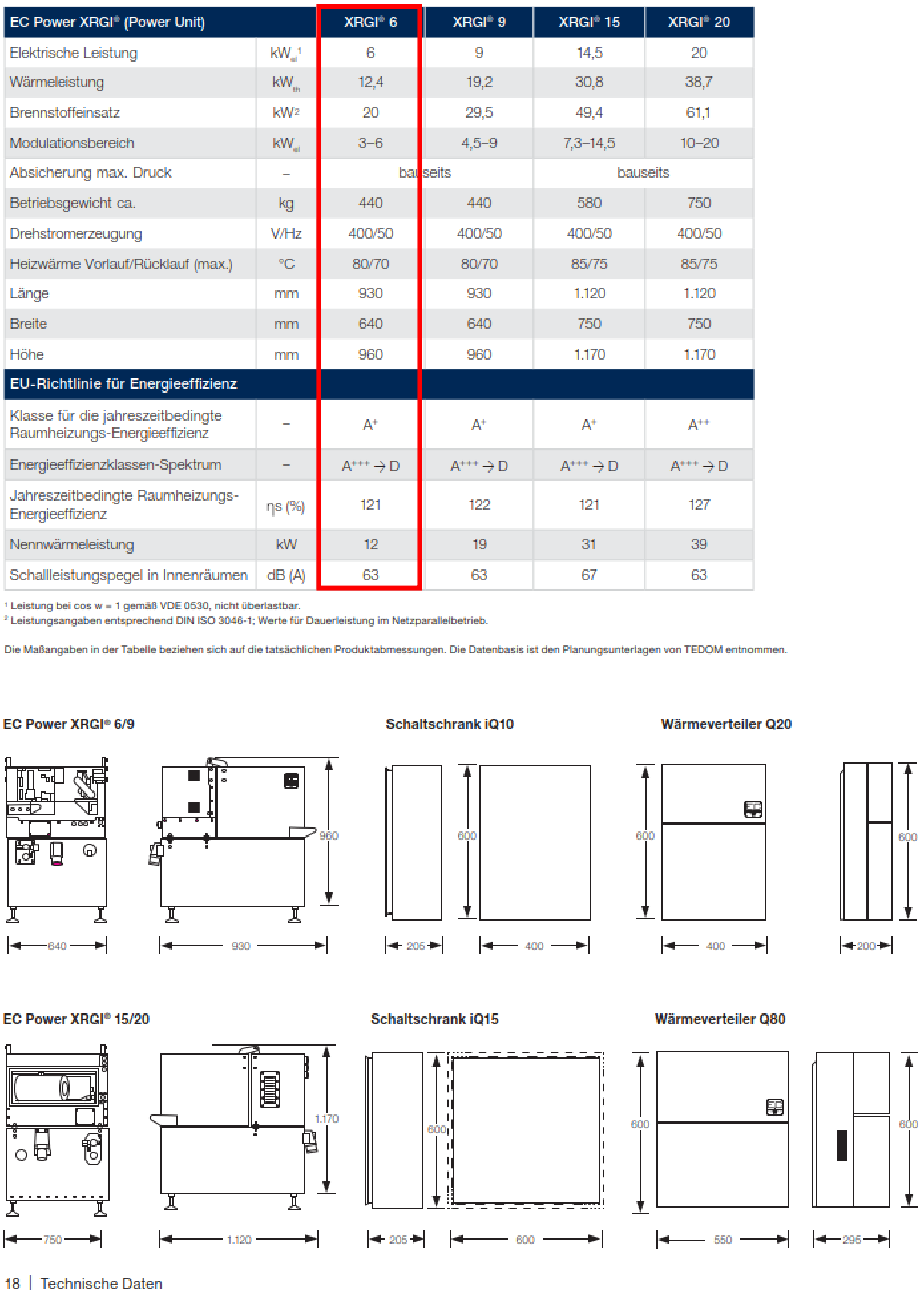
(E0) Elektrische Daten können ohne vorherige Ankündigung geändert werden. Daher ist es notwendig, sich immer auf den elektrischen Schaltplan zu beziehen.

66: Wird das Gerät voraussichtlich über einen längeren Zeitraum unter solchen Bedingungen betrieben, sollte geeignetes Zubehör für den Betrieb bei niedrigen Außentemperaturen verwendet werden

(wenn verfügbar) : IDRO VASC RAV RAM KTC.

11.4.4 Data sheet: Combined Heat and Power (CHP) – EC Power XRGI 6 (Buderus)

- 20/12/2023: Extracted from (Buderus GmbH, 2021)



EC Power XRGI® (Power Unit)		XRGI® 6	XRGI® 9	XRGI® 15	XRGI® 20
Elektrische Leistung	kW_{el}[1]	6	9	14,5	20
Wärmeleistung	kW_{th}	12,4	19,2	30,8	38,7
Brennstoffeinsatz	kW[2]	20	29,5	49,4	61,1
Modulationsbereich	kW_{el}	3–6	4,5–9	7,3–14,5	10–20
Absicherung max. Druck	–	bauseits		bauseits	
Betriebsgewicht ca.	kg	440	440	580	750
Drehstromerzeugung	V/Hz	400/50	400/50	400/50	400/50
Heizwärme Vorlauf/Rücklauf (max.)	°C	80/70	80/70	85/75	85/75
Länge	mm	930	930	1.120	1.120
Breite	mm	640	640	750	750
Höhe	mm	960	960	1.170	1.170
EU-Richtlinie für Energieeffizienz					
Klasse für die jahreszeitbedingte Raumheizungs-Energieeffizienz	–	A⁺	A⁺	A⁺	A⁺⁺
Energieeffizienzklassen-Spektrum	–	A⁺⁺⁺ → D	A⁺⁺⁺ → D	A⁺⁺⁺ → D	A⁺⁺⁺ → D
Jahreszeitbedingte Raumheizungs-Energieeffizienz	ηs (%)	121	122	121	127
Nennwärmeleistung	kW	12	19	31	39
Schallleistungspegel in Innenräumen	dB (A)	63	63	67	63

[1] Leistung bei cos w = 1 gemäß VDE 0530, nicht überlastbar.

[2] Leistungsangaben entsprechend DIN ISO 3046-1; Werte für Dauerleistung im Netzparallelbetrieb.

Die Maßangaben in der Tabelle beziehen sich auf die tatsächlichen Produktabmessungen. Die Datenbasis ist den Planungsunterlagen von TEDOM entnommen.

EC Power XRGI® 6/9

Schaltschrank iQ10

Wärmeverteiler Q20

EC Power XRGI® 15/20

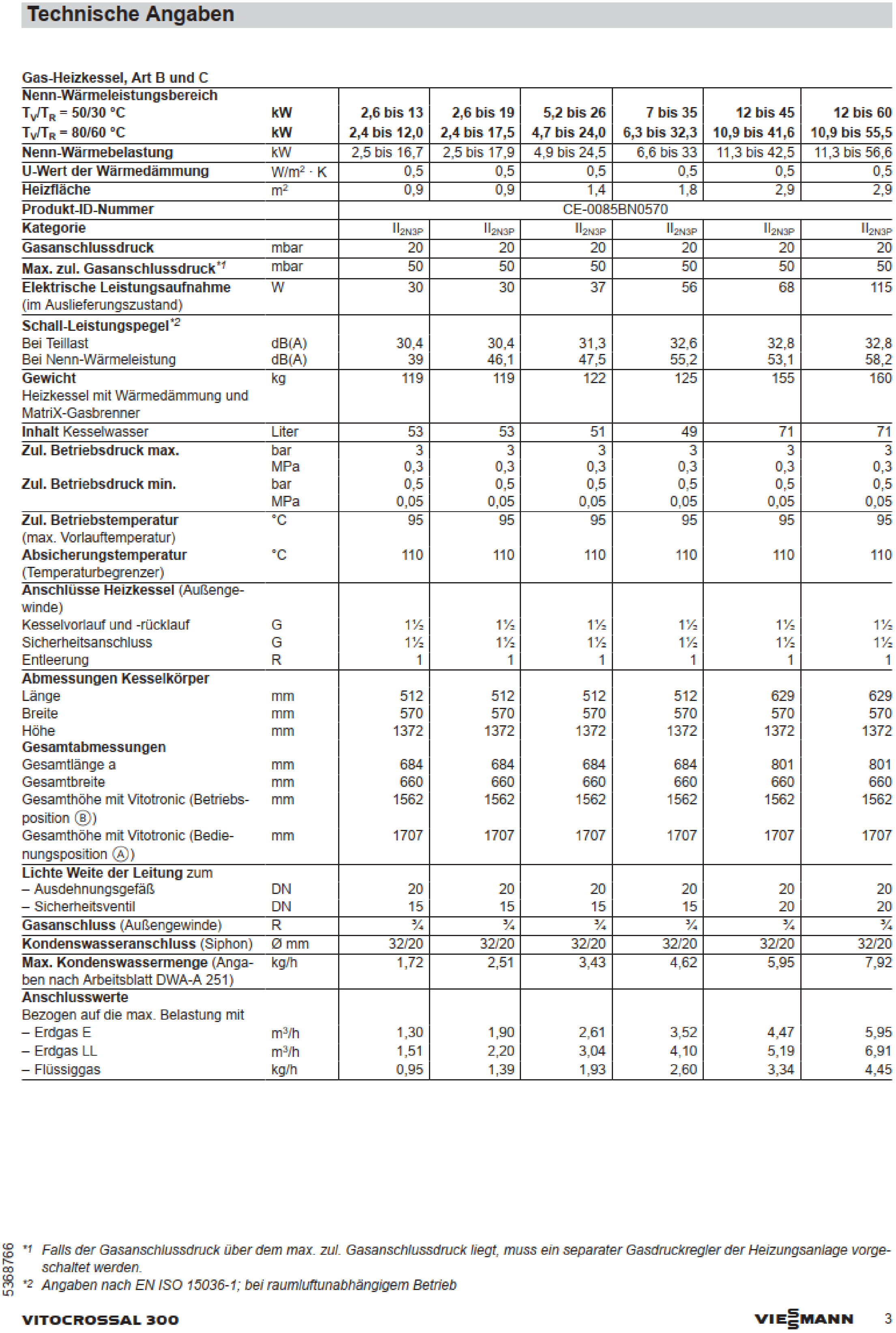
Schaltschrank iQ15

Wärmeverteiler Q80

18 | Technische Daten

11.4.5 Data sheet: Condensing gas boiler – Vitocrossal 300 - 35 kW (Viessmann)

- 02/02/2024: Extracted from (Viessmann Climate Solutions SE, 2022)



Technische Angaben

Gas-Heizkessel, Art B und C

Nenn-Wärmeleistungsbereich							
T_V/T_R = 50/30 °C	**kW**	**2,6 bis 13**	**2,6 bis 19**	**5,2 bis 26**	**7 bis 35**	**12 bis 45**	**12 bis 60**
T_V/T_R = 80/60 °C	**kW**	**2,4 bis 12,0**	**2,4 bis 17,5**	**4,7 bis 24,0**	**6,3 bis 32,3**	**10,9 bis 41,6**	**10,9 bis 55,5**
Nenn-Wärmebelastung	kW	2,5 bis 16,7	2,5 bis 17,9	4,9 bis 24,5	6,6 bis 33	11,3 bis 42,5	11,3 bis 56,6
U-Wert der Wärmedämmung	W/m² · K	0,5	0,5	0,5	0,5	0,5	0,5
Heizfläche	m²	0,9	0,9	1,4	1,8	2,9	2,9
Produkt-ID-Nummer		CE-0085BN0570					
Kategorie		II_{2N3P}	II_{2N3P}	II_{2N3P}	II_{2N3P}	II_{2N3P}	II_{2N3P}
Gasanschlussdruck	mbar	20	20	20	20	20	20
Max. zul. Gasanschlussdruck[*1]	mbar	50	50	50	50	50	50
Elektrische Leistungsaufnahme (im Auslieferungszustand)	W	30	30	37	56	68	115
Schall-Leistungspegel[*2]							
Bei Teillast	dB(A)	30,4	30,4	31,3	32,6	32,8	32,8
Bei Nenn-Wärmeleistung	dB(A)	39	46,1	47,5	55,2	53,1	58,2
Gewicht Heizkessel mit Wärmedämmung und MatriX-Gasbrenner	kg	119	119	122	125	155	160
Inhalt Kesselwasser	Liter	53	53	51	49	71	71
Zul. Betriebsdruck max.	bar	3	3	3	3	3	3
	MPa	0,3	0,3	0,3	0,3	0,3	0,3
Zul. Betriebsdruck min.	bar	0,5	0,5	0,5	0,5	0,5	0,5
	MPa	0,05	0,05	0,05	0,05	0,05	0,05
Zul. Betriebstemperatur (max. Vorlauftemperatur)	°C	95	95	95	95	95	95
Absicherungstemperatur (Temperaturbegrenzer)	°C	110	110	110	110	110	110
Anschlüsse Heizkessel (Außengewinde)							
Kesselvorlauf und -rücklauf	G	1½	1½	1½	1½	1½	1½
Sicherheitsanschluss	G	1½	1½	1½	1½	1½	1½
Entleerung	R	1	1	1	1	1	1
Abmessungen Kesselkörper							
Länge	mm	512	512	512	512	629	629
Breite	mm	570	570	570	570	570	570
Höhe	mm	1372	1372	1372	1372	1372	1372
Gesamtabmessungen							
Gesamtlänge a	mm	684	684	684	684	801	801
Gesamtbreite	mm	660	660	660	660	660	660
Gesamthöhe mit Vitotronic (Betriebsposition Ⓑ)	mm	1562	1562	1562	1562	1562	1562
Gesamthöhe mit Vitotronic (Bedienungsposition Ⓐ)	mm	1707	1707	1707	1707	1707	1707
Lichte Weite der Leitung zum							
– Ausdehnungsgefäß	DN	20	20	20	20	20	20
– Sicherheitsventil	DN	15	15	15	15	20	20
Gasanschluss (Außengewinde)	R	¾	¾	¾	¾	¾	¾
Kondenswasseranschluss (Siphon)	Ø mm	32/20	32/20	32/20	32/20	32/20	32/20
Max. Kondenswassermenge (Angaben nach Arbeitsblatt DWA-A 251)	kg/h	1,72	2,51	3,43	4,62	5,95	7,92
Anschlusswerte							
Bezogen auf die max. Belastung mit							
– Erdgas E	m³/h	1,30	1,90	2,61	3,52	4,47	5,95
– Erdgas LL	m³/h	1,51	2,20	3,04	4,10	5,19	6,91
– Flüssiggas	kg/h	0,95	1,39	1,93	2,60	3,34	4,45

[*1] *Falls der Gasanschlussdruck über dem max. zul. Gasanschlussdruck liegt, muss ein separater Gasdruckregler der Heizungsanlage vorgeschaltet werden.*

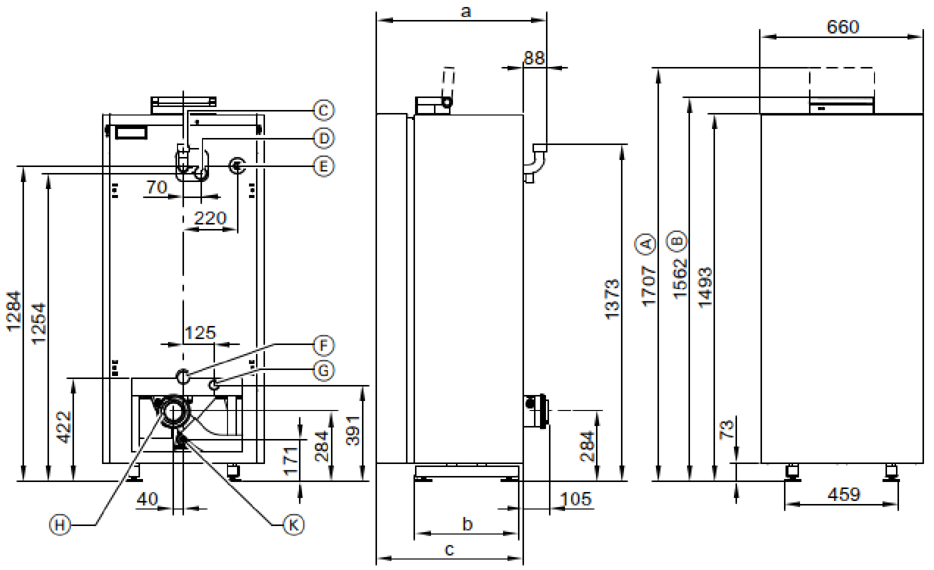
[*2] *Angaben nach EN ISO 15036-1; bei raumluftunabhängigem Betrieb*

5368766

VITOCROSSAL 300 VIESSMANN 3

Technische Angaben (Fortsetzung)

Gas-Heizkessel, Art B und C							
Nenn-Wärmeleistungsbereich							
T_V/T_R = 50/30 °C	**kW**	**2,6 bis 13**	**2,6 bis 19**	**5,2 bis 26**	**7 bis 35**	**12 bis 45**	**12 bis 60**
T_V/T_R = 80/60 °C	**kW**	**2,4 bis 12,0**	**2,4 bis 17,5**	**4,7 bis 24,0**	**6,3 bis 32,3**	**10,9 bis 41,6**	**10,9 bis 55,5**
Abgaskennwerte[*3]							
Temperatur (bei Rücklauftemperatur 30 °C)							
– Bei Nenn-Wärmeleistung	°C	45	45	45	45	45	45
– Bei unterer Wärmeleistung	°C	32	32	32	32	32	32
Temperatur (bei Rücklauftemperatur 60 °C)	°C	75	75	75	75	75	75
Massestrom bei Erdgas							
– Bei Nenn-Wärmeleistung	kg/h	23	34	46	62	80	106
– Bei unterer Wärmeleistung	kg/h	5	5	9	12	21	21
Massestrom bei Flüssiggas							
– Bei Nenn-Wärmeleistung	kg/h	21	30	41	56	72	96
– Bei unterer Wärmeleistung	kg/h	4	4	8	11	19	19
CO_2 Emissionen bei Erdgas							
– Bei Nenn-Wärmeleistung	%	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2
– Bei unterer Wärmeleistung	%	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2	7,7 bis 9,2
CO_2 Emissionen bei Flüssiggas							
– Bei Nenn-Wärmeleistung	%	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9
– Bei unterer Wärmeleistung	%	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9	9,3 bis 10,9
Verfügbarer Förderdruck am Abgasstutzen	Pa mbar	130 1,3	130 1,3	130 1,3	130 1,3	130 1,3	130 1,3
NOx-Klasse (EN 15502)	%	6	6	6	6	6	6
Abgasanschluss	∅ mm	80	80	80	80	110	110
Innendurchmesser Kesselanschluss-Stück	∅ mm	80,5 +0,8/-0	80,5 +0,8/-0	80,5 +0,8/-0	80,5 +0,8/-0	110,5 +0,8/-0	110,5 +0,8/-0
Zuluftanschluss	∅ mm	125	125	125	125	150	150
Innendurchmesser Kesselanschluss-Stück	∅ mm	126 ±0,5	126 ±0,5	126 ±0,5	126 ±0,5	151,6 ±0,5	151,6 ±0,5
Norm-Nutzungsgrad Bei T_V/T_R = 40/30 °C	%	Bis 98 (H_s)					
Energieeffizienzklasse		A	A	A	A	A	A



Ⓐ Höhe mit Vitotronic in Bedienposition
Ⓑ Höhe mit Vitotronic in Betriebsposition

[*3] *Rechenwerte zur Auslegung der Abgasanlage nach EN 13384.*
Abgastemperaturen als gemessene Bruttowerte bei 20 °C Verbrennungslufttemperatur.
Die Abgastemperatur bei Rücklauftemperatur von 30 °C ist maßgeblich zur Auslegung der Abgasanlage.

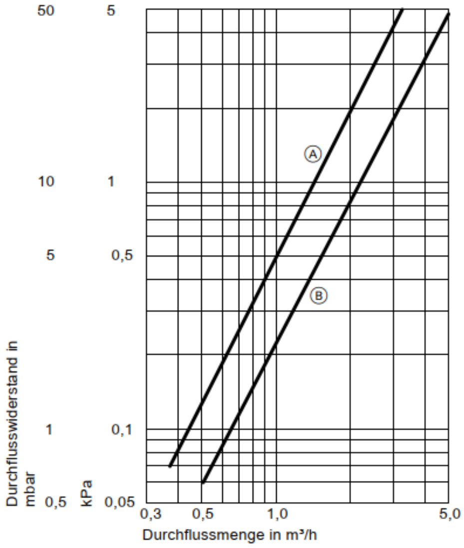
Technische Angaben (Fortsetzung)

Ⓒ Sicherheitsanschluss
(Sicherheitsventil und Entlüftung)
Ⓓ Kesselvorlauf
Ⓔ Gasanschluss
Ⓕ Kesselrücklauf
Ⓖ Sicherheitsrücklauf und Entleerung
(Ausdehnungsgefäß)
Ⓗ Kesselanschluss-Stück für Abgas- Zuluftanschluss
Ⓚ Kondenswasserablauf

Maßtabelle

Nenn-Wärmeleistung	kW	13 bis 35	45 und 60
a	mm	684	801
b	mm	418	535
c	mm	595	712

Heizwasserseitiger Durchflusswiderstand



Ⓐ Nenn-Wärmeleistung 13 bis 35 kW
Ⓑ Nenn-Wärmeleistung 45 und 60 kW

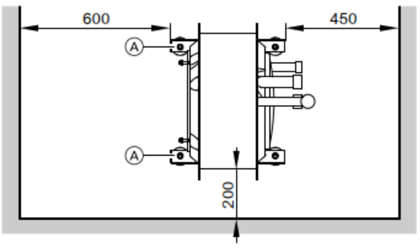
Der Vitocrossal 300 ist nur für Pumpenwarmwasser-Heizungen geeignet.

Nenn-Wärmeleistung (kW)	ΔT = 10 K		ΔT = 15 K		ΔT = 20 K	
	Durchflussmenge (m³/h)	Widerstand (mbar)	Durchflussmenge (m³/h)	Widerstand (mbar)	Durchflussmenge (m³/h)	Widerstand (mbar)
13	1,12	6,1	0,74	3,8	0,56	1,5
19	1,63	12,8	1,09	6,0	0,82	3,5
26	2,24	23,0	1,49	10,8	1,12	6,2
35	3,01	40,5	2,01	18,9	1,51	11,0
45	3,87	28,5	2,58	13,4	1,94	7,8
60	5,16	48,8	3,44	23,3	2,58	13,5

$\Delta T = T_V - T_R$

Technische Angaben (Fortsetzung)

Mindestabstände



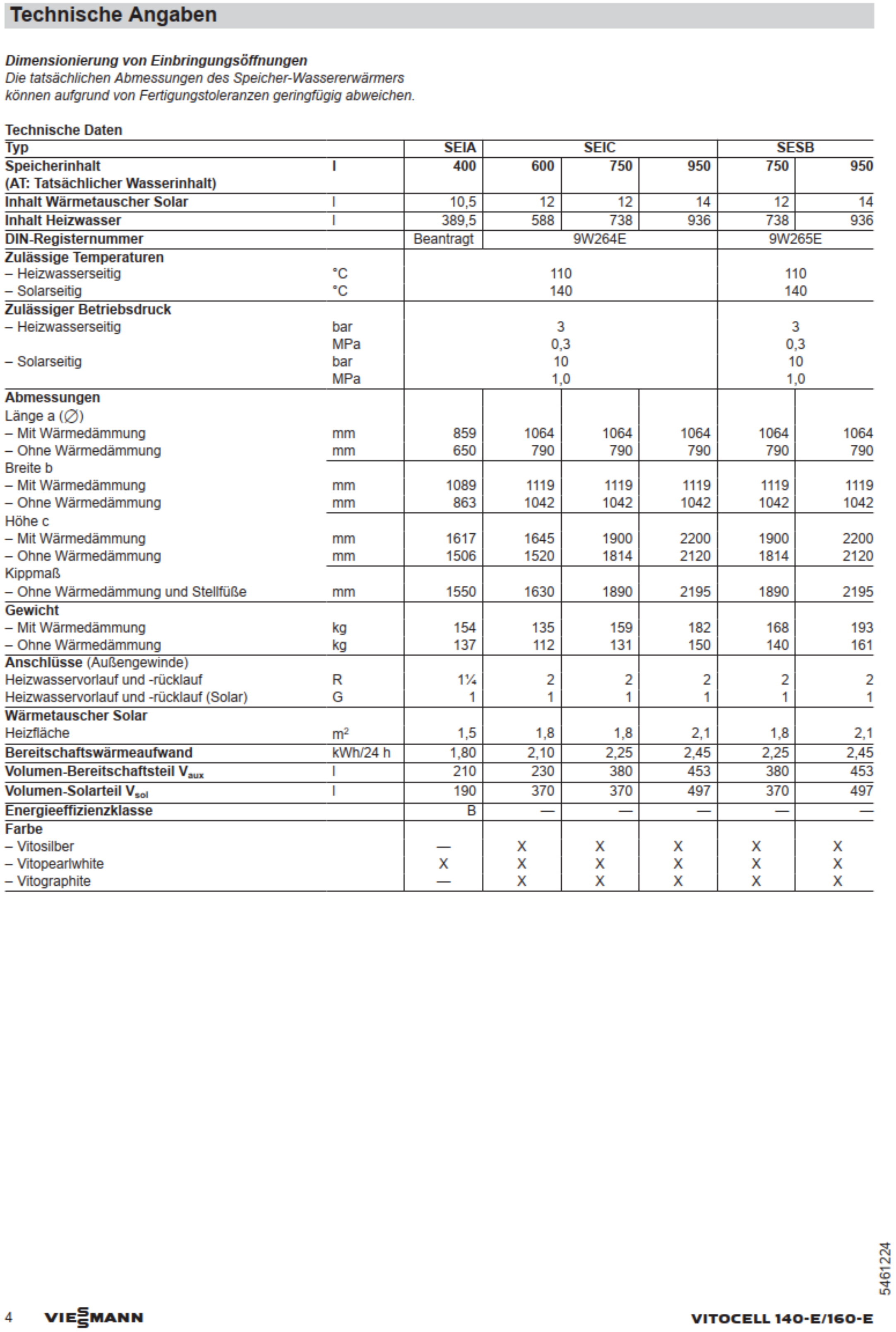
(Kesselkörper ohne Wärmedämmung)

Bei raumluft**ab**hängigem Betrieb muss der Aufstellraum eine Zuluftöffnung mit einem freien Querschnitt von min. 150 cm² bzw. 2 × 75 cm² haben.
Zur einfachen Montage und Wartung sollten die angegebenen Maße eingehalten werden.

Ⓐ Fußschienen

11.4.6 Data sheet: Buffer tanks - Vitocell 140-E Type SEIC (600 l) and Vitocell 140-E Type SEIA (400 l)

- 05/03/2024: Extracted from (Viessmann Climate Solutions SE, 2023b)



Technische Angaben

Dimensionierung von Einbringungsöffnungen
Die tatsächlichen Abmessungen des Speicher-Wassererwärmers können aufgrund von Fertigungstoleranzen geringfügig abweichen.

Technische Daten

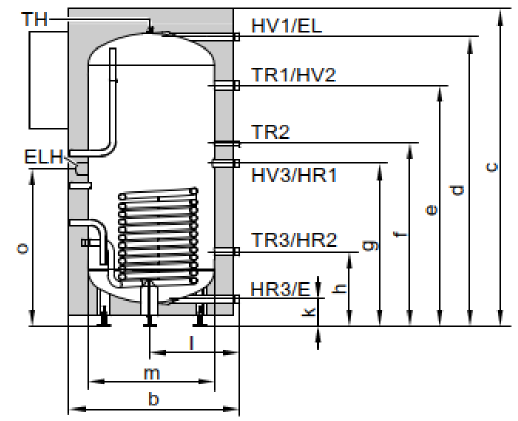
Typ		**SEIA**	**SEIC**			**SESB**	
Speicherinhalt (AT: Tatsächlicher Wasserinhalt)	l	**400**	**600**	**750**	**950**	**750**	**950**
Inhalt Wärmetauscher Solar	l	10,5	12	12	14	12	14
Inhalt Heizwasser	l	389,5	588	738	936	738	936
DIN-Registernummer		Beantragt	9W264E			9W265E	
Zulässige Temperaturen							
– Heizwasserseitig	°C	110				110	
– Solarseitig	°C	140				140	
Zulässiger Betriebsdruck							
– Heizwasserseitig	bar	3				3	
	MPa	0,3				0,3	
– Solarseitig	bar	10				10	
	MPa	1,0				1,0	
Abmessungen							
Länge a (∅)							
– Mit Wärmedämmung	mm	859	1064	1064	1064	1064	1064
– Ohne Wärmedämmung	mm	650	790	790	790	790	790
Breite b							
– Mit Wärmedämmung	mm	1089	1119	1119	1119	1119	1119
– Ohne Wärmedämmung	mm	863	1042	1042	1042	1042	1042
Höhe c							
– Mit Wärmedämmung	mm	1617	1645	1900	2200	1900	2200
– Ohne Wärmedämmung	mm	1506	1520	1814	2120	1814	2120
Kippmaß							
– Ohne Wärmedämmung und Stellfüße	mm	1550	1630	1890	2195	1890	2195
Gewicht							
– Mit Wärmedämmung	kg	154	135	159	182	168	193
– Ohne Wärmedämmung	kg	137	112	131	150	140	161
Anschlüsse (Außengewinde)							
Heizwasservorlauf und -rücklauf	R	1¼	2	2	2	2	2
Heizwasservorlauf und -rücklauf (Solar)	G	1	1	1	1	1	1
Wärmetauscher Solar							
Heizfläche	m²	1,5	1,8	1,8	2,1	1,8	2,1
Bereitschaftswärmeaufwand	kWh/24 h	1,80	2,10	2,25	2,45	2,25	2,45
Volumen-Bereitschaftsteil V_{aux}	l	210	230	380	453	380	453
Volumen-Solarteil V_{sol}	l	190	370	370	497	370	497
Energieeffizienzklasse		B	—	—	—	—	—
Farbe							
– Vitosilber		—	X	X	X	X	X
– Vitopearlwhite		X	X	X	X	X	X
– Vitographite		—	X	X	X	X	X

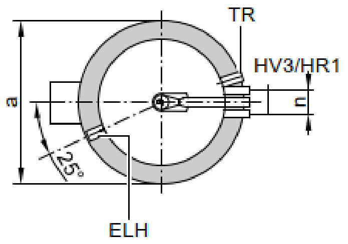
5461224

4 VIESSMANN VITOCELL 140-E/160-E

Technische Angaben (Fortsetzung)

Abmessungen Typ SEIA, 400 l Inhalt



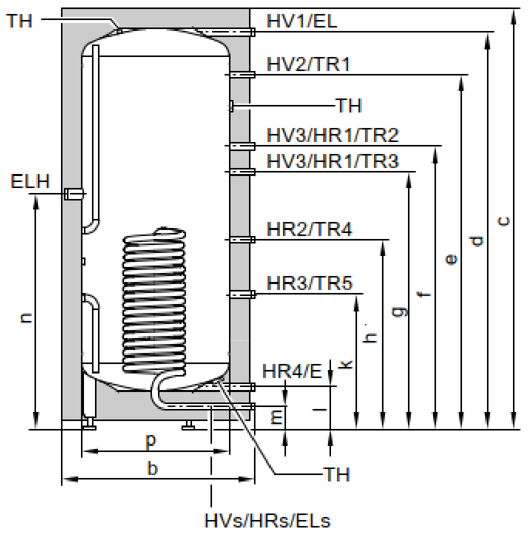


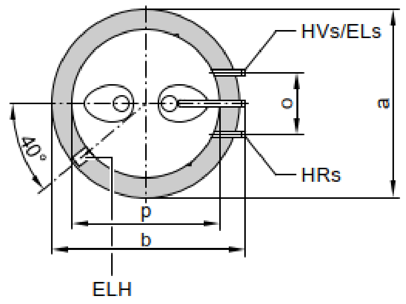
E	Entleerung
EL	Entlüftung
HR	Heizwasserrücklauf
HV	Heizwasservorlauf
TH	Befestigung Thermometerfühler oder Befestigung für zusätzlichen Sensor (Klemmbügel)
TR	Tauchhülse für Speichertemperatursensor/Temperaturregler (Innendurchmesser 16 mm)
ELH	Muffe für Elektro-Heizeinsatz-EHE (Rp 1½)

Maße Typ SEIA

Speicherinhalt		**l**	**400**
Länge (∅)	a	mm	859
Breite			
– Ohne Solar-Divicon	b	mm	898
– Mit Solar-Divicon	b	mm	1089
Höhe	c	mm	1617
	d	mm	1458
	e	mm	1206
	f	mm	911
	g	mm	806
	h	mm	351
	k	mm	107
	l	mm	455
∅ ohne Wärmedämmung	m	mm	∅ 650
	n	mm	120
	o	mm	785

Abmessungen Typ SEIC, 600, 750 und 950 l Inhalt





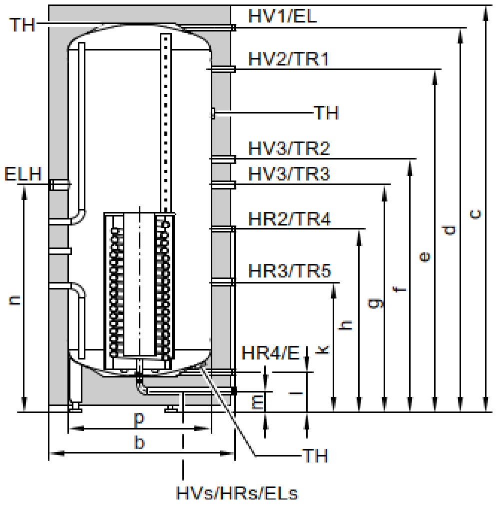
E	Entleerung
EL	Entlüftung
EL$_s$	Entlüftung Wärmetauscher Solar
ELH	Muffe für Elektro-Heizeinsatz-EHE (Rp 1½)
HR	Heizwasserrücklauf
HR$_s$	Heizwasserrücklauf Solaranlage
HV	Heizwasservorlauf
HV$_s$	Heizwasservorlauf Solaranlage
TH	Befestigung Thermometerfühler oder Befestigung für zusätzlichen Sensor (Klemmbügel)
TR	Klemmsystem zur Befestigung von Tauchtemperatursensoren am Speichermantel mit Aufnahmen für 3 Tauchtemperatursensoren pro Klemmsystem

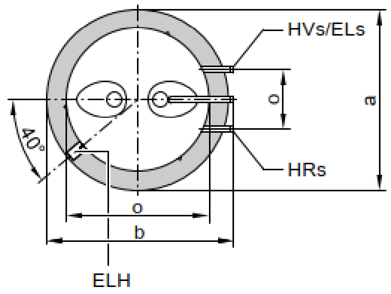
Technische Angaben (Fortsetzung)

Maße Typ SEIC

Speicherinhalt		**l**	**600**	**750**	**950**
Länge (∅)	a	mm	1064	1064	1064
Breite	b	mm	1119	1119	1119
Höhe	c	mm	1645	1900	2200
	d	mm	1497	1777	2083
	e	mm	1296	1559	1864
	f	mm	926	1180	1300
	g	mm	785	1039	1159
	h	mm	598	676	752
	k	mm	355	386	386
	l	mm	155	155	155
	m	mm	75	75	75
	n	mm	910	1010	1033
	o	mm	370	370	370
Länge (∅) ohne Wärmedämmung	p	mm	790	790	790

Abmessungen Typ SESB, 750 und 950 l Inhalt





E	Entleerung
EL	Entlüftung

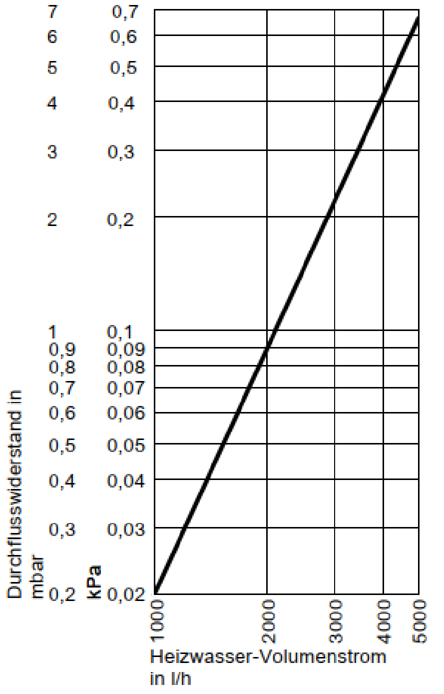
EL_s	Entlüftung Wärmetauscher Solar
ELH	Muffe für Elektro-Heizeinsatz-EHE (Rp 1½)
HR	Heizwasserrücklauf
HR_s	Heizwasserrücklauf Solaranlage
HV	Heizwasservorlauf
HV_s	Heizwasservorlauf Solaranlage
TH	Befestigung Thermometerfühler oder Befestigung für zusätzlichen Sensor (Klemmbügel)
TR	Klemmsystem zur Befestigung von Tauchtemperatursensoren am Speichermantel mit Aufnahmen für 3 Tauchtemperatursensoren pro Klemmsystem

Technische Angaben (Fortsetzung)

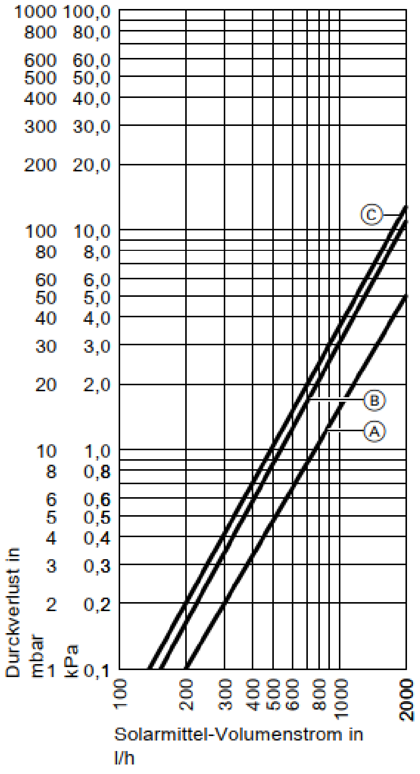
Maße Typ SESB

Speicherinhalt		**l**	**750**	**950**
Länge (∅)	a	mm	1064	1064
Breite	b	mm	1119	1119
Höhe	c	mm	1900	2200
	d	mm	1777	2083
	e	mm	1559	1864
	f	mm	1180	1300
	g	mm	1039	1159
	h	mm	676	752
	k	mm	386	386
	l	mm	155	155
	m	mm	75	75
	n	mm	1010	1033
	o	mm	370	370
Länge (∅) ohne Wärmedämmung	p	mm	790	790

Heizwasserseitiger Durchflusswiderstand



Solarseitiger Durchflusswiderstand

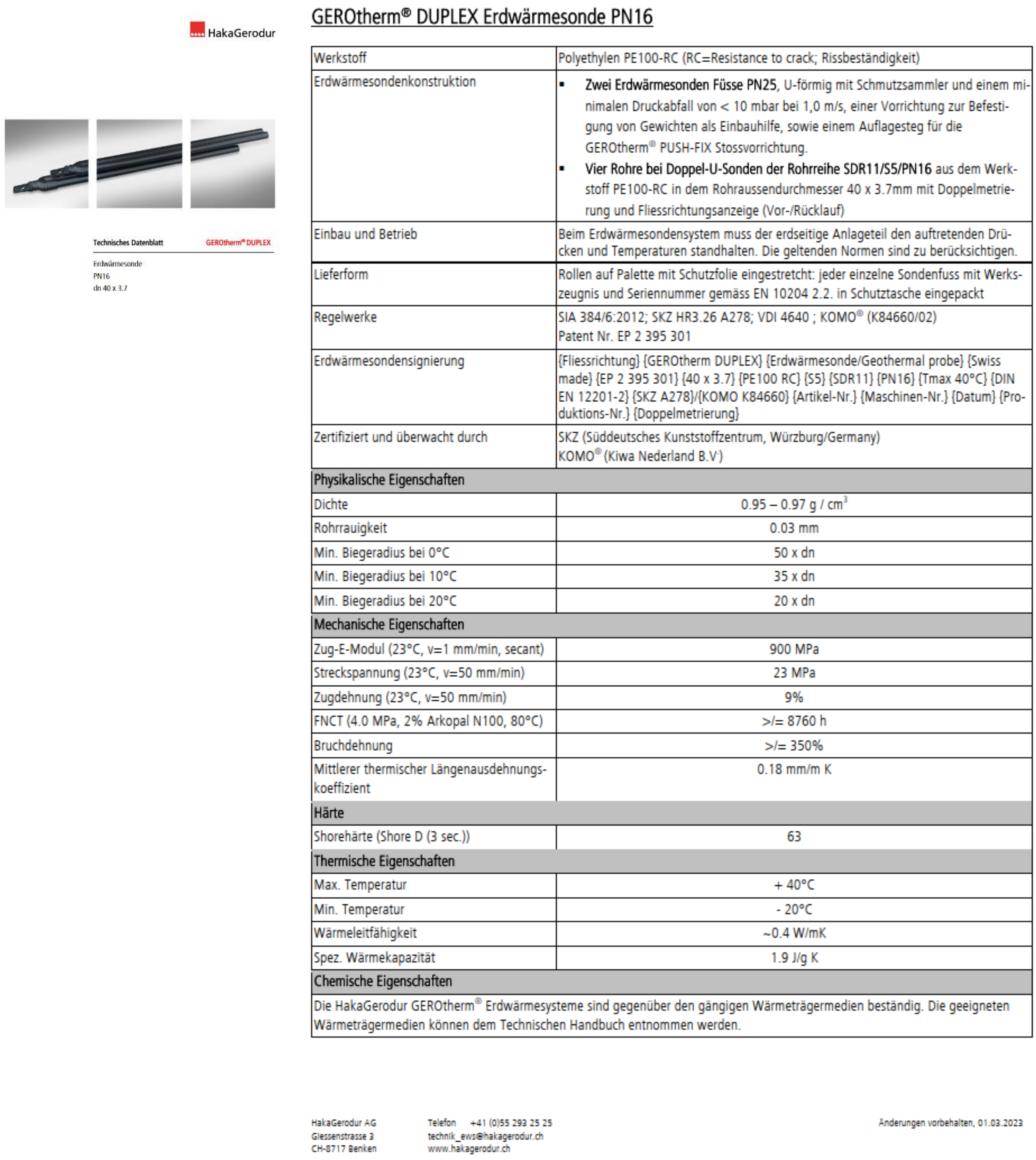


Ⓐ Speicherinhalt 400 l
Ⓑ Speicherinhalt 600 und 750 l
Ⓒ Speicherinhalt 950 l

11.4.7 Data sheets: Ground heat exchanger

11.4.7.1 Pipes DN 40 for ground heat exchanger

- 06/03/2024: Extracted from (HakaGerodur AG, 2023b)



HakaGerodur

Technisches Datenblatt GEROtherm® DUPLEX

Erdwärmesonde
PN16
dn 40 x 3.7

GEROtherm® DUPLEX Erdwärmesonde PN16

Werkstoff	Polyethylen PE100-RC (RC=Resistance to crack; Rissbeständigkeit)
Erdwärmesondenkonstruktion	▪ **Zwei Erdwärmesonden Füsse PN25**, U-förmig mit Schmutzsammler und einem minimalen Druckabfall von < 10 mbar bei 1,0 m/s, einer Vorrichtung zur Befestigung von Gewichten als Einbauhilfe, sowie einem Auflagesteg für die GEROtherm® PUSH-FIX Stossvorrichtung. ▪ **Vier Rohre bei Doppel-U-Sonden der Rohrreihe SDR11/S5/PN16** aus dem Werkstoff PE100-RC in dem Rohraussendurchmesser 40 x 3.7mm mit Doppelmetrierung und Fliessrichtungsanzeige (Vor-/Rücklauf)
Einbau und Betrieb	Beim Erdwärmesondensystem muss der erdseitige Anlageteil den auftretenden Drücken und Temperaturen standhalten. Die geltenden Normen sind zu berücksichtigen.
Lieferform	Rollen auf Palette mit Schutzfolie eingestretcht: jeder einzelne Sondenfuss mit Werkszeugnis und Seriennummer gemäss EN 10204 2.2. in Schutztasche eingepackt
Regelwerke	SIA 384/6:2012; SKZ HR3.26 A278; VDI 4640 ; KOMO® (K84660/02) Patent Nr. EP 2 395 301
Erdwärmesondensignierung	{Fliessrichtung} {GEROtherm DUPLEX} {Erdwärmesonde/Geothermal probe} {Swiss made} {EP 2 395 301} {40 x 3.7} {PE100 RC} {S5} {SDR11} {PN16} {Tmax 40°C} {DIN EN 12201-2} {SKZ A278}/{KOMO K84660} {Artikel-Nr.} {Maschinen-Nr.} {Datum} {Produktions-Nr.} {Doppelmetrierung}
Zertifiziert und überwacht durch	SKZ (Süddeutsches Kunststoffzentrum, Würzburg/Germany) KOMO® (Kiwa Nederland B.V)
Physikalische Eigenschaften	
Dichte	0.95 – 0.97 g / cm^3
Rohrrauigkeit	0.03 mm
Min. Biegeradius bei 0°C	50 x dn
Min. Biegeradius bei 10°C	35 x dn
Min. Biegeradius bei 20°C	20 x dn
Mechanische Eigenschaften	
Zug-E-Modul (23°C, v=1 mm/min, secant)	900 MPa
Streckspannung (23°C, v=50 mm/min)	23 MPa
Zugdehnung (23°C, v=50 mm/min)	9%
FNCT (4.0 MPa, 2% Arkopal N100, 80°C)	>/= 8760 h
Bruchdehnung	>/= 350%
Mittlerer thermischer Längenausdehnungskoeffizient	0.18 mm/m K
Härte	
Shorehärte (Shore D (3 sec.))	63
Thermische Eigenschaften	
Max. Temperatur	+ 40°C
Min. Temperatur	- 20°C
Wärmeleitfähigkeit	~0.4 W/mK
Spez. Wärmekapazität	1.9 J/g K
Chemische Eigenschaften	
Die HakaGerodur GEROtherm® Erdwärmesysteme sind gegenüber den gängigen Wärmeträgermedien beständig. Die geeigneten Wärmeträgermedien können dem Technischen Handbuch entnommen werden.	

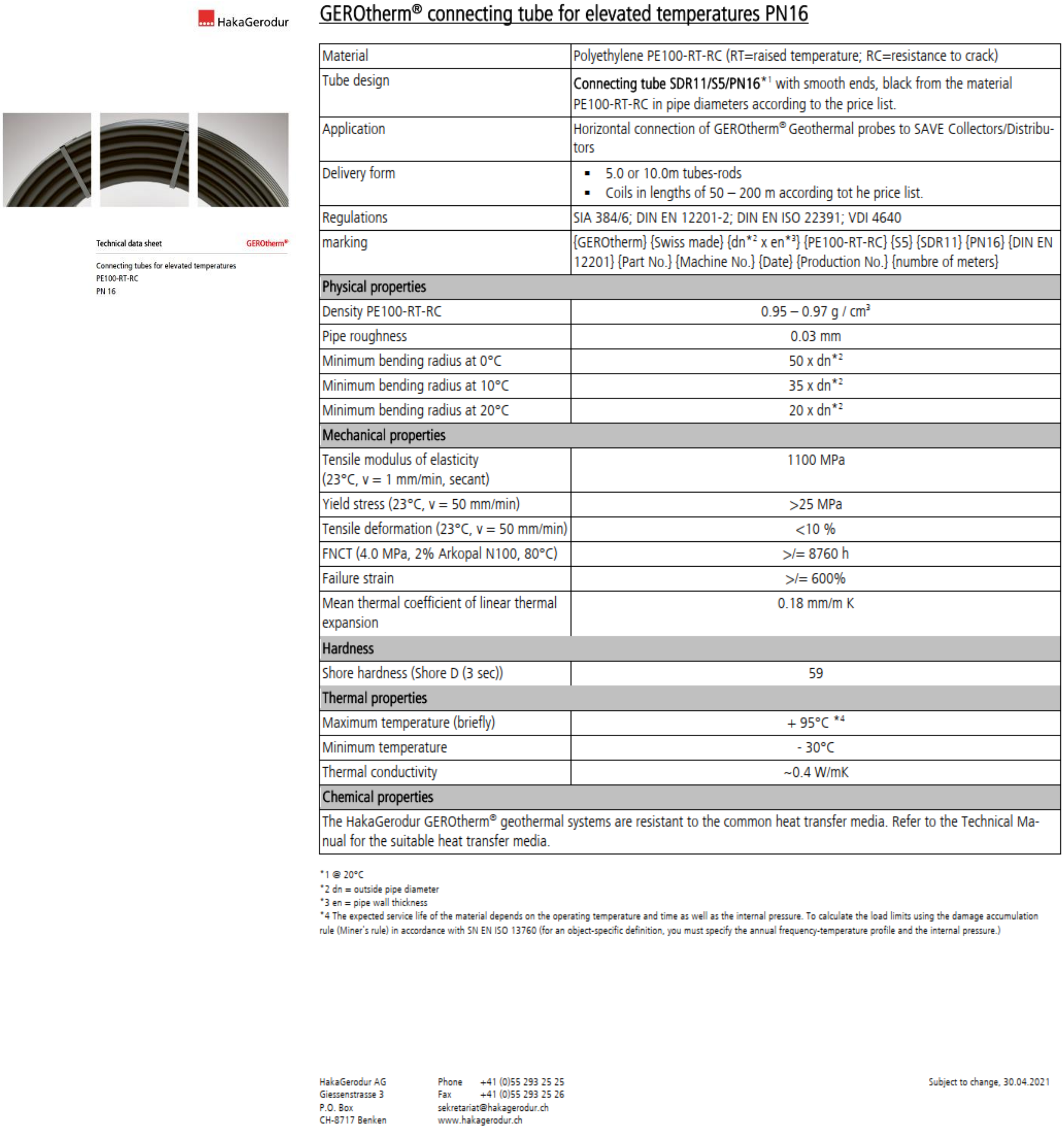
HakaGerodur AG
Giessenstrasse 3
CH-8717 Benken

Telefon +41 (0)55 293 25 25
technik_ews@hakagerodur.ch
www.hakagerodur.ch

Änderungen vorbehalten, 01.03.2023

11.4.7.2 Distribution pipes DN50

07/03/2024: Extracted from (HakaGerodur AG, 2021)



HakaGerodur

Technical data sheet GEROtherm®

Connecting tubes for elevated temperatures
PE100-RT-RC
PN 16

GEROtherm® connecting tube for elevated temperatures PN16

Material	Polyethylene PE100-RT-RC (RT=raised temperature; RC=resistance to crack)
Tube design	**Connecting tube SDR11/S5/PN16**[*1] with smooth ends, black from the material PE100-RT-RC in pipe diameters according to the price list.
Application	Horizontal connection of GEROtherm® Geothermal probes to SAVE Collectors/Distributors
Delivery form	▪ 5.0 or 10.0m tubes-rods ▪ Coils in lengths of 50 – 200 m according tot he price list.
Regulations	SIA 384/6; DIN EN 12201-2; DIN EN ISO 22391; VDI 4640
marking	{GEROtherm} {Swiss made} {dn[*2] x en[*3]} {PE100-RT-RC} {S5} {SDR11} {PN16} {DIN EN 12201} {Part No.} {Machine No.} {Date} {Production No.} {numbre of meters}
Physical properties	
Density PE100-RT-RC	0.95 – 0.97 g / cm^3
Pipe roughness	0.03 mm
Minimum bending radius at 0°C	50 x dn[*2]
Minimum bending radius at 10°C	35 x dn[*2]
Minimum bending radius at 20°C	20 x dn[*2]
Mechanical properties	
Tensile modulus of elasticity (23°C, v = 1 mm/min, secant)	1100 MPa
Yield stress (23°C, v = 50 mm/min)	>25 MPa
Tensile deformation (23°C, v = 50 mm/min)	<10 %
FNCT (4.0 MPa, 2% Arkopal N100, 80°C)	>/= 8760 h
Failure strain	>/= 600%
Mean thermal coefficient of linear thermal expansion	0.18 mm/m K
Hardness	
Shore hardness (Shore D (3 sec))	59
Thermal properties	
Maximum temperature (briefly)	+ 95°C [*4]
Minimum temperature	- 30°C
Thermal conductivity	~0.4 W/mK
Chemical properties	
The HakaGerodur GEROtherm® geothermal systems are resistant to the common heat transfer media. Refer to the Technical Manual for the suitable heat transfer media.	

*1 @ 20°C
*2 dn = outside pipe diameter
*3 en = pipe wall thickness
*4 The expected service life of the material depends on the operating temperature and time as well as the internal pressure. To calculate the load limits using the damage accumulation rule (Miner's rule) in accordance with SN EN ISO 13760 (for an object-specific definition, you must specify the annual frequency-temperature profile and the internal pressure.)

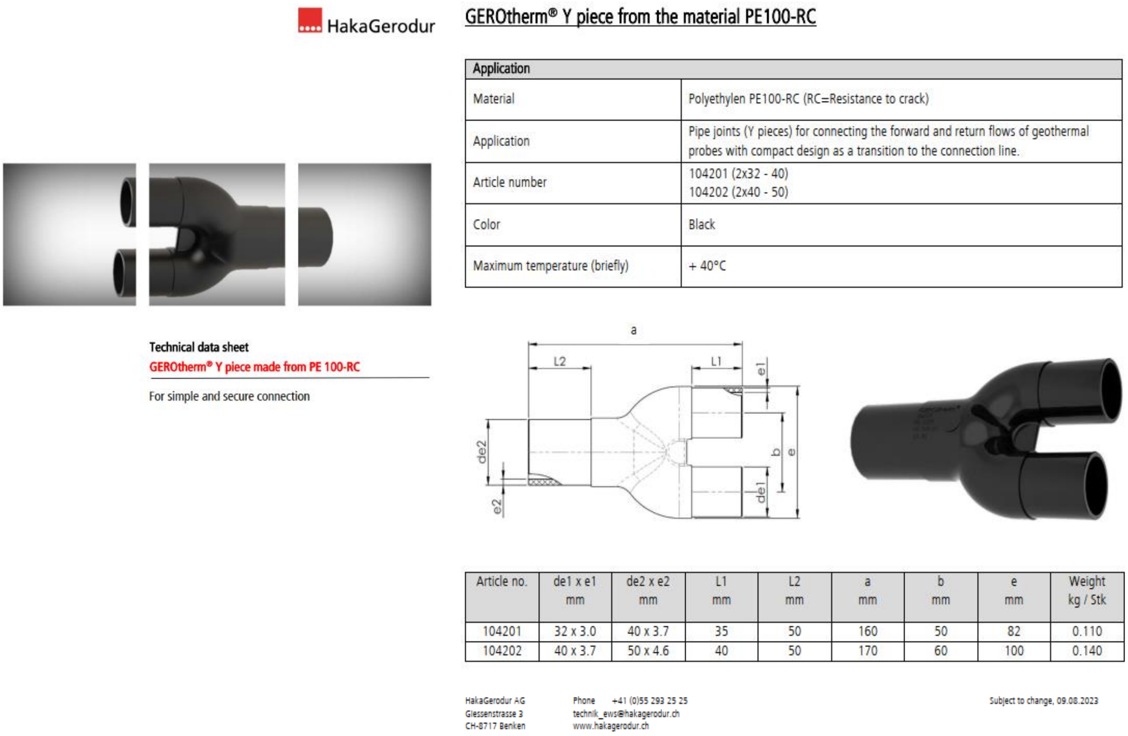
HakaGerodur AG
Giessenstrasse 3
P.O. Box
CH-8717 Benken

Phone +41 (0)55 293 25 25
Fax +41 (0)55 293 25 26
sekretariat@hakagerodur.ch
www.hakagerodur.ch

Subject to change, 30.04.2021

11.4.7.3 *Y-piece for ground heat exchanger*

- 07/03/2024: Extracted from (HakaGerodur AG, 2023c)



HakaGerodur

GEROtherm® Y piece from the material PE100-RC

Application	
Material	Polyethylen PE100-RC (RC=Resistance to crack)
Application	Pipe joints (Y pieces) for connecting the forward and return flows of geothermal probes with compact design as a transition to the connection line.
Article number	104201 (2x32 - 40) 104202 (2x40 - 50)
Color	Black
Maximum temperature (briefly)	+ 40°C

Technical data sheet

GEROtherm® Y piece made from PE 100-RC

For simple and secure connection

Article no.	de1 x e1 mm	de2 x e2 mm	L1 mm	L2 mm	a mm	b mm	e mm	Weight kg / Stk
104201	32 x 3.0	40 x 3.7	35	50	160	50	82	0.110
104202	40 x 3.7	50 x 4.6	40	50	170	60	100	0.140

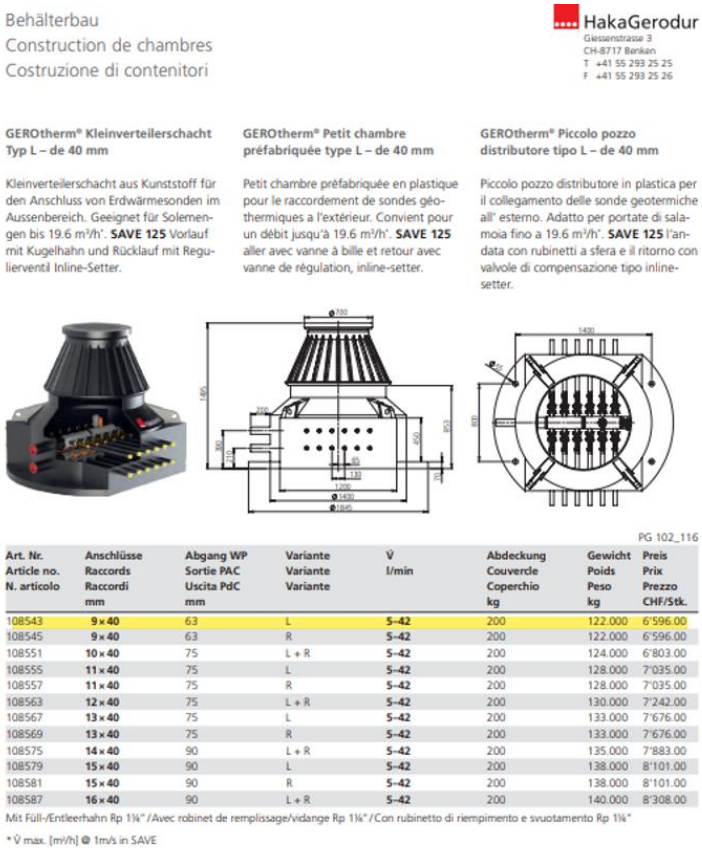
HakaGerodur AG
Giessenstrasse 3
CH-8717 Benken

Phone +41 (0)55 293 25 25
technik_ews@hakagerodur.ch
www.hakagerodur.ch

Subject to change, 09.08.2023

11.4.7.4 *Manifold for ground heat exchanger*

- 06/03/2024: Extracted from (HakaGerodur AG, 2023a)



Behälterbau
Construction de chambres
Costruzione di contenitori

HakaGerodur
Giessenstrasse 3
CH-8717 Benken
T +41 55 293 25 25
F +41 55 293 25 26

GEROtherm® Kleinverteilerschacht Typ L – de 40 mm

Kleinverteilerschacht aus Kunststoff für den Anschluss von Erdwärmesonden im Aussenbereich. Geeignet für Solemengen bis 19.6 m³/h*. **SAVE 125** Vorlauf mit Kugelhahn und Rücklauf mit Regulierventil Inline-Setter.

GEROtherm® Petit chambre préfabriquée type L – de 40 mm

Petit chambre préfabriquée en plastique pour le raccordement de sondes géothermiques a l'extérieur. Convient pour un débit jusqu'à 19.6 m³/h*. **SAVE 125** aller avec vanne à bille et retour avec vanne de régulation, inline-setter.

GEROtherm® Piccolo pozzo distributore tipo L – de 40 mm

Piccolo pozzo distributore in plastica per il collegamento delle sonde geotermiche all' esterno. Adatto per portate di salamoia fino a 19.6 m³/h*. **SAVE 125** l'andata con rubinetti a sfera e il ritorno con valvole di compensazione tipo inline-setter.

PG 102_116

Art. Nr. Article no. N. articolo	Anschlüsse Raccords Raccordi mm	Abgang WP Sortie PAC Uscita PdC mm	Variante Variante Variante	V̇ l/min	Abdeckung Couvercle Coperchio kg	Gewicht Poids Peso kg	Preis Prix Prezzo CHF/Stk.
108543	**9 × 40**	63	L	**5–42**	200	122.000	6'596.00
108545	**9 × 40**	63	R	**5–42**	200	122.000	6'596.00
108551	**10 × 40**	75	L + R	**5–42**	200	124.000	6'803.00
108555	**11 × 40**	75	L	**5–42**	200	128.000	7'035.00
108557	**11 × 40**	75	R	**5–42**	200	128.000	7'035.00
108563	**12 × 40**	75	L + R	**5–42**	200	130.000	7'242.00
108567	**13 × 40**	75	L	**5–42**	200	133.000	7'676.00
108569	**13 × 40**	75	R	**5–42**	200	133.000	7'676.00
108575	**14 × 40**	90	L + R	**5–42**	200	135.000	7'883.00
108579	**15 × 40**	90	L	**5–42**	200	138.000	8'101.00
108581	**15 × 40**	90	R	**5–42**	200	138.000	8'101.00
108587	**16 × 40**	90	L + R	**5–42**	200	140.000	8'308.00

Mit Füll-/Entleerhahn Rp 1¼" /Avec robinet de remplissage/vidange Rp 1¼" / Con rubinetto di riempimento e svuotamento Rp 1¼"

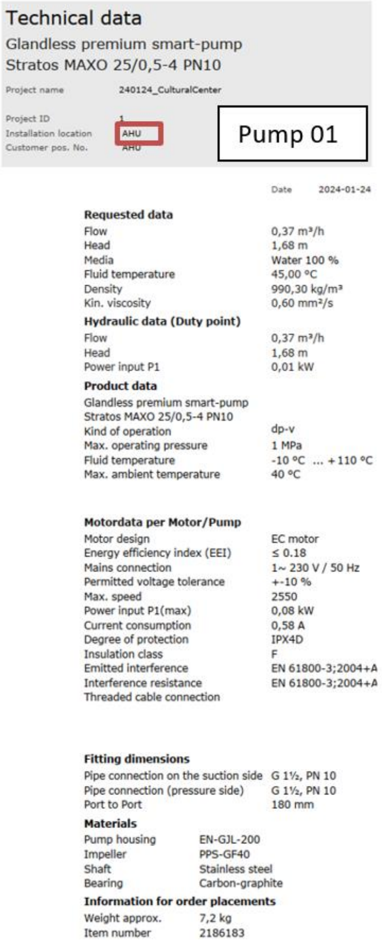
* V̇ max. [m³/h] @ 1m/s in SAVE

11.4.8 Data sheets: Components

11.4.8.1 Pumps

- Planned with Wilo-Select 4 from WILO SE: (WILO SE, 2024)

11.4.8.1.1 Secondary circuit pumps– heating loops



Technical data

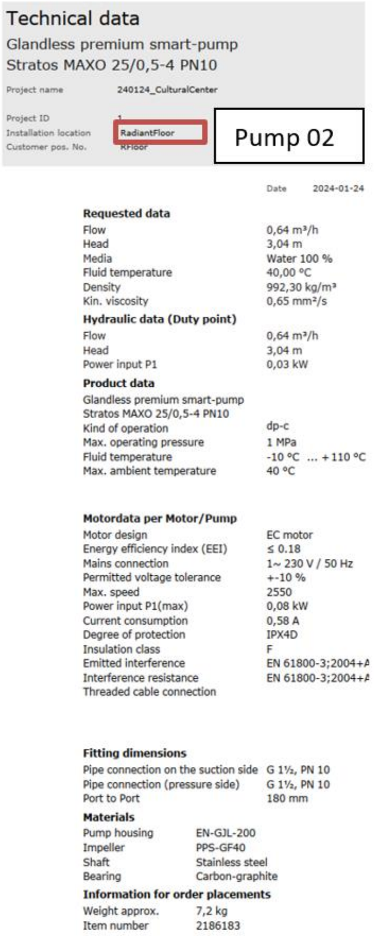
Glandless premium smart-pump
Stratos MAXO 25/0,5-4 PN10

Project name	240124_CulturalCenter
Project ID	1
Installation location	AHU
Customer pos. No.	AHU

Pump 01

Date 2024-01-24

Requested data	
Flow	0,37 m³/h
Head	1,68 m
Media	Water 100 %
Fluid temperature	45,00 °C
Density	990,30 kg/m³
Kin. viscosity	0,60 mm²/s
Hydraulic data (Duty point)	
Flow	0,37 m³/h
Head	1,68 m
Power input P1	0,01 kW
Product data	
Glandless premium smart-pump Stratos MAXO 25/0,5-4 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... +110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	2550
Power input P1(max)	0,08 kW
Current consumption	0,58 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A
Interference resistance	EN 61800-3;2004+A
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm
Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186183



Technical data

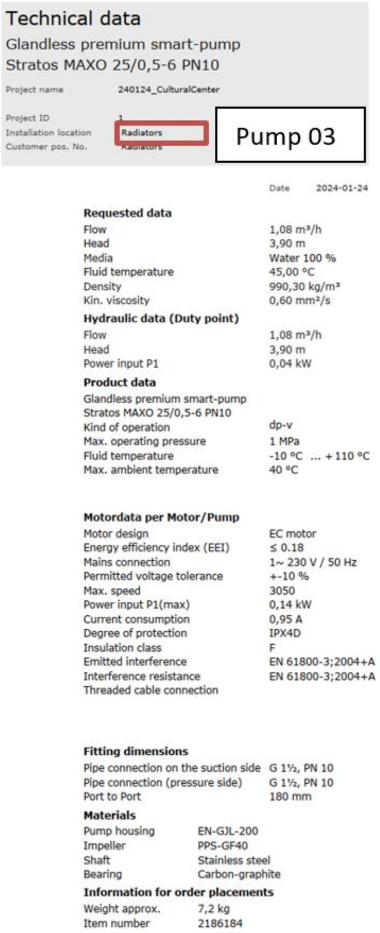
Glandless premium smart-pump
Stratos MAXO 25/0,5-4 PN10

Project name	240124_CulturalCenter
Project ID	1
Installation location	RadiantFloor
Customer pos. No.	RFloor

Pump 02

Date 2024-01-24

Requested data	
Flow	0,64 m³/h
Head	3,04 m
Media	Water 100 %
Fluid temperature	40,00 °C
Density	992,30 kg/m³
Kin. viscosity	0,65 mm²/s
Hydraulic data (Duty point)	
Flow	0,64 m³/h
Head	3,04 m
Power input P1	0,03 kW
Product data	
Glandless premium smart-pump Stratos MAXO 25/0,5-4 PN10	
Kind of operation	dp-c
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... +110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	2550
Power input P1(max)	0,08 kW
Current consumption	0,58 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A
Interference resistance	EN 61800-3;2004+A
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm
Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186183



Technical data

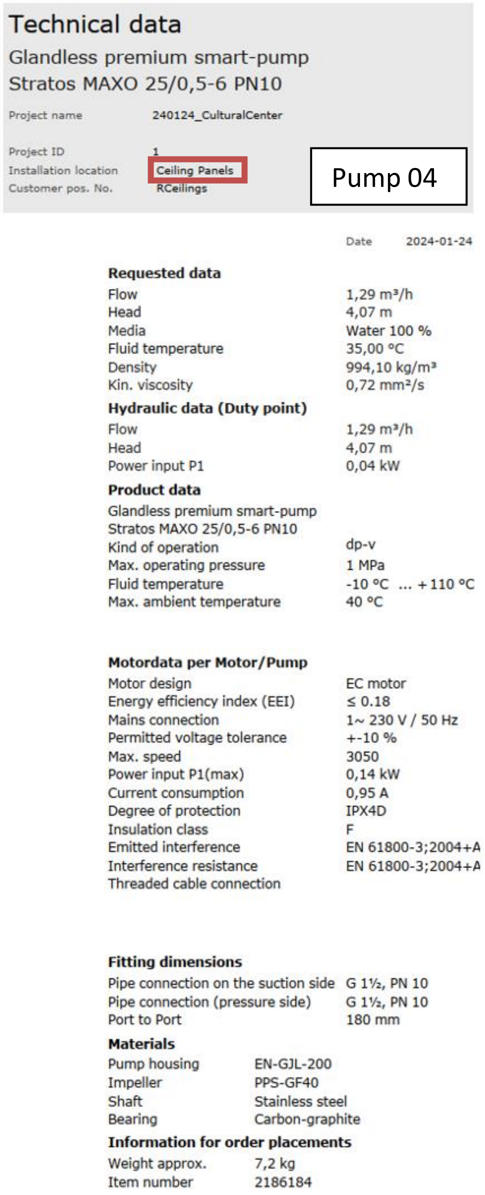
Glandless premium smart-pump
Stratos MAXO 25/0,5-6 PN10

Project name	240124_CulturalCenter
Project ID	1
Installation location	Radiators
Customer pos. No.	Radiators

Pump 03

Date 2024-01-24

Requested data	
Flow	1,08 m³/h
Head	3,90 m
Media	Water 100 %
Fluid temperature	45,00 °C
Density	990,30 kg/m³
Kin. viscosity	0,60 mm²/s
Hydraulic data (Duty point)	
Flow	1,08 m³/h
Head	3,90 m
Power input P1	0,04 kW
Product data	
Glandless premium smart-pump Stratos MAXO 25/0,5-6 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... +110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3050
Power input P1(max)	0,14 kW
Current consumption	0,95 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A
Interference resistance	EN 61800-3;2004+A
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm
Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186184



Technical data

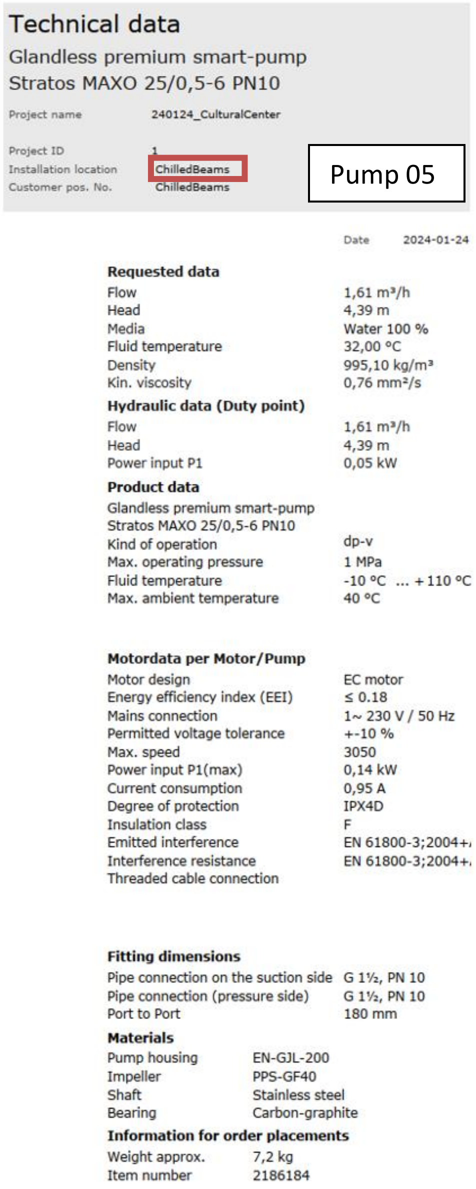
Glandless premium smart-pump
Stratos MAXO 25/0,5-6 PN10

Project name	240124_CulturalCenter
Project ID	1
Installation location	Ceiling Panels
Customer pos. No.	RCeilings

Pump 04

Date 2024-01-24

Requested data	
Flow	1,29 m³/h
Head	4,07 m
Media	Water 100 %
Fluid temperature	35,00 °C
Density	994,10 kg/m³
Kin. viscosity	0,72 mm²/s
Hydraulic data (Duty point)	
Flow	1,29 m³/h
Head	4,07 m
Power input P1	0,04 kW
Product data	
Glandless premium smart-pump Stratos MAXO 25/0,5-6 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... +110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3050
Power input P1(max)	0,14 kW
Current consumption	0,95 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A
Interference resistance	EN 61800-3;2004+A
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm
Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186184



Technical data

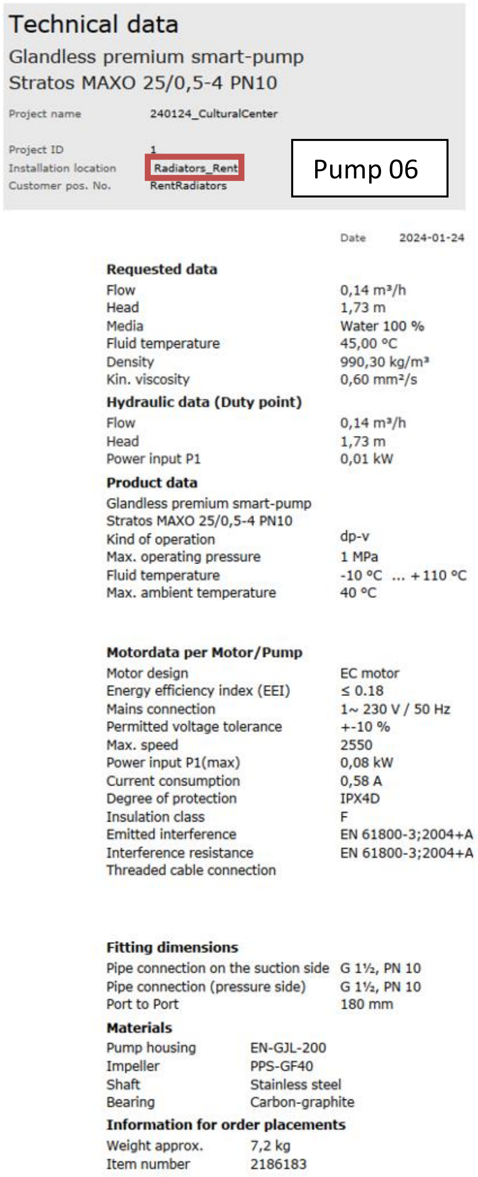
Glandless premium smart-pump
Stratos MAXO 25/0,5-6 PN10

Project name	240124_CulturalCenter
Project ID	1
Installation location	ChilledBeams
Customer pos. No.	ChilledBeams

Pump 05

Date 2024-01-24

Requested data	
Flow	1,61 m³/h
Head	4,39 m
Media	Water 100 %
Fluid temperature	32,00 °C
Density	995,10 kg/m³
Kin. viscosity	0,76 mm²/s
Hydraulic data (Duty point)	
Flow	1,61 m³/h
Head	4,39 m
Power input P1	0,05 kW
Product data	
Glandless premium smart-pump Stratos MAXO 25/0,5-6 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... +110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3050
Power input P1(max)	0,14 kW
Current consumption	0,95 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+
Interference resistance	EN 61800-3;2004+
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm
Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186184



Technical data

Glandless premium smart-pump
Stratos MAXO 25/0,5-4 PN10

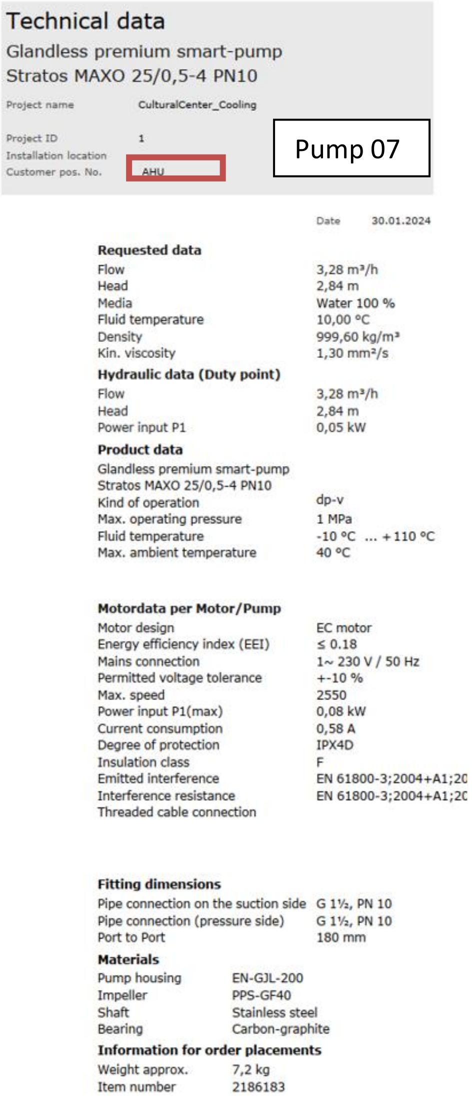
Project name	240124_CulturalCenter
Project ID	1
Installation location	Radiators_Rent
Customer pos. No.	RentRadiators

Pump 06

Date 2024-01-24

Requested data	
Flow	0,14 m³/h
Head	1,73 m
Media	Water 100 %
Fluid temperature	45,00 °C
Density	990,30 kg/m³
Kin. viscosity	0,60 mm²/s
Hydraulic data (Duty point)	
Flow	0,14 m³/h
Head	1,73 m
Power input P1	0,01 kW
Product data	
Glandless premium smart-pump Stratos MAXO 25/0,5-4 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... +110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	2550
Power input P1(max)	0,08 kW
Current consumption	0,58 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A
Interference resistance	EN 61800-3;2004+A
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm
Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186183

11.4.8.1.2 Secondary circuit pumps – cooling loops



Technical data

Glandless premium smart-pump
Stratos MAXO 25/0,5-4 PN10

Pump 07

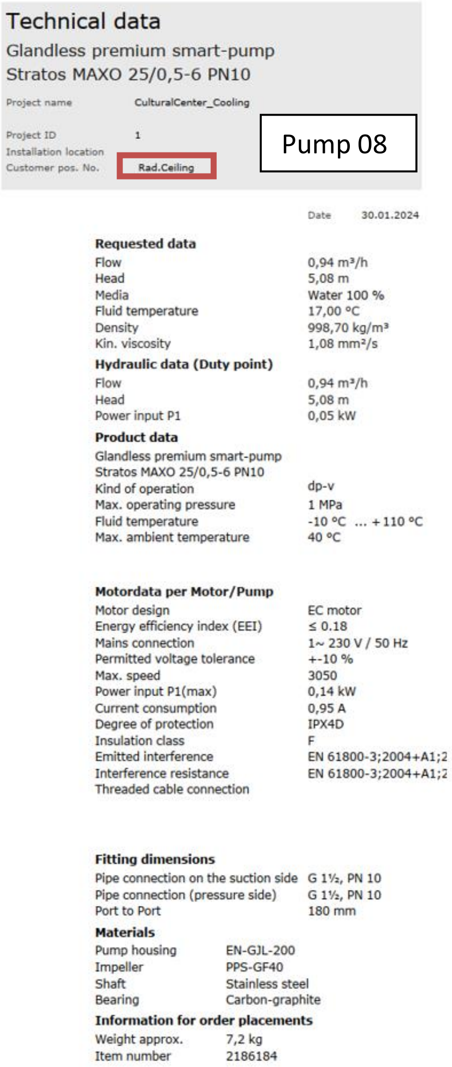
Project name	CulturalCenter_Cooling
Project ID	1
Installation location	
Customer pos. No.	AHU
Date	30.01.2024

Requested data	
Flow	3,28 m³/h
Head	2,84 m
Media	Water 100 %
Fluid temperature	10,00 °C
Density	999,60 kg/m³
Kin. viscosity	1,30 mm²/s
Hydraulic data (Duty point)	
Flow	3,28 m³/h
Head	2,84 m
Power input P1	0,05 kW
Product data	
Glandless premium smart-pump	
Stratos MAXO 25/0,5-4 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C

Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	2550
Power input P1(max)	0,08 kW
Current consumption	0,58 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;20
Interference resistance	EN 61800-3;2004+A1;20
Threaded cable connection	

Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm

Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186183



Technical data

Glandless premium smart-pump
Stratos MAXO 25/0,5-6 PN10

Pump 08

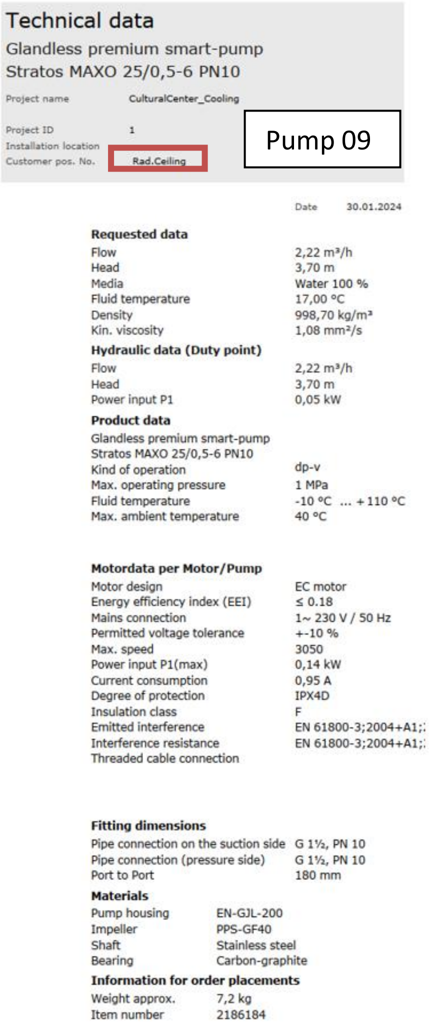
Project name	CulturalCenter_Cooling
Project ID	1
Installation location	
Customer pos. No.	Rad.Ceiling
Date	30.01.2024

Requested data	
Flow	0,94 m³/h
Head	5,08 m
Media	Water 100 %
Fluid temperature	17,00 °C
Density	998,70 kg/m³
Kin. viscosity	1,08 mm²/s
Hydraulic data (Duty point)	
Flow	0,94 m³/h
Head	5,08 m
Power input P1	0,05 kW
Product data	
Glandless premium smart-pump	
Stratos MAXO 25/0,5-6 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C

Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3050
Power input P1(max)	0,14 kW
Current consumption	0,95 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	

Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm

Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186184



Technical data

Glandless premium smart-pump
Stratos MAXO 25/0,5-6 PN10

Pump 09

Project name	CulturalCenter_Cooling
Project ID	1
Installation location	
Customer pos. No.	Rad.Ceiling
Date	30.01.2024

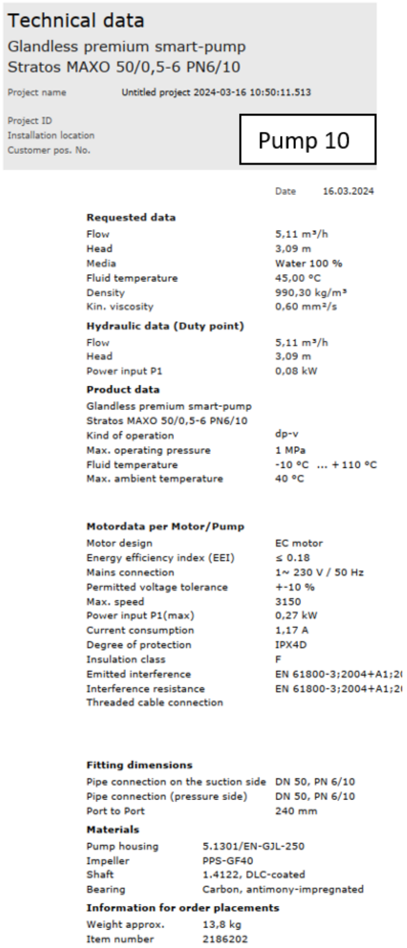
Requested data	
Flow	2,22 m³/h
Head	3,70 m
Media	Water 100 %
Fluid temperature	17,00 °C
Density	998,70 kg/m³
Kin. viscosity	1,08 mm²/s
Hydraulic data (Duty point)	
Flow	2,22 m³/h
Head	3,70 m
Power input P1	0,05 kW
Product data	
Glandless premium smart-pump	
Stratos MAXO 25/0,5-6 PN10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C

Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3050
Power input P1(max)	0,14 kW
Current consumption	0,95 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;
Interference resistance	EN 61800-3;2004+A1;
Threaded cable connection	

Fitting dimensions	
Pipe connection on the suction side	G 1½, PN 10
Pipe connection (pressure side)	G 1½, PN 10
Port to Port	180 mm

Materials	
Pump housing	EN-GJL-200
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	7,2 kg
Item number	2186184

11.4.8.1.3 Secondary circuit – installation room



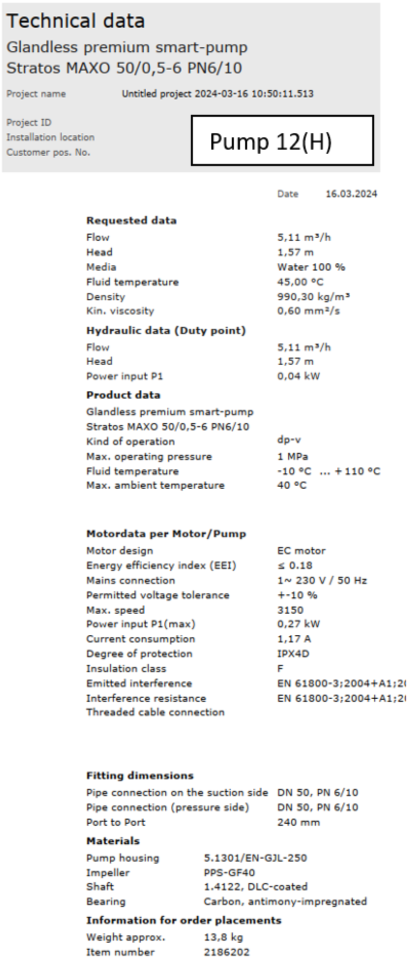
Technical data

Glandless premium smart-pump
Stratos MAXO 50/0,5-6 PN6/10

Project name	Untitled project 2024-03-16 10:50:11.513
Project ID	
Installation location	
Customer pos. No.	

Pump 10

Date	16.03.2024
Requested data	
Flow	5,11 m³/h
Head	3,09 m
Media	Water 100 %
Fluid temperature	45,00 °C
Density	990,30 kg/m³
Kin. viscosity	0,60 mm²/s
Hydraulic data (Duty point)	
Flow	5,11 m³/h
Head	3,09 m
Power input P1	0,08 kW
Product data	
Glandless premium smart-pump Stratos MAXO 50/0,5-6 PN6/10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3150
Power input P1(max)	0,27 kW
Current consumption	1,17 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	DN 50, PN 6/10
Pipe connection (pressure side)	DN 50, PN 6/10
Port to Port	240 mm
Materials	
Pump housing	5.1301/EN-GJL-250
Impeller	PPS-GF40
Shaft	1.4122, DLC-coated
Bearing	Carbon, antimony-impregnated
Information for order placements	
Weight approx.	13,8 kg
Item number	2186202



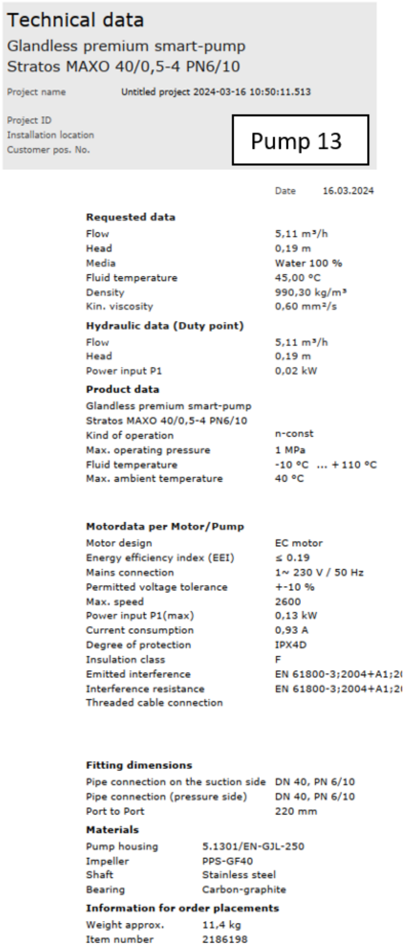
Technical data

Glandless premium smart-pump
Stratos MAXO 50/0,5-6 PN6/10

Project name	Untitled project 2024-03-16 10:50:11.513
Project ID	
Installation location	
Customer pos. No.	

Pump 12(H)

Date	16.03.2024
Requested data	
Flow	5,11 m³/h
Head	1,57 m
Media	Water 100 %
Fluid temperature	45,00 °C
Density	990,30 kg/m³
Kin. viscosity	0,60 mm²/s
Hydraulic data (Duty point)	
Flow	5,11 m³/h
Head	1,57 m
Power input P1	0,04 kW
Product data	
Glandless premium smart-pump Stratos MAXO 50/0,5-6 PN6/10	
Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3150
Power input P1(max)	0,27 kW
Current consumption	1,17 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	DN 50, PN 6/10
Pipe connection (pressure side)	DN 50, PN 6/10
Port to Port	240 mm
Materials	
Pump housing	5.1301/EN-GJL-250
Impeller	PPS-GF40
Shaft	1.4122, DLC-coated
Bearing	Carbon, antimony-impregnated
Information for order placements	
Weight approx.	13,8 kg
Item number	2186202



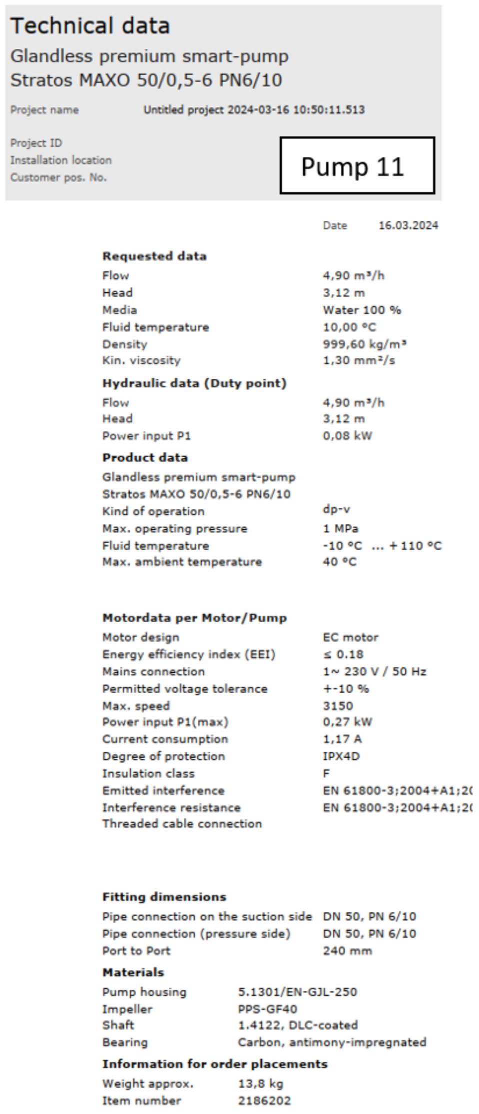
Technical data

Glandless premium smart-pump
Stratos MAXO 40/0,5-4 PN6/10

Project name	Untitled project 2024-03-16 10:50:11.513
Project ID	
Installation location	
Customer pos. No.	

Pump 13

Date	16.03.2024
Requested data	
Flow	5,11 m³/h
Head	0,19 m
Media	Water 100 %
Fluid temperature	45,00 °C
Density	990,30 kg/m³
Kin. viscosity	0,60 mm²/s
Hydraulic data (Duty point)	
Flow	5,11 m³/h
Head	0,19 m
Power input P1	0,02 kW
Product data	
Glandless premium smart-pump Stratos MAXO 40/0,5-4 PN6/10	
Kind of operation	n-const
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.19
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	2600
Power input P1(max)	0,13 kW
Current consumption	0,93 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	DN 40, PN 6/10
Pipe connection (pressure side)	DN 40, PN 6/10
Port to Port	220 mm
Materials	
Pump housing	5.1301/EN-GJL-250
Impeller	PPS-GF40
Shaft	Stainless steel
Bearing	Carbon-graphite
Information for order placements	
Weight approx.	11,4 kg
Item number	2186198



Technical data

Glandless premium smart-pump
Stratos MAXO 50/0,5-6 PN6/10

Project name	Untitled project 2024-03-16 10:50:11.513
Project ID	
Installation location	
Customer pos. No.	

Pump 11

Date 16.03.2024

Requested data

Flow	4,90 m³/h
Head	3,12 m
Media	Water 100 %
Fluid temperature	10,00 °C
Density	999,60 kg/m³
Kin. viscosity	1,30 mm²/s

Hydraulic data (Duty point)

Flow	4,90 m³/h
Head	3,12 m
Power input P1	0,08 kW

Product data

Glandless premium smart-pump
Stratos MAXO 50/0,5-6 PN6/10

Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C

Motordata per Motor/Pump

Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3150
Power input P1(max)	0,27 kW
Current consumption	1,17 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	

Fitting dimensions

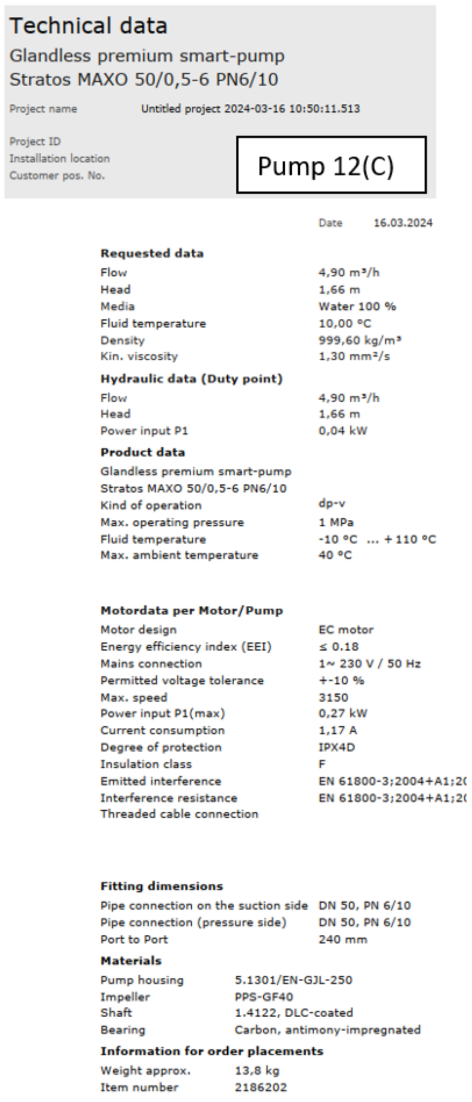
Pipe connection on the suction side	DN 50, PN 6/10
Pipe connection (pressure side)	DN 50, PN 6/10
Port to Port	240 mm

Materials

Pump housing	5.1301/EN-GJL-250
Impeller	PPS-GF40
Shaft	1.4122, DLC-coated
Bearing	Carbon, antimony-impregnated

Information for order placements

Weight approx.	13,8 kg
Item number	2186202



Technical data

Glandless premium smart-pump
Stratos MAXO 50/0,5-6 PN6/10

Project name	Untitled project 2024-03-16 10:50:11.513
Project ID	
Installation location	
Customer pos. No.	

Pump 12(C)

Date 16.03.2024

Requested data

Flow	4,90 m³/h
Head	1,66 m
Media	Water 100 %
Fluid temperature	10,00 °C
Density	999,60 kg/m³
Kin. viscosity	1,30 mm²/s

Hydraulic data (Duty point)

Flow	4,90 m³/h
Head	1,66 m
Power input P1	0,04 kW

Product data

Glandless premium smart-pump
Stratos MAXO 50/0,5-6 PN6/10

Kind of operation	dp-v
Max. operating pressure	1 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C

Motordata per Motor/Pump

Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.18
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3150
Power input P1(max)	0,27 kW
Current consumption	1,17 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	

Fitting dimensions

Pipe connection on the suction side	DN 50, PN 6/10
Pipe connection (pressure side)	DN 50, PN 6/10
Port to Port	240 mm

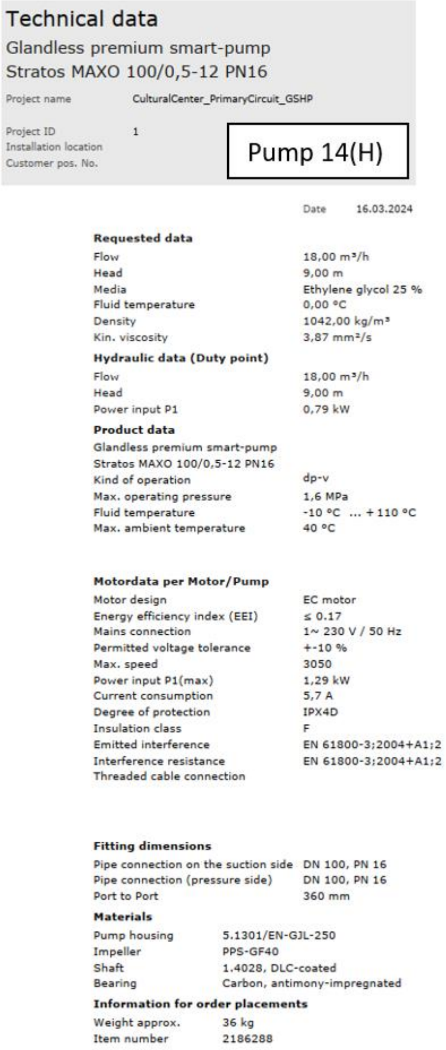
Materials

Pump housing	5.1301/EN-GJL-250
Impeller	PPS-GF40
Shaft	1.4122, DLC-coated
Bearing	Carbon, antimony-impregnated

Information for order placements

Weight approx.	13,8 kg
Item number	2186202

11.4.8.1.4 Primary circuit pumps



Technical data

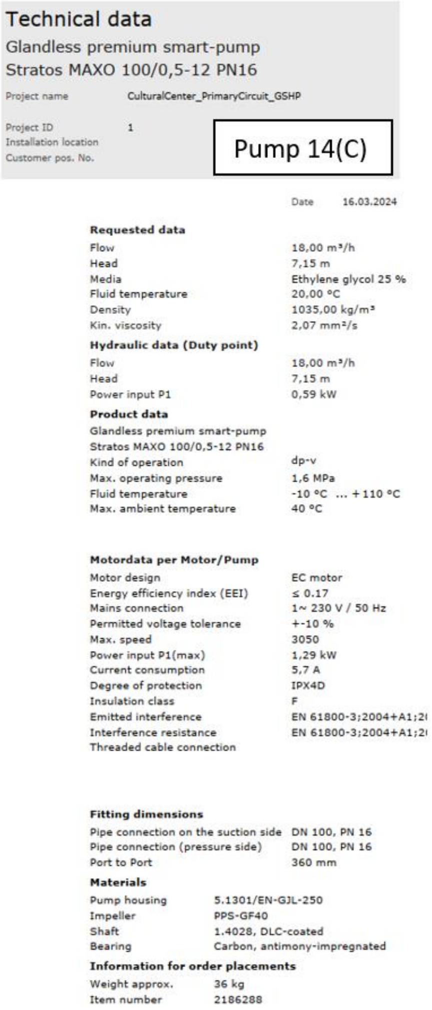
Glandless premium smart-pump
Stratos MAXO 100/0,5-12 PN16

Project name	CulturalCenter_PrimaryCircuit_GSHP
Project ID	1
Installation location	
Customer pos. No.	

Pump 14(H)

Date 16.03.2024

Requested data	
Flow	18,00 m³/h
Head	9,00 m
Media	Ethylene glycol 25 %
Fluid temperature	0,00 °C
Density	1042,00 kg/m³
Kin. viscosity	3,87 mm²/s
Hydraulic data (Duty point)	
Flow	18,00 m³/h
Head	9,00 m
Power input P1	0,79 kW
Product data	
Glandless premium smart-pump	
Stratos MAXO 100/0,5-12 PN16	
Kind of operation	dp-v
Max. operating pressure	1,6 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.17
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3050
Power input P1(max)	1,29 kW
Current consumption	5,7 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	DN 100, PN 16
Pipe connection (pressure side)	DN 100, PN 16
Port to Port	360 mm
Materials	
Pump housing	5.1301/EN-GJL-250
Impeller	PPS-GF40
Shaft	1.4028, DLC-coated
Bearing	Carbon, antimony-impregnated
Information for order placements	
Weight approx.	36 kg
Item number	2186288



Technical data

Glandless premium smart-pump
Stratos MAXO 100/0,5-12 PN16

Project name	CulturalCenter_PrimaryCircuit_GSHP
Project ID	1
Installation location	
Customer pos. No.	

Pump 14(C)

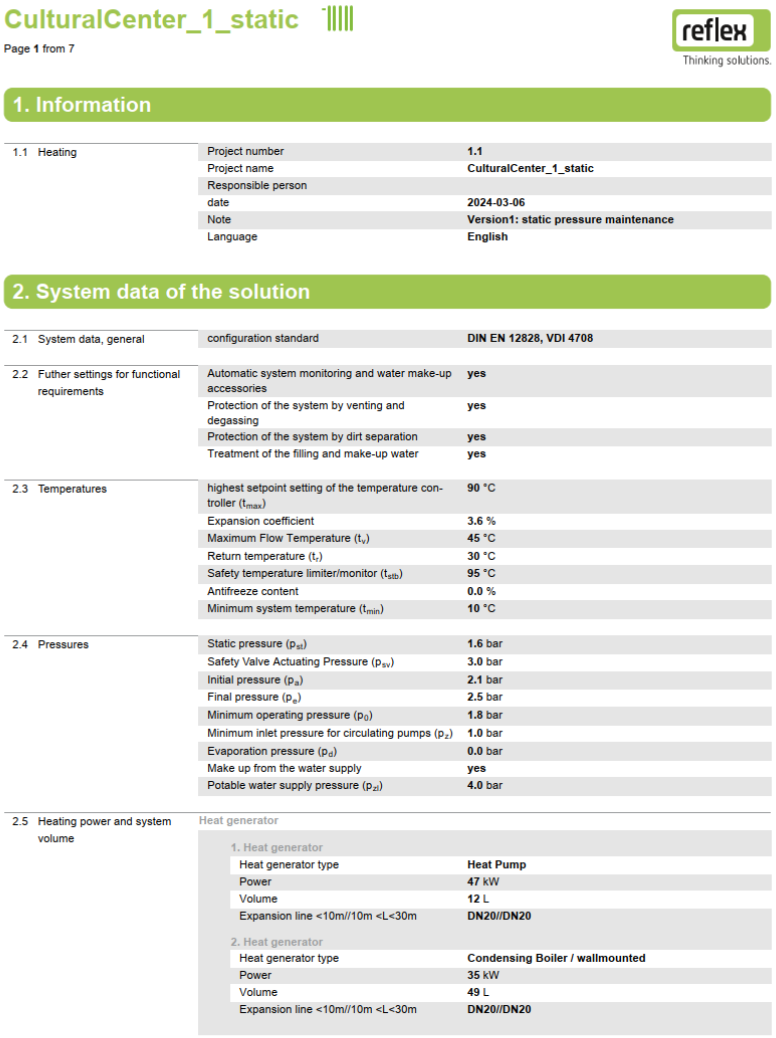
Date 16.03.2024

Requested data	
Flow	18,00 m³/h
Head	7,15 m
Media	Ethylene glycol 25 %
Fluid temperature	20,00 °C
Density	1035,00 kg/m³
Kin. viscosity	2,07 mm²/s
Hydraulic data (Duty point)	
Flow	18,00 m³/h
Head	7,15 m
Power input P1	0,59 kW
Product data	
Glandless premium smart-pump	
Stratos MAXO 100/0,5-12 PN16	
Kind of operation	dp-v
Max. operating pressure	1,6 MPa
Fluid temperature	-10 °C ... + 110 °C
Max. ambient temperature	40 °C
Motordata per Motor/Pump	
Motor design	EC motor
Energy efficiency index (EEI)	≤ 0.17
Mains connection	1~ 230 V / 50 Hz
Permitted voltage tolerance	+-10 %
Max. speed	3050
Power input P1(max)	1,29 kW
Current consumption	5,7 A
Degree of protection	IPX4D
Insulation class	F
Emitted interference	EN 61800-3;2004+A1;2
Interference resistance	EN 61800-3;2004+A1;2
Threaded cable connection	
Fitting dimensions	
Pipe connection on the suction side	DN 100, PN 16
Pipe connection (pressure side)	DN 100, PN 16
Port to Port	360 mm
Materials	
Pump housing	5.1301/EN-GJL-250
Impeller	PPS-GF40
Shaft	1.4028, DLC-coated
Bearing	Carbon, antimony-impregnated
Information for order placements	
Weight approx.	36 kg
Item number	2186288

11.4.8.2 Pressure maintenance

11.4.8.2.1 Secondary circuit

- Planned with “Reflex Solutions Pro Version 24.02” from the manufacturer Reflex Winkelmann GmbH: (Reflex Winkelmann GmbH, 2024)



CulturalCenter_1_static

Page **1** from 7

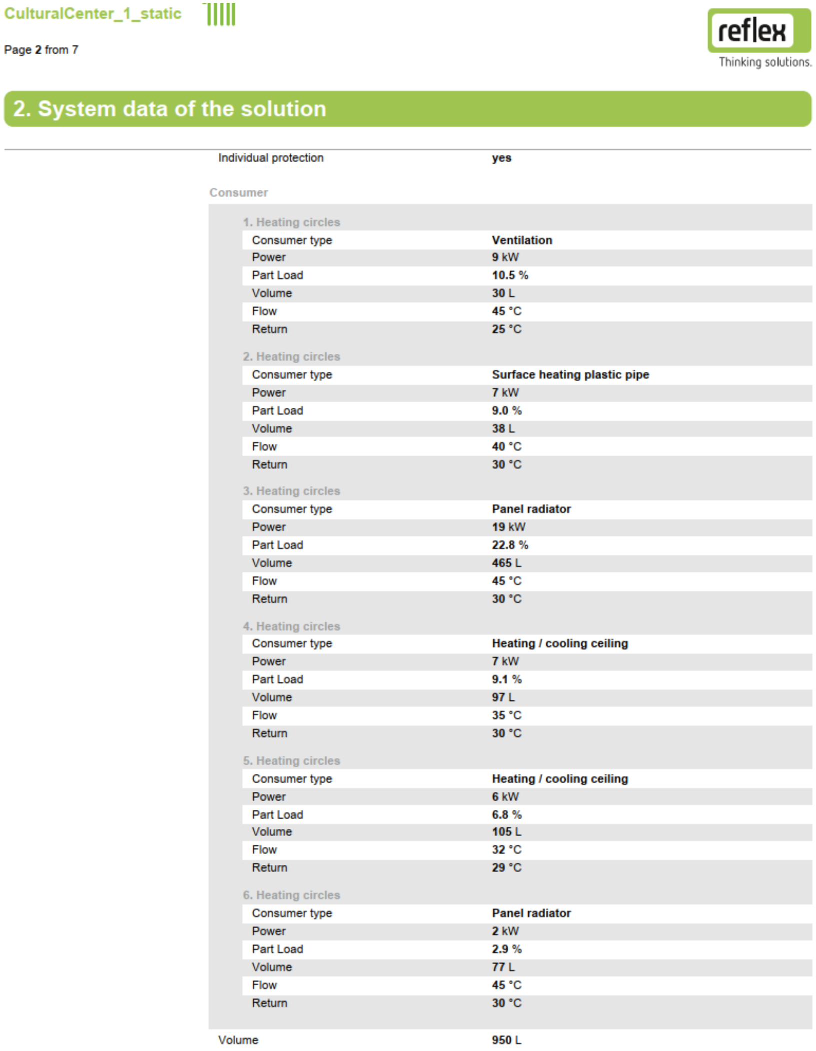
reflex
Thinking solutions.

1. Information

1.1 Heating	Project number	**1.1**
	Project name	**CulturalCenter_1_static**
	Responsible person	
	date	**2024-03-06**
	Note	**Version1: static pressure maintenance**
	Language	**English**

2. System data of the solution

2.1 System data, general	configuration standard	**DIN EN 12828, VDI 4708**
2.2 Futher settings for functional requirements	Automatic system monitoring and water make-up accessories	**yes**
	Protection of the system by venting and degassing	**yes**
	Protection of the system by dirt separation	**yes**
	Treatment of the filling and make-up water	**yes**
2.3 Temperatures	highest setpoint setting of the temperature controller (t_{max})	**90 °C**
	Expansion coefficient	**3.6 %**
	Maximum Flow Temperature (t_v)	**45 °C**
	Return temperature (t_r)	**30 °C**
	Safety temperature limiter/monitor (t_{stb})	**95 °C**
	Antifreeze content	**0.0 %**
	Minimum system temperature (t_{min})	**10 °C**
2.4 Pressures	Static pressure (p_{st})	**1.6** bar
	Safety Valve Actuating Pressure (p_{sv})	**3.0** bar
	Initial pressure (p_a)	**2.1** bar
	Final pressure (p_e)	**2.5** bar
	Minimum operating pressure (p_0)	**1.8** bar
	Minimum inlet pressure for circulating pumps (p_z)	**1.0** bar
	Evaporation pressure (p_d)	**0.0** bar
	Make up from the water supply	**yes**
	Potable water supply pressure (p_{zl})	**4.0** bar
2.5 Heating power and system volume	Heat generator	
	1. Heat generator	
	Heat generator type	**Heat Pump**
	Power	**47** kW
	Volume	**12** L
	Expansion line <10m//10m <L<30m	**DN20//DN20**
	2. Heat generator	
	Heat generator type	**Condensing Boiler / wallmounted**
	Power	**35** kW
	Volume	**49** L
	Expansion line <10m//10m <L<30m	**DN20//DN20**



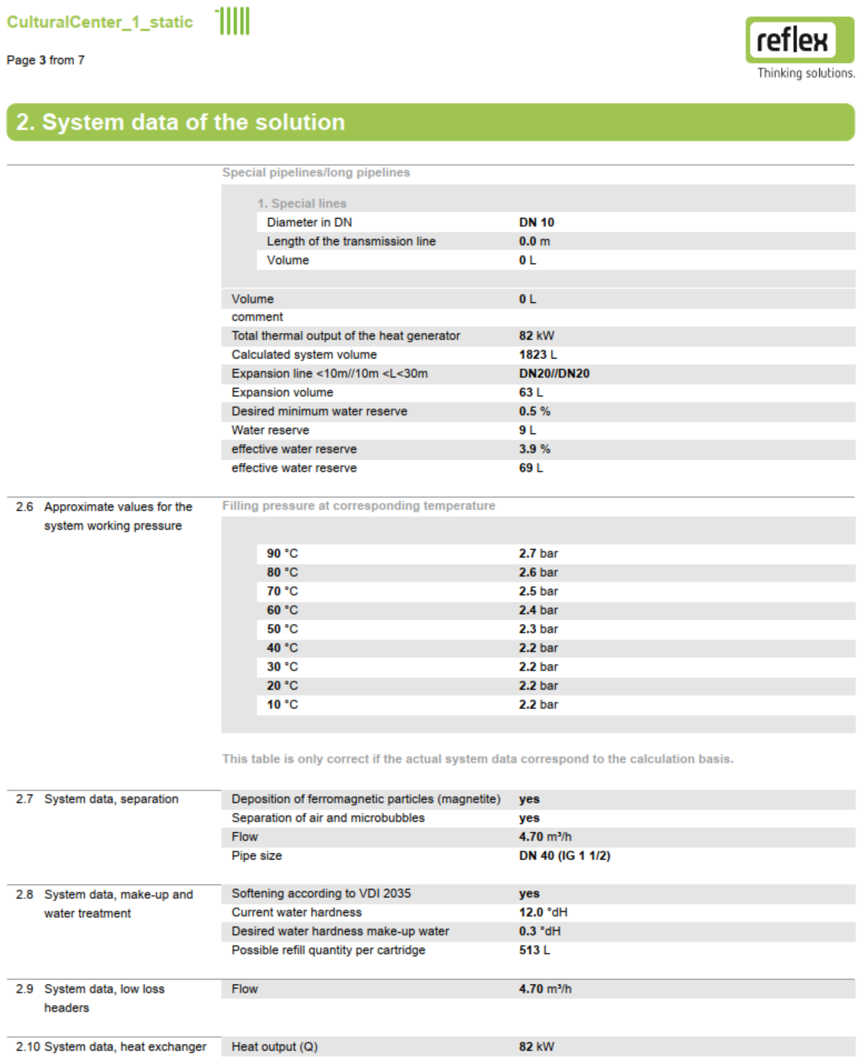
CulturalCenter_1_static

Page **2** from 7

reflex
Thinking solutions.

2. System data of the solution

Individual protection	**yes**
Consumer	
1. Heating circles	
Consumer type	**Ventilation**
Power	**9** kW
Part Load	**10.5** %
Volume	**30** L
Flow	**45** °C
Return	**25** °C
2. Heating circles	
Consumer type	**Surface heating plastic pipe**
Power	**7** kW
Part Load	**9.0** %
Volume	**38** L
Flow	**40** °C
Return	**30** °C
3. Heating circles	
Consumer type	**Panel radiator**
Power	**19** kW
Part Load	**22.8** %
Volume	**465** L
Flow	**45** °C
Return	**30** °C
4. Heating circles	
Consumer type	**Heating / cooling ceiling**
Power	**7** kW
Part Load	**9.1** %
Volume	**97** L
Flow	**35** °C
Return	**30** °C
5. Heating circles	
Consumer type	**Heating / cooling ceiling**
Power	**6** kW
Part Load	**6.8** %
Volume	**105** L
Flow	**32** °C
Return	**29** °C
6. Heating circles	
Consumer type	**Panel radiator**
Power	**2** kW
Part Load	**2.9** %
Volume	**77** L
Flow	**45** °C
Return	**30** °C
Volume	**950** L



CulturalCenter_1_static

Page **3** from 7

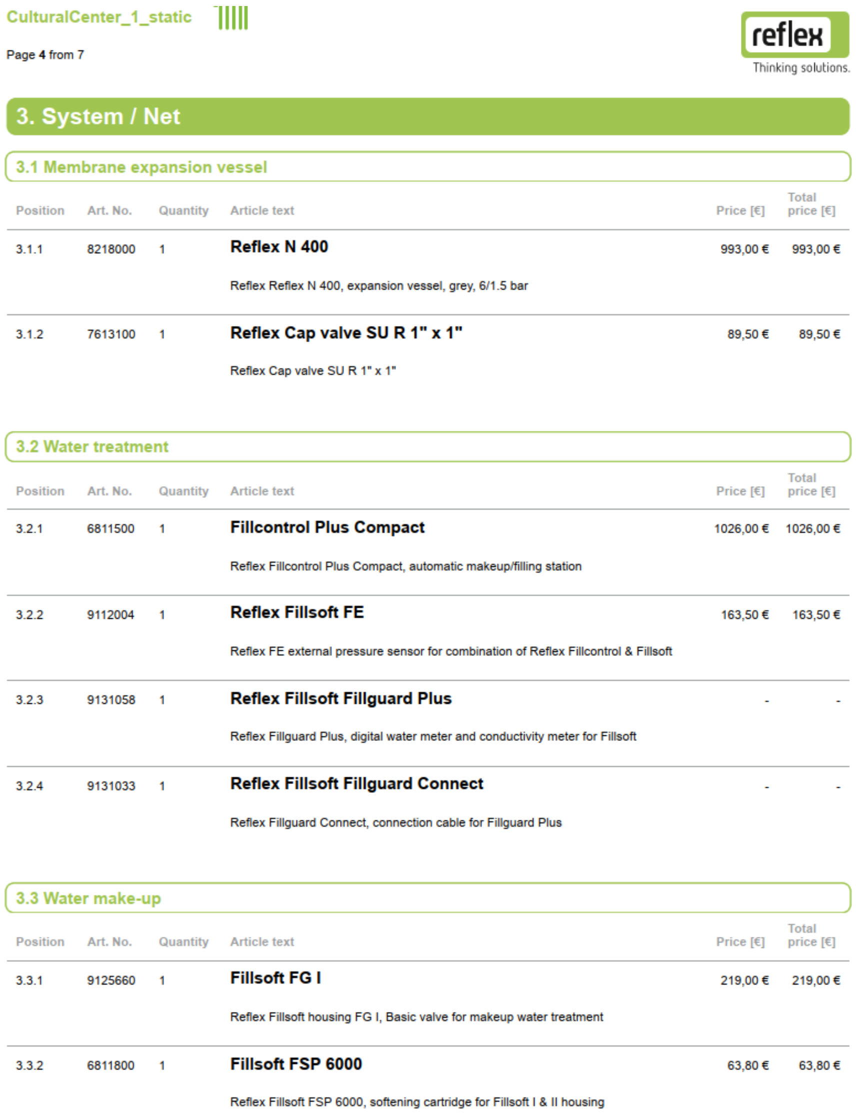
reflex
Thinking solutions.

2. System data of the solution

	Special pipelines/long pipelines	
	1. Special lines	
	Diameter in DN	**DN 10**
	Length of the transmission line	**0.0** m
	Volume	**0** L
	Volume	**0** L
	comment	
	Total thermal output of the heat generator	**82** kW
	Calculated system volume	**1823** L
	Expansion line <10m//10m <L<30m	**DN20//DN20**
	Expansion volume	**63** L
	Desired minimum water reserve	**0.5** %
	Water reserve	**9** L
	effective water reserve	**3.9** %
	effective water reserve	**69** L
2.6 Approximate values for the system working pressure	Filling pressure at corresponding temperature	
	90 °C	**2.7** bar
	80 °C	**2.6** bar
	70 °C	**2.5** bar
	60 °C	**2.4** bar
	50 °C	**2.3** bar
	40 °C	**2.2** bar
	30 °C	**2.2** bar
	20 °C	**2.2** bar
	10 °C	**2.2** bar

This table is only correct if the actual system data correspond to the calculation basis.

2.7 System data, separation	Deposition of ferromagnetic particles (magnetite)	**yes**
	Separation of air and microbubbles	**yes**
	Flow	**4.70** m³/h
	Pipe size	**DN 40 (IG 1 1/2)**
2.8 System data, make-up and water treatment	Softening according to VDI 2035	**yes**
	Current water hardness	**12.0** °dH
	Desired water hardness make-up water	**0.3** °dH
	Possible refill quantity per cartridge	**513** L
2.9 System data, low loss headers	Flow	**4.70** m³/h
2.10 System data, heat exchanger	Heat output (Q)	**82** kW



CulturalCenter_1_static

Page **4** from 7

reflex
Thinking solutions.

3. System / Net

3.1 Membrane expansion vessel

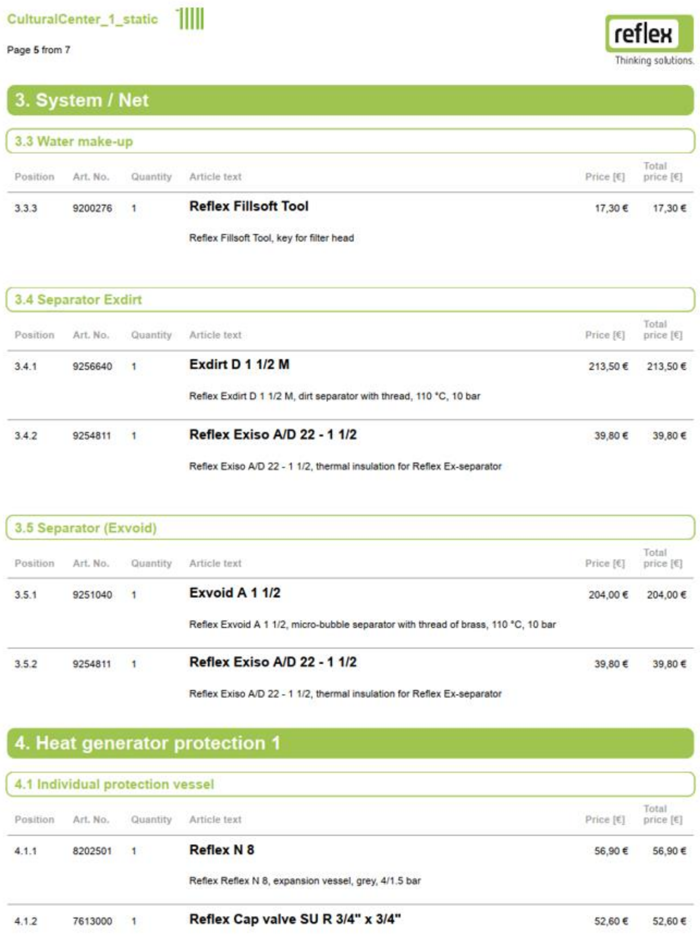
Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.1.1	8218000	1	**Reflex N 400** Reflex Reflex N 400, expansion vessel, grey, 6/1.5 bar	993,00 €	993,00 €
3.1.2	7613100	1	**Reflex Cap valve SU R 1" x 1"** Reflex Cap valve SU R 1" x 1"	89,50 €	89,50 €

3.2 Water treatment

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.2.1	6811500	1	**Fillcontrol Plus Compact** Reflex Fillcontrol Plus Compact, automatic makeup/filling station	1026,00 €	1026,00 €
3.2.2	9112004	1	**Reflex Fillsoft FE** Reflex FE external pressure sensor for combination of Reflex Fillcontrol & Fillsoft	163,50 €	163,50 €
3.2.3	9131058	1	**Reflex Fillsoft Fillguard Plus** Reflex Fillguard Plus, digital water meter and conductivity meter for Fillsoft	-	-
3.2.4	9131033	1	**Reflex Fillsoft Fillguard Connect** Reflex Fillguard Connect, connection cable for Fillguard Plus	-	-

3.3 Water make-up

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.3.1	9125660	1	**Fillsoft FG I** Reflex Fillsoft housing FG I, Basic valve for makeup water treatment	219,00 €	219,00 €
3.3.2	6811800	1	**Fillsoft FSP 6000** Reflex Fillsoft FSP 6000, softening cartridge for Fillsoft I & II housing	63,80 €	63,80 €



CulturalCenter_1_static

Page 5 from 7

Thinking solutions.

3. System / Net

3.3 Water make-up

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.3.3	9200276	1	**Reflex Fillsoft Tool** Reflex Fillsoft Tool, key for filter head	17,30 €	17,30 €

3.4 Separator Exdirt

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.4.1	9256640	1	**Exdirt D 1 1/2 M** Reflex Exdirt D 1 1/2 M, dirt separator with thread, 110 °C, 10 bar	213,50 €	213,50 €
3.4.2	9254811	1	**Reflex Exiso A/D 22 - 1 1/2** Reflex Exiso A/D 22 - 1 1/2, thermal insulation for Reflex Ex-separator	39,80 €	39,80 €

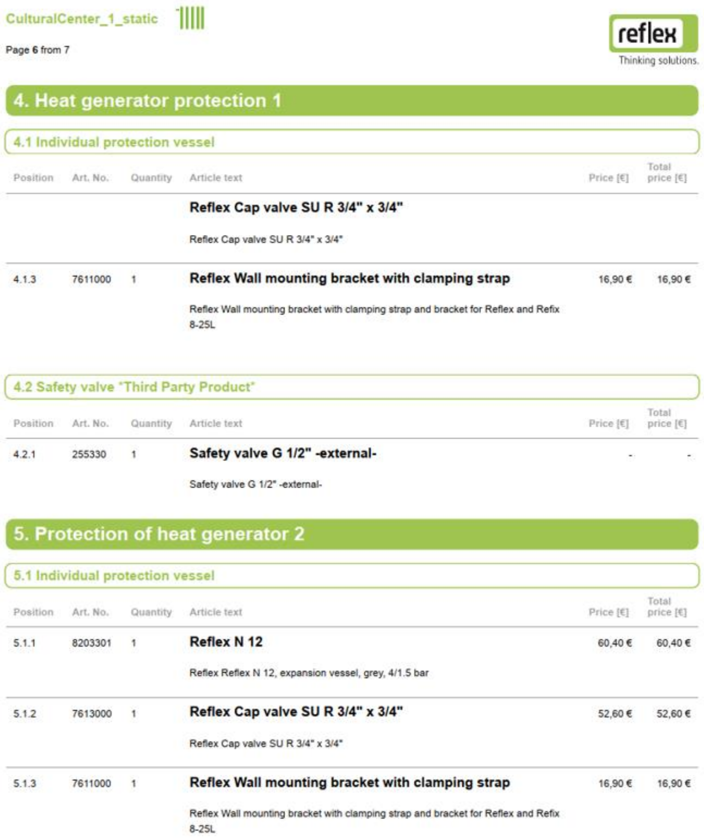
3.5 Separator (Exvoid)

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.5.1	9251040	1	**Exvoid A 1 1/2** Reflex Exvoid A 1 1/2, micro-bubble separator with thread of brass, 110 °C, 10 bar	204,00 €	204,00 €
3.5.2	9254811	1	**Reflex Exiso A/D 22 - 1 1/2** Reflex Exiso A/D 22 - 1 1/2, thermal insulation for Reflex Ex-separator	39,80 €	39,80 €

4. Heat generator protection 1

4.1 Individual protection vessel

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
4.1.1	8202501	1	**Reflex N 8** Reflex Reflex N 8, expansion vessel, grey, 4/1.5 bar	56,90 €	56,90 €
4.1.2	7613000	1	**Reflex Cap valve SU R 3/4" x 3/4"**	52,60 €	52,60 €



CulturalCenter_1_static

Page 6 from 7

Thinking solutions.

4. Heat generator protection 1

4.1 Individual protection vessel

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
			Reflex Cap valve SU R 3/4" x 3/4" Reflex Cap valve SU R 3/4" x 3/4"		
4.1.3	7611000	1	**Reflex Wall mounting bracket with clamping strap** Reflex Wall mounting bracket with clamping strap and bracket for Reflex and Refix 8-25L	16,90 €	16,90 €

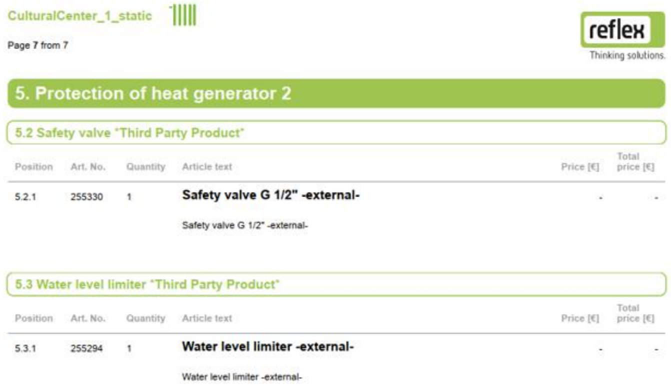
4.2 Safety valve "Third Party Product"

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
4.2.1	255330	1	**Safety valve G 1/2" -external-** Safety valve G 1/2" -external-	-	-

5. Protection of heat generator 2

5.1 Individual protection vessel

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
5.1.1	8203301	1	**Reflex N 12** Reflex Reflex N 12, expansion vessel, grey, 4/1.5 bar	60,40 €	60,40 €
5.1.2	7613000	1	**Reflex Cap valve SU R 3/4" x 3/4"** Reflex Cap valve SU R 3/4" x 3/4"	52,60 €	52,60 €
5.1.3	7611000	1	**Reflex Wall mounting bracket with clamping strap** Reflex Wall mounting bracket with clamping strap and bracket for Reflex and Refix 8-25L	16,90 €	16,90 €



CulturalCenter_1_static

Page 7 from 7

Thinking solutions.

5. Protection of heat generator 2

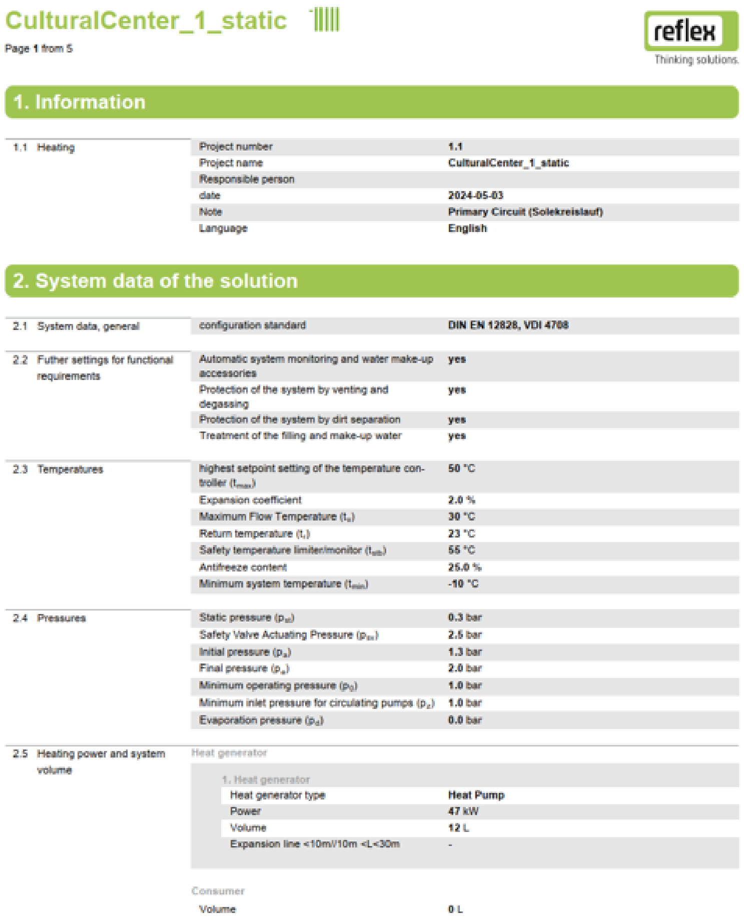
5.2 Safety valve "Third Party Product"

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
5.2.1	255330	1	**Safety valve G 1/2" -external-** Safety valve G 1/2" -external-	-	-

5.3 Water level limiter "Third Party Product"

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
5.3.1	255294	1	**Water level limiter -external-** Water level limiter -external-	-	-

11.4.8.2.2 Primary circuit



CulturalCenter_1_static

Page 1 from 5

reflex Thinking solutions.

1. Information

1.1 Heating	Project number	**1.1**
	Project name	**CulturalCenter_1_static**
	Responsible person	
	date	**2024-05-03**
	Note	**Primary Circuit (Solekreislauf)**
	Language	**English**

2. System data of the solution

2.1 System data, general	configuration standard	**DIN EN 12828, VDI 4708**
2.2 Futher settings for functional requirements	Automatic system monitoring and water make-up accessories	**yes**
	Protection of the system by venting and degassing	**yes**
	Protection of the system by dirt separation	**yes**
	Treatment of the filling and make-up water	**yes**
2.3 Temperatures	highest setpoint setting of the temperature controller (t_{max})	**50 °C**
	Expansion coefficient	**2.0 %**
	Maximum Flow Temperature (t_v)	**30 °C**
	Return temperature (t_r)	**23 °C**
	Safety temperature limiter/monitor (t_{stb})	**55 °C**
	Antifreeze content	**25.0 %**
	Minimum system temperature (t_{min})	**-10 °C**
2.4 Pressures	Static pressure (p_{st})	**0.3 bar**
	Safety Valve Actuating Pressure (p_{sv})	**2.5 bar**
	Initial pressure (p_a)	**1.3 bar**
	Final pressure (p_e)	**2.0 bar**
	Minimum operating pressure (p_0)	**1.0 bar**
	Minimum inlet pressure for circulating pumps (p_z)	**1.0 bar**
	Evaporation pressure (p_d)	**0.0 bar**

2.5 Heating power and system volume

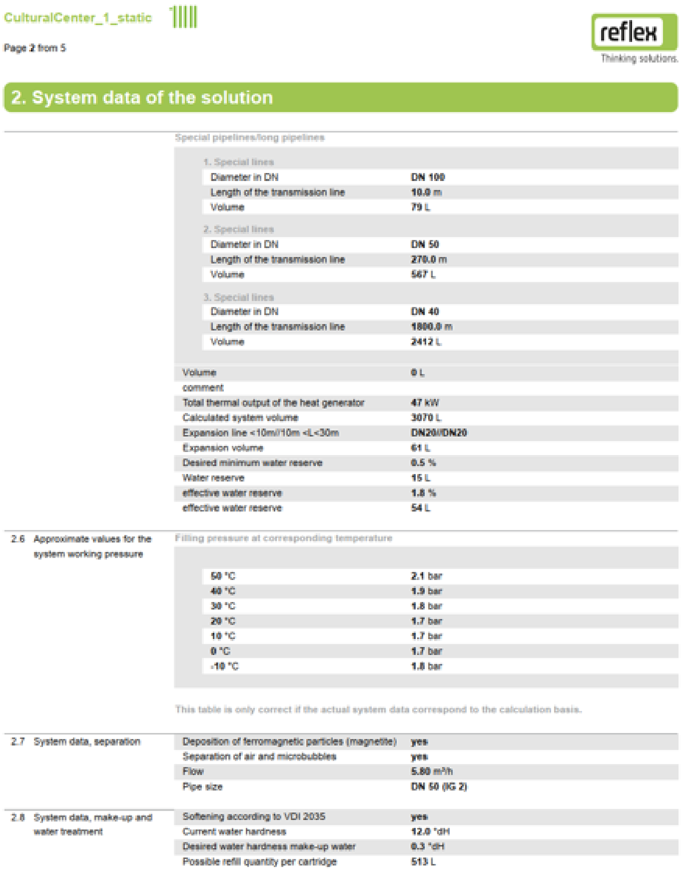
Heat generator

1. Heat generator

Heat generator type	**Heat Pump**
Power	**47 kW**
Volume	**12 L**
Expansion line <10m//10m <L<30m	-

Consumer

Volume	**0 L**



CulturalCenter_1_static

Page 2 from 5

reflex Thinking solutions.

2. System data of the solution

Special pipelines/long pipelines

1. Special lines

Diameter in DN	**DN 100**
Length of the transmission line	**10.0 m**
Volume	**79 L**

2. Special lines

Diameter in DN	**DN 50**
Length of the transmission line	**270.0 m**
Volume	**567 L**

3. Special lines

Diameter in DN	**DN 40**
Length of the transmission line	**1800.0 m**
Volume	**2412 L**

Volume	**0 L**
comment	
Total thermal output of the heat generator	**47 kW**
Calculated system volume	**3070 L**
Expansion line <10m//10m <L<30m	**DN20//DN20**
Expansion volume	**61 L**
Desired minimum water reserve	**0.5 %**
Water reserve	**15 L**
effective water reserve	**1.8 %**
effective water reserve	**54 L**

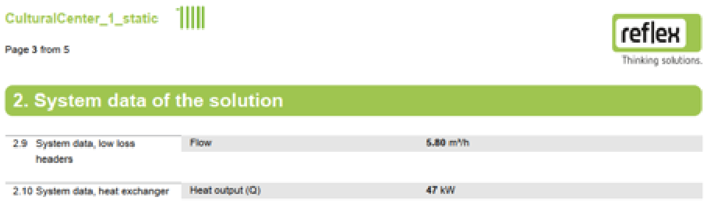
2.6 Approximate values for the system working pressure

Filling pressure at corresponding temperature

50 °C	**2.1 bar**
40 °C	**1.9 bar**
30 °C	**1.8 bar**
20 °C	**1.7 bar**
10 °C	**1.7 bar**
0 °C	**1.7 bar**
-10 °C	**1.8 bar**

This table is only correct if the actual system data correspond to the calculation basis.

2.7 System data, separation	Deposition of ferromagnetic particles (magnetite)	**yes**
	Separation of air and microbubbles	**yes**
	Flow	**5.80 m³/h**
	Pipe size	**DN 50 (IG 2)**
2.8 System data, make-up and water treatment	Softening according to VDI 2035	**yes**
	Current water hardness	**12.0 °dH**
	Desired water hardness make-up water	**0.3 °dH**
	Possible refill quantity per cartridge	**513 L**



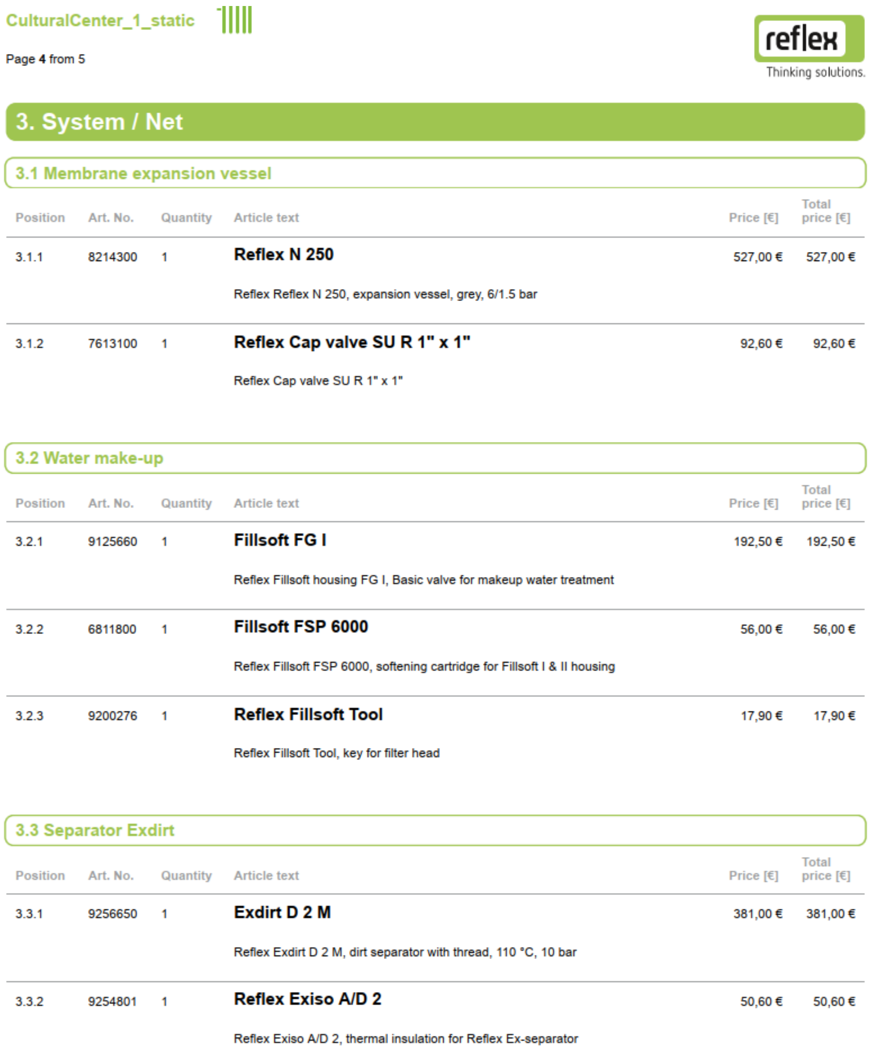
CulturalCenter_1_static

Page 3 from 5

reflex Thinking solutions.

2. System data of the solution

2.9 System data, low loss headers	Flow	**5.80 m³/h**
2.10 System data, heat exchanger	Heat output (Q)	**47 kW**



CulturalCenter_1_static

Page **4** from 5

reflex
Thinking solutions.

3. System / Net

3.1 Membrane expansion vessel

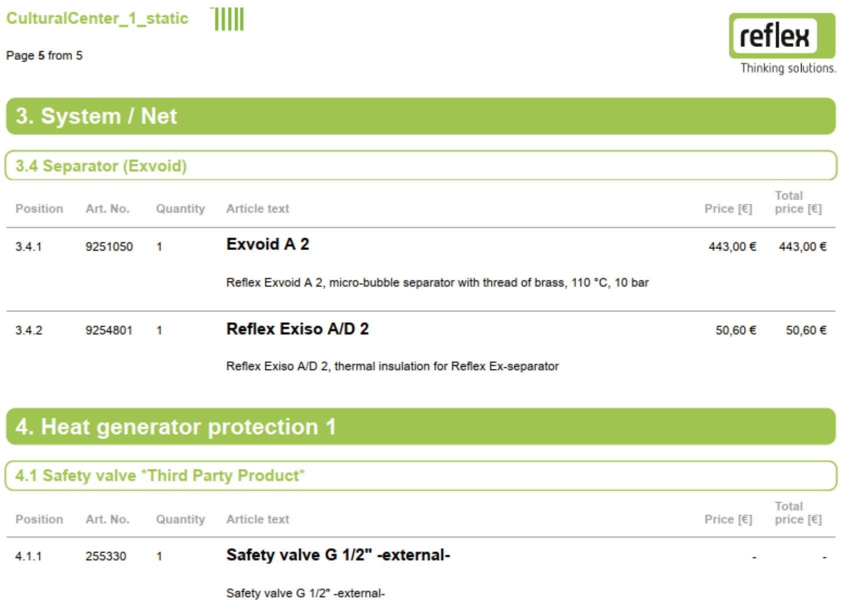
Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.1.1	8214300	1	**Reflex N 250** Reflex Reflex N 250, expansion vessel, grey, 6/1.5 bar	527,00 €	527,00 €
3.1.2	7613100	1	**Reflex Cap valve SU R 1" x 1"** Reflex Cap valve SU R 1" x 1"	92,60 €	92,60 €

3.2 Water make-up

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.2.1	9125660	1	**Fillsoft FG I** Reflex Fillsoft housing FG I, Basic valve for makeup water treatment	192,50 €	192,50 €
3.2.2	6811800	1	**Fillsoft FSP 6000** Reflex Fillsoft FSP 6000, softening cartridge for Fillsoft I & II housing	56,00 €	56,00 €
3.2.3	9200276	1	**Reflex Fillsoft Tool** Reflex Fillsoft Tool, key for filter head	17,90 €	17,90 €

3.3 Separator Exdirt

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.3.1	9256650	1	**Exdirt D 2 M** Reflex Exdirt D 2 M, dirt separator with thread, 110 °C, 10 bar	381,00 €	381,00 €
3.3.2	9254801	1	**Reflex Exiso A/D 2** Reflex Exiso A/D 2, thermal insulation for Reflex Ex-separator	50,60 €	50,60 €



CulturalCenter_1_static

Page **5** from 5

reflex
Thinking solutions.

3. System / Net

3.4 Separator (Exvoid)

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
3.4.1	9251050	1	**Exvoid A 2** Reflex Exvoid A 2, micro-bubble separator with thread of brass, 110 °C, 10 bar	443,00 €	443,00 €
3.4.2	9254801	1	**Reflex Exiso A/D 2** Reflex Exiso A/D 2, thermal insulation for Reflex Ex-separator	50,60 €	50,60 €

4. Heat generator protection 1

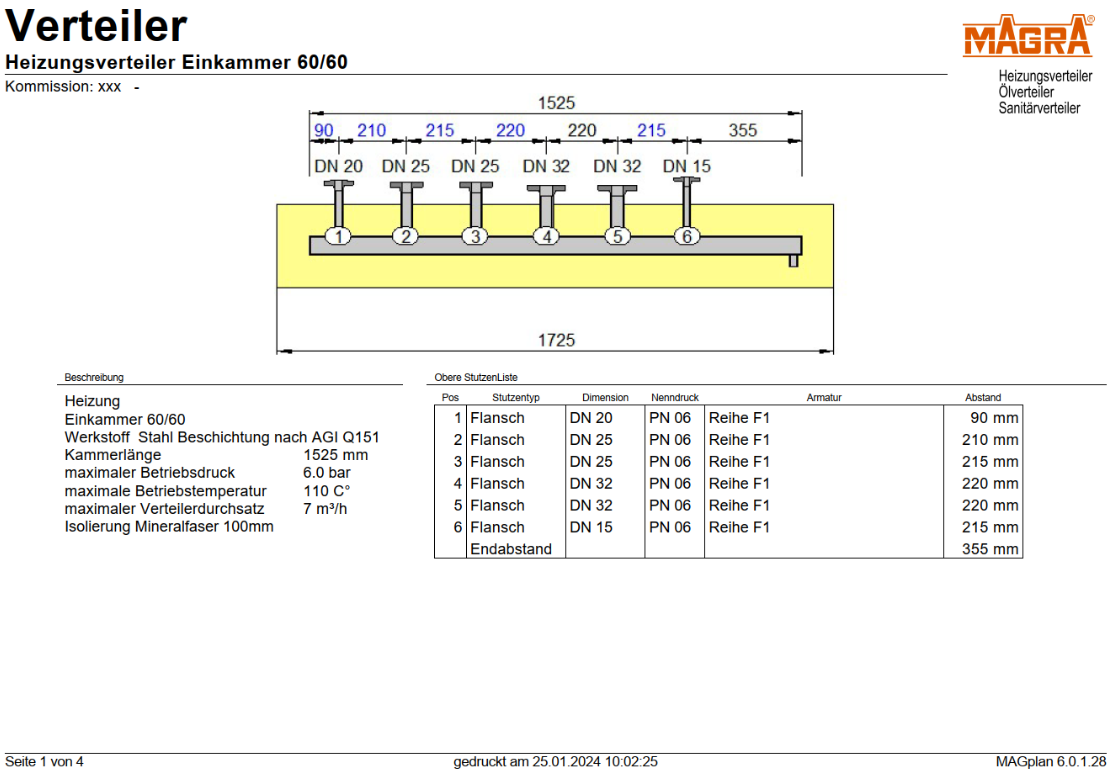
4.1 Safety valve "Third Party Product"

Position	Art. No.	Quantity	Article text	Price [€]	Total price [€]
4.1.1	255330	1	**Safety valve G 1/2" -external-** Safety valve G 1/2" -external-	-	-

11.4.8.3 Manifolds

11.4.8.3.1 Heating manifolds for supply distribution and return collection

- Planned with MAGplan 6.0.1.28 of MAGRA Maile + Grammer GmbH: (MAGRA Maile + Grammer GmbH, 2024)



Verteiler

Heizungsverteiler Einkammer 60/60

Kommission: xxx -

Beschreibung

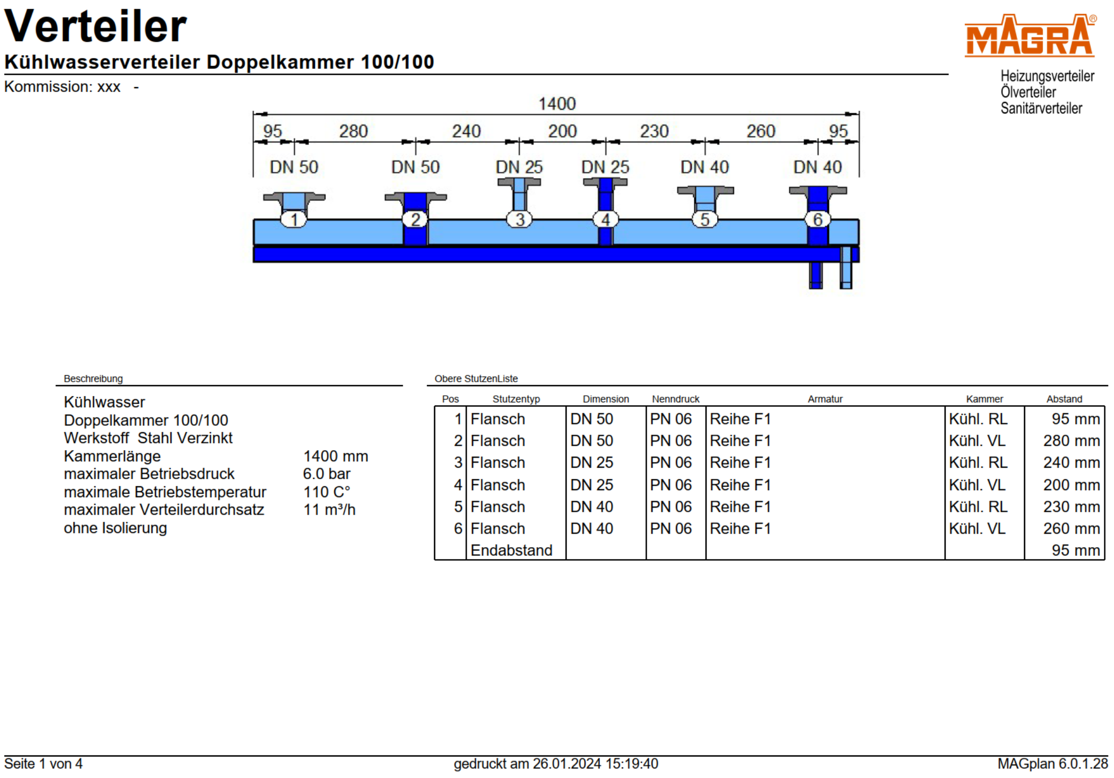
Heizung
Einkammer 60/60
Werkstoff Stahl Beschichtung nach AGI Q151
Kammerlänge 1525 mm
maximaler Betriebsdruck 6.0 bar
maximale Betriebstemperatur 110 C°
maximaler Verteilerdurchsatz 7 m³/h
Isolierung Mineralfaser 100mm

Obere StutzenListe

Pos	Stutzentyp	Dimension	Nenndruck	Armatur	Abstand
1	Flansch	DN 20	PN 06	Reihe F1	90 mm
2	Flansch	DN 25	PN 06	Reihe F1	210 mm
3	Flansch	DN 25	PN 06	Reihe F1	215 mm
4	Flansch	DN 32	PN 06	Reihe F1	220 mm
5	Flansch	DN 32	PN 06	Reihe F1	220 mm
6	Flansch	DN 15	PN 06	Reihe F1	215 mm
	Endabstand				355 mm

Seite 1 von 4 gedruckt am 25.01.2024 10:02:25 MAGplan 6.0.1.28

11.4.8.3.2 Cooling manifold



Verteiler

Kühlwasserverteiler Doppelkammer 100/100

Kommission: xxx -

Beschreibung

Kühlwasser
Doppelkammer 100/100
Werkstoff Stahl Verzinkt
Kammerlänge 1400 mm
maximaler Betriebsdruck 6.0 bar
maximale Betriebstemperatur 110 C°
maximaler Verteilerdurchsatz 11 m³/h
ohne Isolierung

Obere StutzenListe

Pos	Stutzentyp	Dimension	Nenndruck	Armatur	Kammer	Abstand
1	Flansch	DN 50	PN 06	Reihe F1	Kühl. RL	95 mm
2	Flansch	DN 50	PN 06	Reihe F1	Kühl. VL	280 mm
3	Flansch	DN 25	PN 06	Reihe F1	Kühl. RL	240 mm
4	Flansch	DN 25	PN 06	Reihe F1	Kühl. VL	200 mm
5	Flansch	DN 40	PN 06	Reihe F1	Kühl. RL	230 mm
6	Flansch	DN 40	PN 06	Reihe F1	Kühl. VL	260 mm
	Endabstand					95 mm

Seite 1 von 4 gedruckt am 26.01.2024 15:19:40 MAGplan 6.0.1.28

PART II: BUDGET

1 BUDGET

The following part consists in detailing the cost estimation associated with the project development. The budget includes the costs related to the main and secondary activities as well as those generated using required resources and equipment.

1.1 Budget related to main activities

The main activities consist in the elaboration of the project by the project engineer which can be split up as follows:

- Review of the state of the art: Review of different references, standards and laws for the elaboration of the theoretical base to develop the project. Estimated duration: one month with approximately 132 hours of working time.
- Review of the existent project documentation: Review of the documentation related to the existent building and to the planned building complex, including plans, technical documentation, and requirements. Estimated duration: half a month with approximately 66 hours of working time.
- Determination of heating and cooling load: Determination of the heating and cooling load of the building complex including the input of the geometry and the technical characteristics of the building to a calculation program, the calculation, and the interpretation of the results. Estimated duration: one month with approximately 132 hours of working time.
- Selection and design of the in-room terminal systems: This part includes the selection and design of the in-room terminal systems like radiant floor, ceiling, and radiators on base of corresponding data sheets. Estimated duration: half a month with approximately 66 hours of working time.
- Selection and design of the distribution network elements: This section contains the selection and design of the distribution network itself, especially its visual representation in plans as well as the calculation of corresponding elements like circulation pumps, strainers, manifolds etc. Estimated duration: one month with approximately 132 hours of working time.
- Comparison, selection, and design of the energy generation system: During this step, a techno-economic analysis and environmental assessment results in the selection and detailed design of the energy generation system. Estimated duration: two months with approximately 264 hours of working time.
- Redaction of the report: Finally, the report describing the elaboration of the project is included in the last section. Estimated duration: one month with approximately 132 hours of working time.

1.2 Budget related to secondary activities

The secondary activities include tutoring, office expenses, etc., as précised in the following:

- Supervision by the university tutor and by the responsible of the HVAC-department: The university tutor as well as the responsible of the corresponding department have supported the realization of the present work with an estimated duration of each approximately 80 hours.

- Office expenses: The use of the office includes the use of electricity, internet service and renting. The duration of the office use is esteemed to be about seven months.

1.3 Budget related to required resources and equipment

Finally, a budget related to engineering equipment as hardware and software is esteemed as follows:

- Hardware: The personal computer used during the development of the project.
- Software: For the realization of the drawings, AutoCAD (2023) software has been used. For the calculations of the heating and cooling load as well as of the distribution network, mainly the program C.A.T.S. has been employed. Furthermore, the Microsoft Office package has been served for calculations (Microsoft Excel) and for report writing (Microsoft Word). For the management of the sources, Mendeley Reference Manager has been used. Finally, different software programs facilitated by the corresponding manufacturer helped developing the project but will not be considered further in the budget since those programs have been provided for free.
- Scientific resources: Necessary literature and required standards for the realization of the project must normally be taken into account but have been facilitated by the free library access as student at the university.

1.4 Unit costs of budget expenses

Unit costs of the activities and equipment required for the elaboration of the project					
Item	**Amount [-]**	**Unit [-]**	**Unit cost [€]**	**Depreciation factor [-]**	**Total cost [€]**
MAIN ACTIVITIES					27,720
State of the art	132	Hour	30	-	3960
Review of the existent documentation	66	Hour	30	-	1980
Determination of heating and cooling load	132	Hour	30	-	3960
Design of the in-room terminal systems	66	Hour	30	-	1980
Design of distribution network	132	Hour	30	-	3960
Design of energy generation system	264	Hour	30	-	7920
Report redaction	132	Hour	30	-	3960
SECONDARY ACTIVITIES					12,600
Supervision by the university tutor	80	Hour	60	-	4800
Supervision by the company responsible	80	Hour	80	-	6400
Proportional electricity bill	7	Month	40	-	280
Proportional internet service	7	Month	10	-	70
Proportional office rent	7	Month	150	-	1050
EQUIPMENT					2,705.62
Personal computer of project engineer 1)	1	Unit	2300	0.12	276.00
AutoCAD Software (2023) 2)	1	Annual software license	1936	0.58	1122.88
C.A.T.S. Software 2)	1	Annual software license	2124	0.58	1232.92
Microsoft Office Package (Individual) 2)	1	Annual software license	69	0.58	40.02

Mendeley Reference Manager [2)]	1	Annual software license	60	0.58	34.80
Scientific Resources	1	Unit	0	0.58	0.00
1) Depreciation factor of 0.12, with a total possible use period of 5 years and a real using period of 7 months					
2) Depreciation factor of 0.58, with a total possible use period of 1 years and a real using period of 7 months					

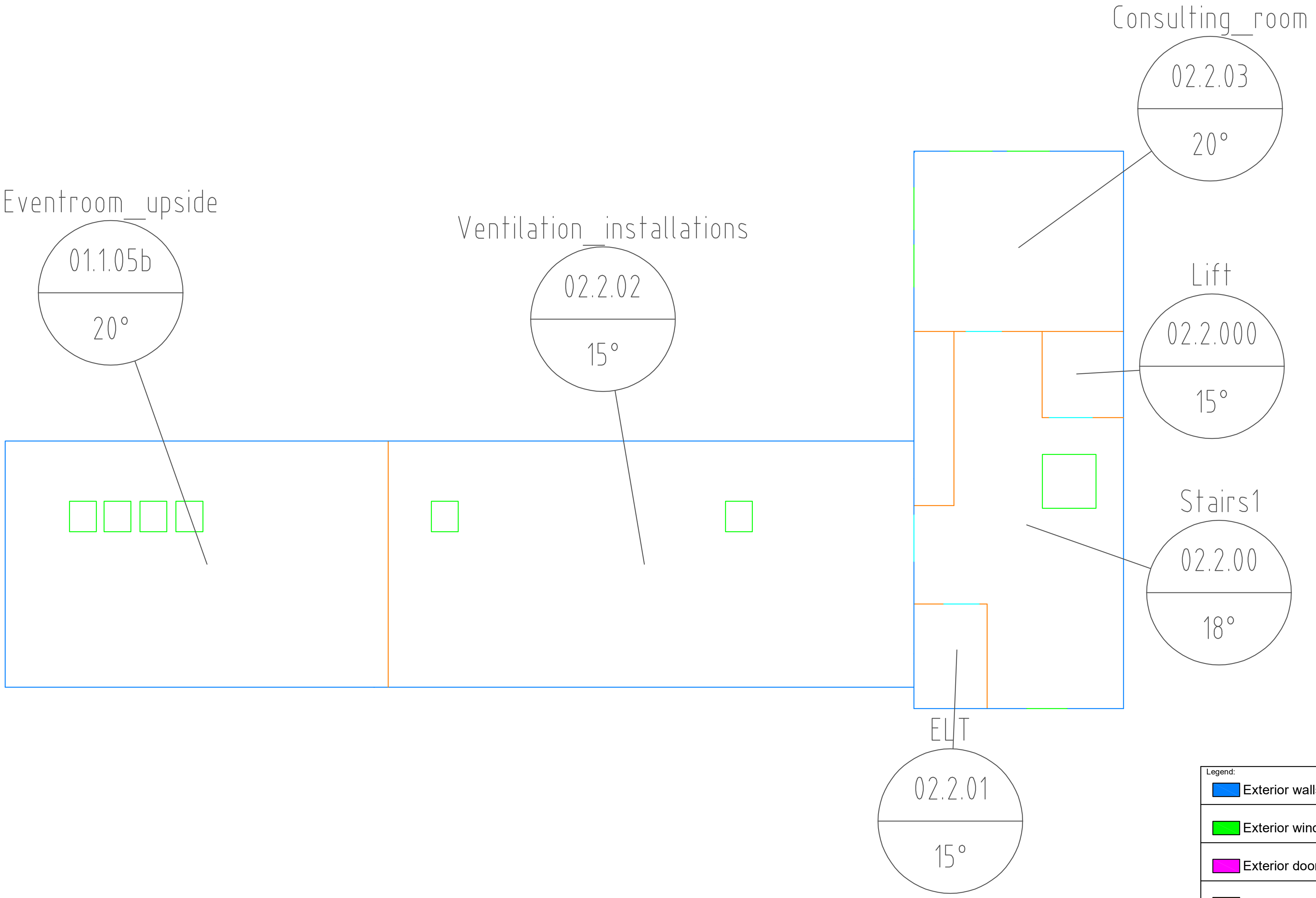
1.5 Budget of the study

Finally, the total costs of the project are illustrated in the following table, including an industrial profit of 6 % and the corresponding value-added tax.

Total budget required for the elaboration of the project	
Item	**Costs [€]**
Main activities	27,720.00
Secondary activities	12,600.00
Equipment	2,705.62
TOTAL PROJECT COSTS	43,025.62
Industrial profit (6%)	2,581.54
OVERALL PROJECT COSTS + BENEFITS	45,607.16
Value-added tax (21%)	9,577.50
FINAL PROJECT BUDGET	**55,184.66**

The final budget of this project is fifty-five thousand one hundred and eighty-four euros with sixty-six cents (including VAT).

PART III: TECHNICAL DRAWINGS



Legend:

🟦 Exterior walls

🟩 Exterior windows

🟪 Exterior doors

🟧 Interior walls

🟦 Interior openings

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

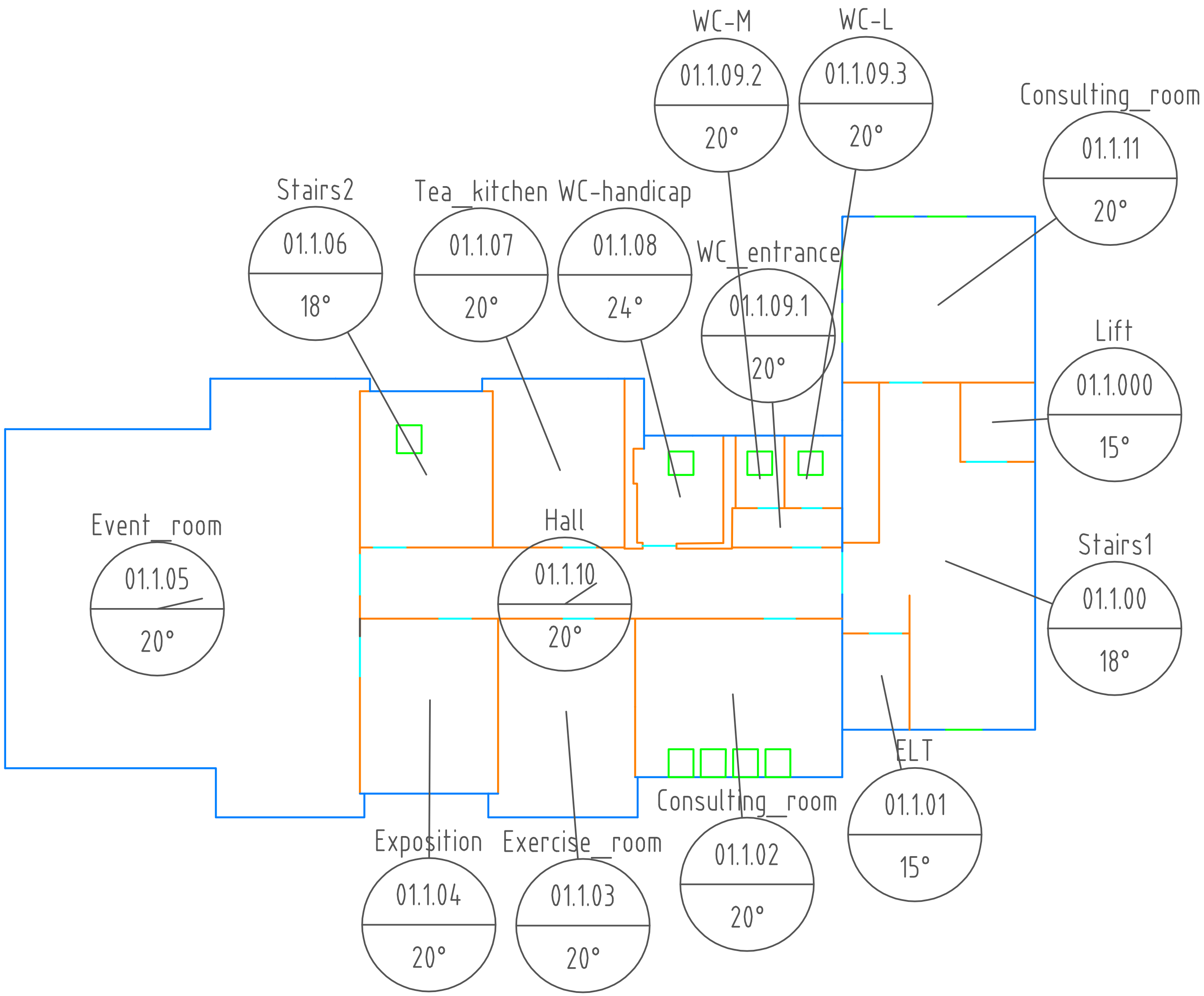
Plan: Room distribution with interior design temperature of floor level 2

Author: Luise Kleideiter

Date: November 2023

Scale: 1:150

Plan No.: 1



Legend:

🟦 Exterior walls

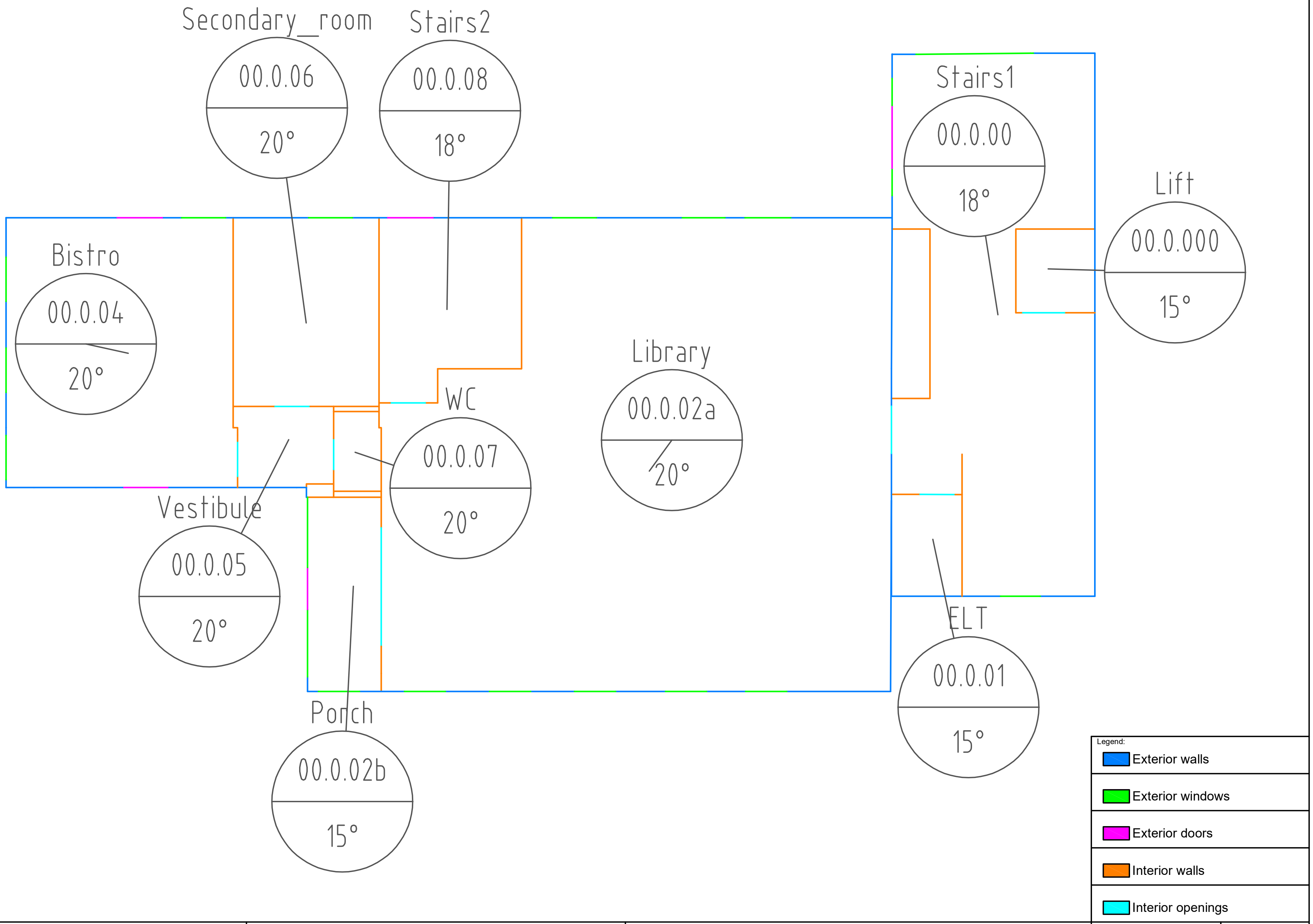
🟩 Exterior windows

🟪 Exterior doors

🟧 Interior walls

🟦 Interior openings

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT UNIVERSITAT POLITÈCNICA DE VALÈNCIA ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA	Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF	Plan: Room distribution with interior design temperature of floor level 1	Date: November 2023	Plan No.: 2
		Author: Luise Kleideiter	Scale: 1:200	



MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

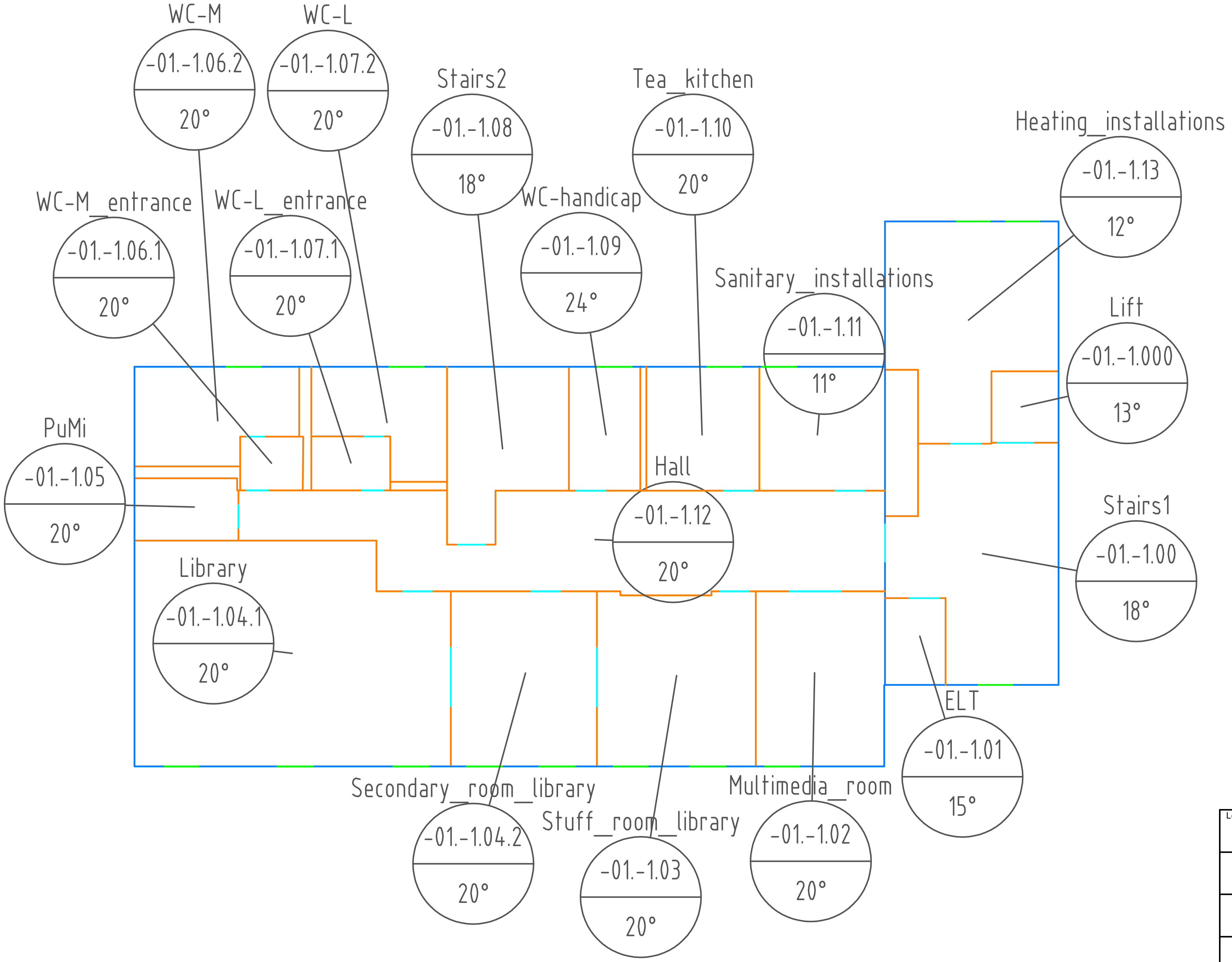
Plan: Room distribution with interior design temperature of floor level 0

Author: Luise Kleideiter

Date: November 2023

Scale: 1:150

Plan No.: 3



Legend:

🟦 Exterior walls

🟩 Exterior windows

🟪 Exterior doors

🟧 Interior walls

🟦 Interior openings

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

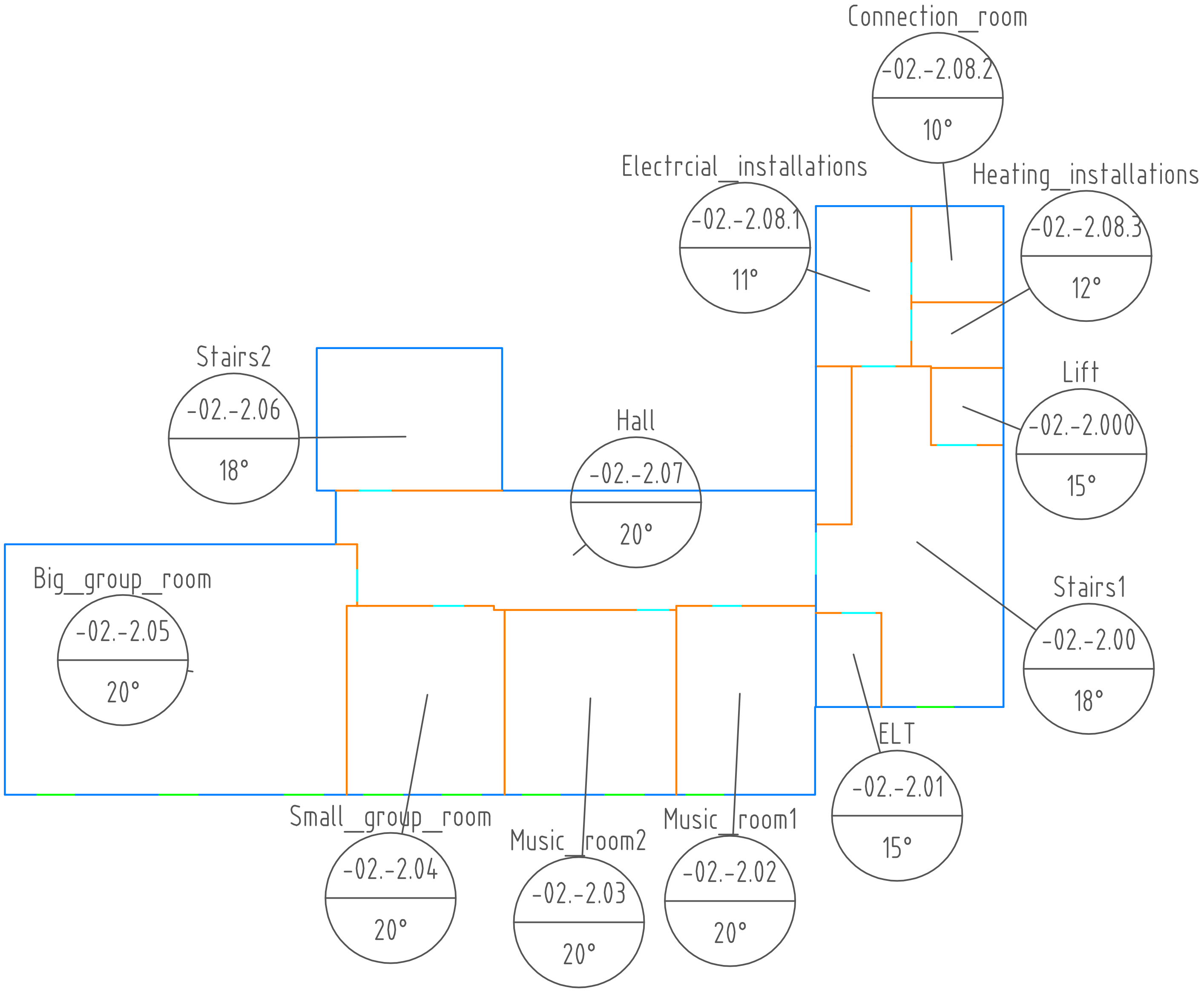
Plan: Room distribution with interior design temperature of floor level -1

Author: Luise Kleideiter

Date: November 2023

Scale: 1:200

Plan No.: 4



Legend:

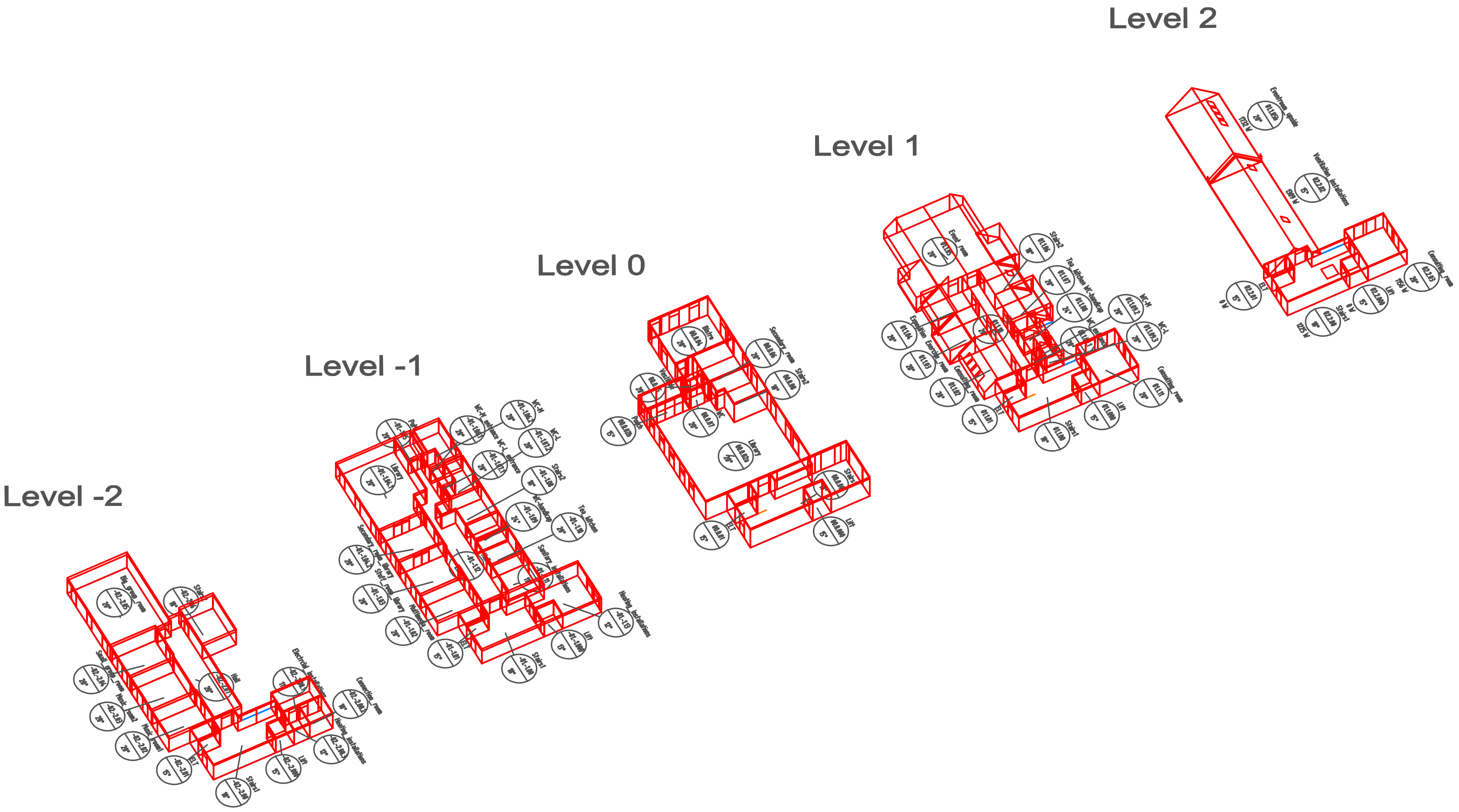
- 🟦 Exterior walls
- 🟩 Exterior windows
- 🟪 Exterior doors
- 🟧 Interior walls
- 🟦 Interior openings

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project:	DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF
Plan:	Room distribution with interior design temperature of floor level -2
Author:	Luise Kleideiter
Date:	November 2023
Scale:	1:200
Plan No.:	5



MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

ESCUELA
TÉCNICA
SUPERIOR
INGENIERÍA
INDUSTRIAL
VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

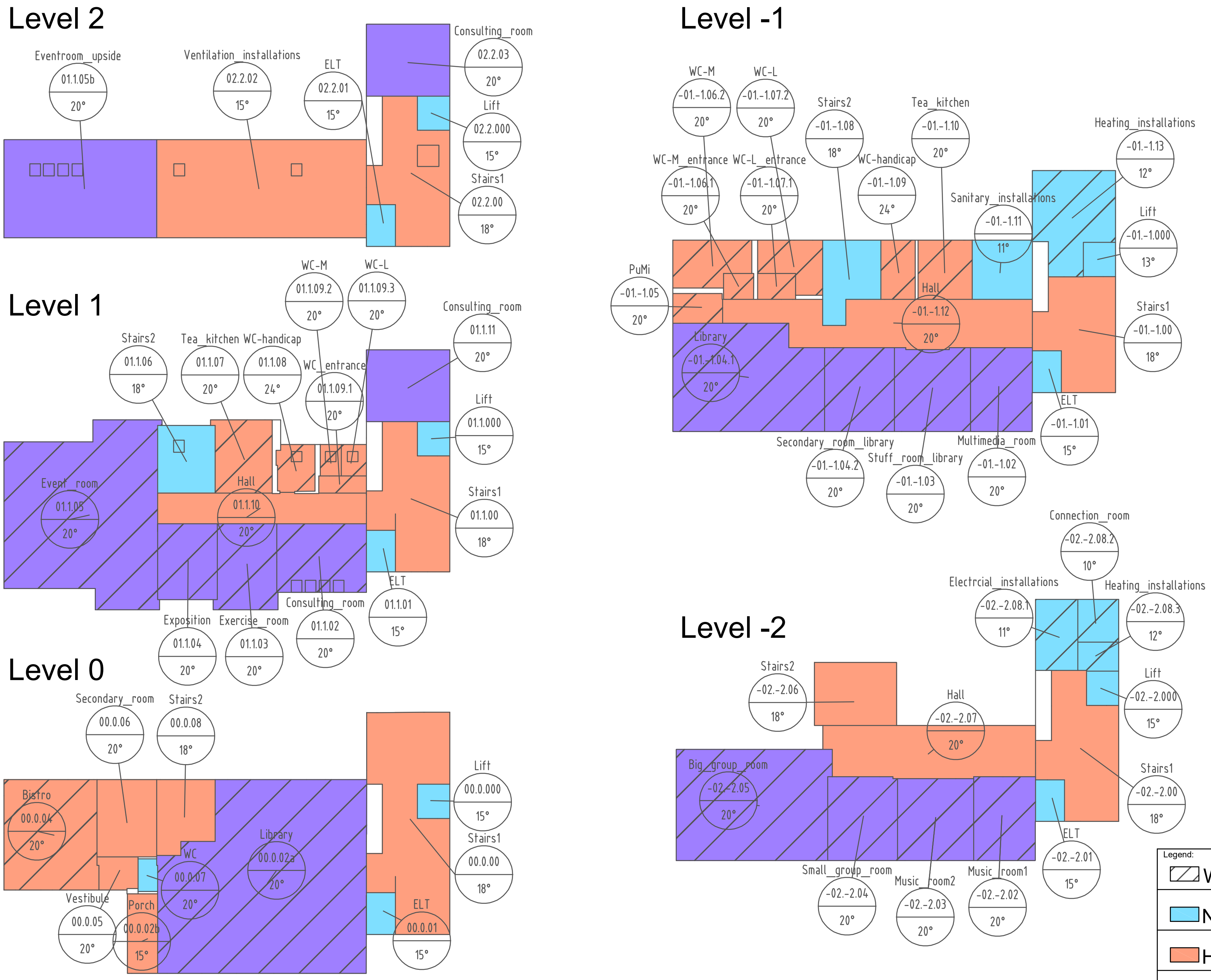
Plan: 3D-model of building complex

Author: Luise Kleideiter

Date: November 2023

Scale: 1:650

Plan No.: 6



Legend:

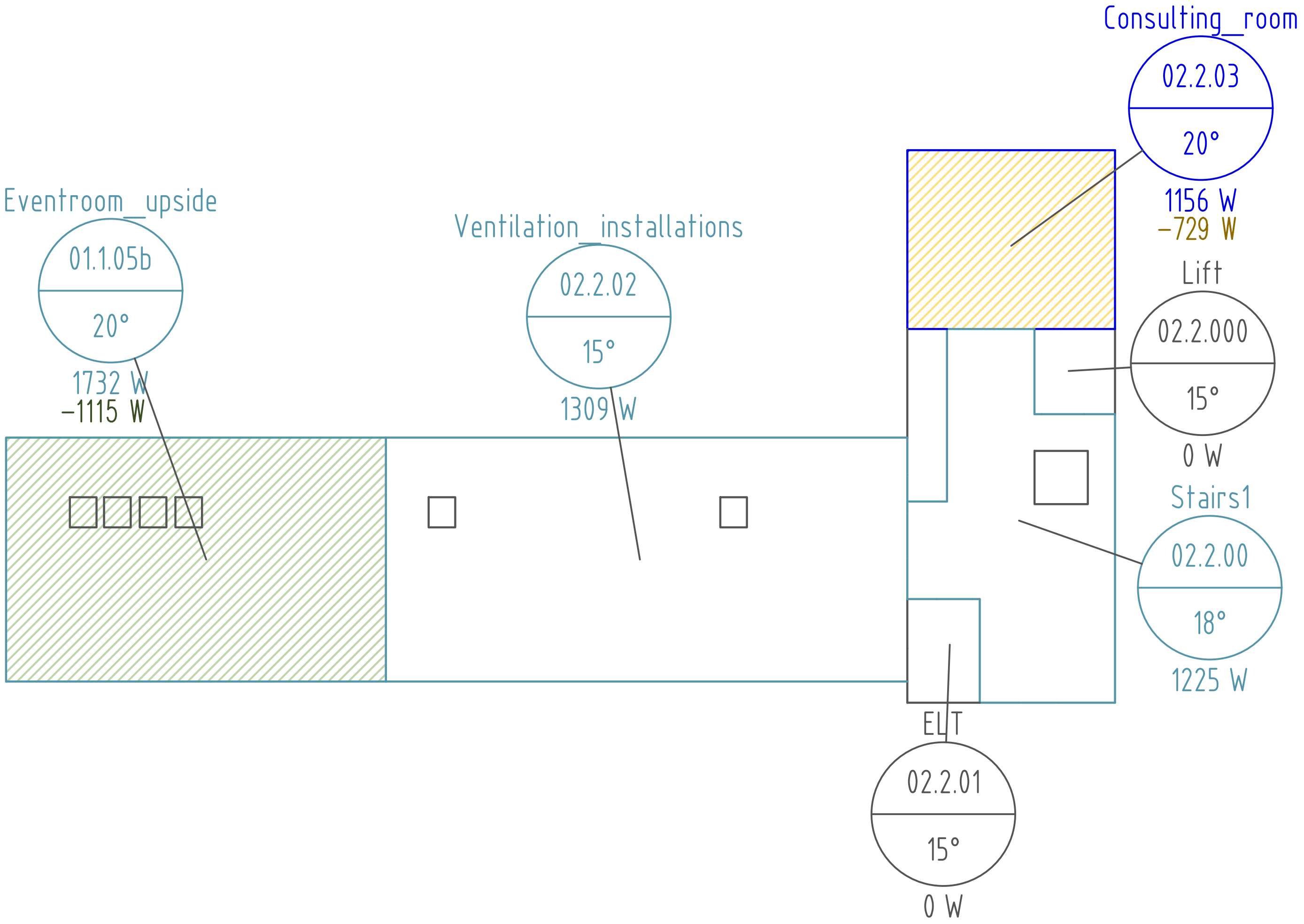
▨ With mechanical ventilation

🟦 Non-conditioned rooms

🟧 Heated rooms

🟪 Heated and cooled rooms

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT UNIVERSITAT POLITÈCNICA DE VALÈNCIA ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA	Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF	Plan: Illustration of non-conditioned, heated, cooled and ventilated rooms	Date: November 2023	Plan No.: 7
		Author: Luise Kleideiter	Scale: 1:400	



Legend:
- ■ Unheated rooms
- 🟦 Heating load of 0 - 40 W/m²
- 🟦 Heating load of 40 - 80 W/m²
- 🟪 Heating load of 80 - 120 W/m²
- 🟥 Heating load of 120-170 W/m²
- ▨ Cooling load of 0 - -20 W/m²
- ▨ Cooling load of -20 - -40 W/m²
- ▨ Cooling load of -40 - -60 W/m²
- ▨ Cooling load of -60 - -80 W/m²

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

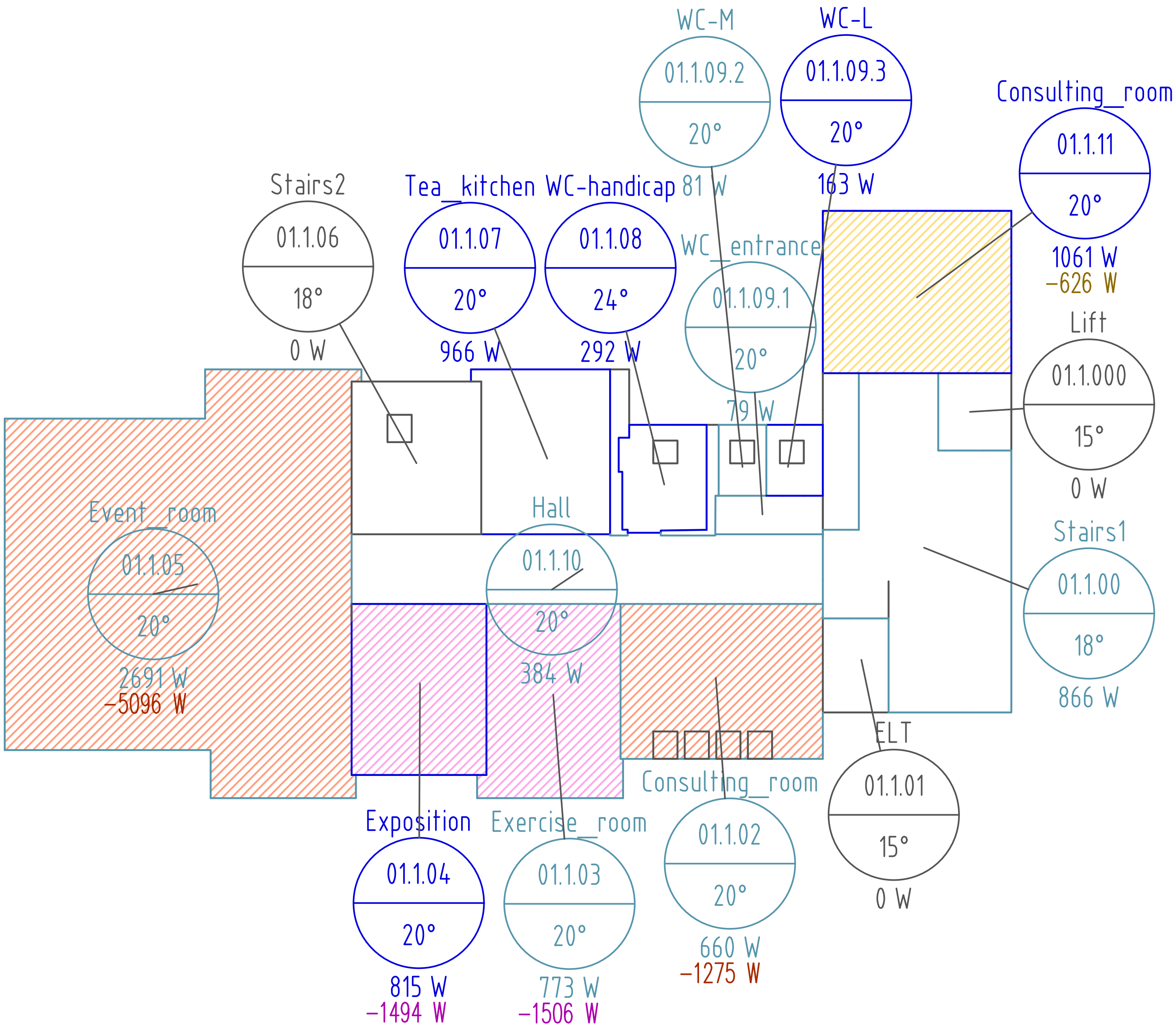
Plan: Heating and cooling load of each room of floor level 2

Author: Luise Kleideiter

Date: November 2023

Scale: 1:200

Plan No.: 8



Legend:

- ■ Unheated rooms
- ■ Heating load of 0 - 40 W/m²
- ■ Heating load of 40 - 80 W/m²
- ■ Heating load of 80 - 120 W/m²
- ■ Heating load of 120-170 W/m²
- ▨ Cooling load of 0 - -20 W/m²
- ▨ Cooling load of -20 - -40 W/m²
- ▨ Cooling load of -40 - -60 W/m²
- ▨ Cooling load of -60 - -80 W/m²

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

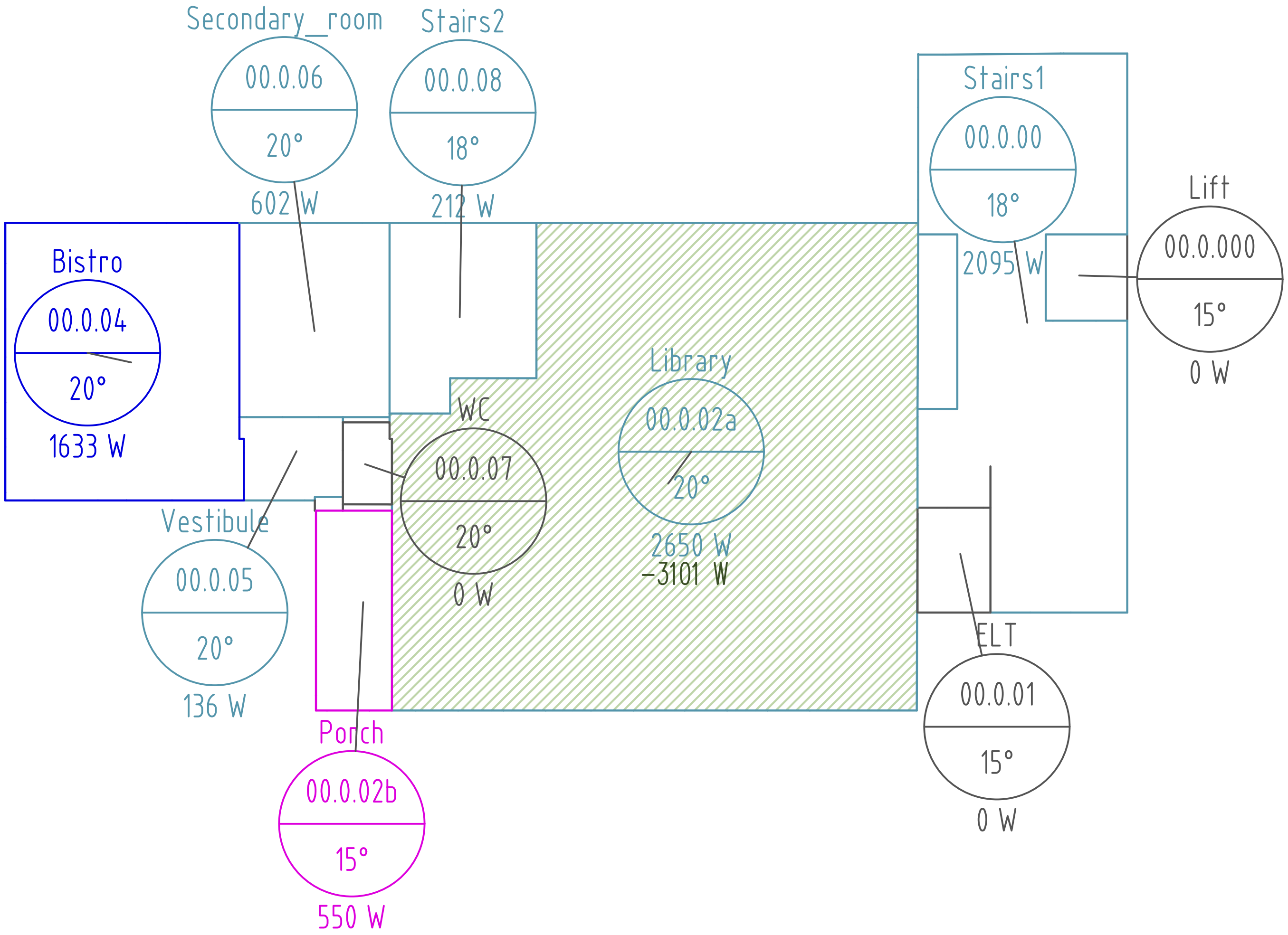
Plan: Heating and cooling load of each room of floor level 1

Author: Luise Kleideiter

Date: November 2023

Scale: 1:200

Plan No.: 9



Legend:

- ■ Unheated rooms
- 🟦 Heating load of 0 - 40 W/m²
- 🟦 Heating load of 40 - 80 W/m²
- 🟪 Heating load of 80 - 120 W/m²
- 🟥 Heating load of 120-170 W/m²
- ▨ Cooling load of 0 - -20 W/m²
- ▨ Cooling load of -20 - -40 W/m²
- ▨ Cooling load of -40 - -60 W/m²
- ▨ Cooling load of -60 - -80 W/m²

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

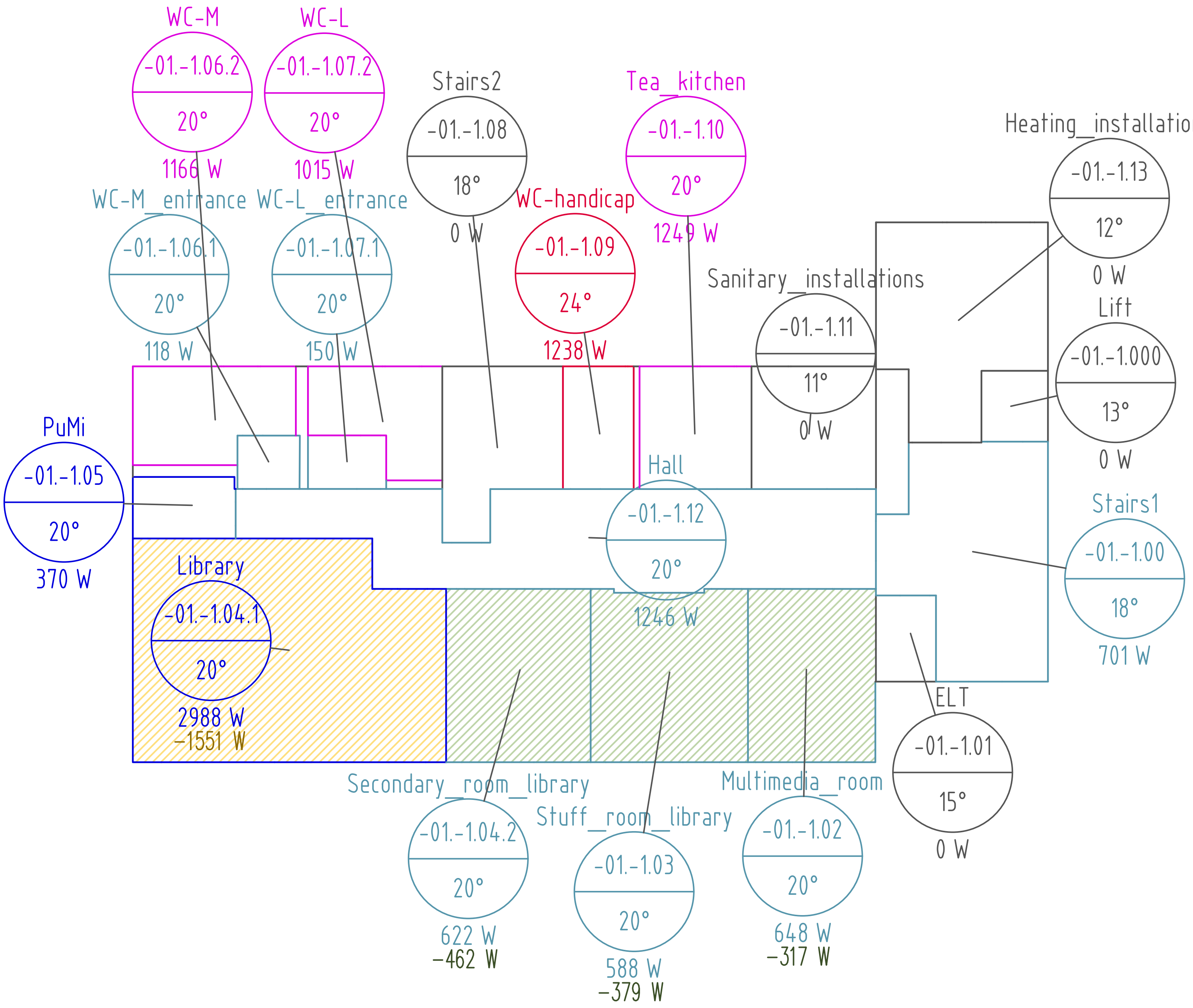
Plan: Heating and cooling load of each room of floor level 0

Author: Luise Kleideiter

Date: November 2023

Scale: 1:200

Plan No.: 10



Legend:

■	Unheated rooms
■	Heating load of 0 - 40 W/m²
■	Heating load of 40 - 80 W/m²
■	Heating load of 80 - 120 W/m²
■	Heating load of 120-170 W/m²
▨	Cooling load of 0 - -20 W/m²
▨	Cooling load of -20 - -40 W/m²
▨	Cooling load of -40 - -60 W/m²
▨	Cooling load of -60 - -80 W/m²

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

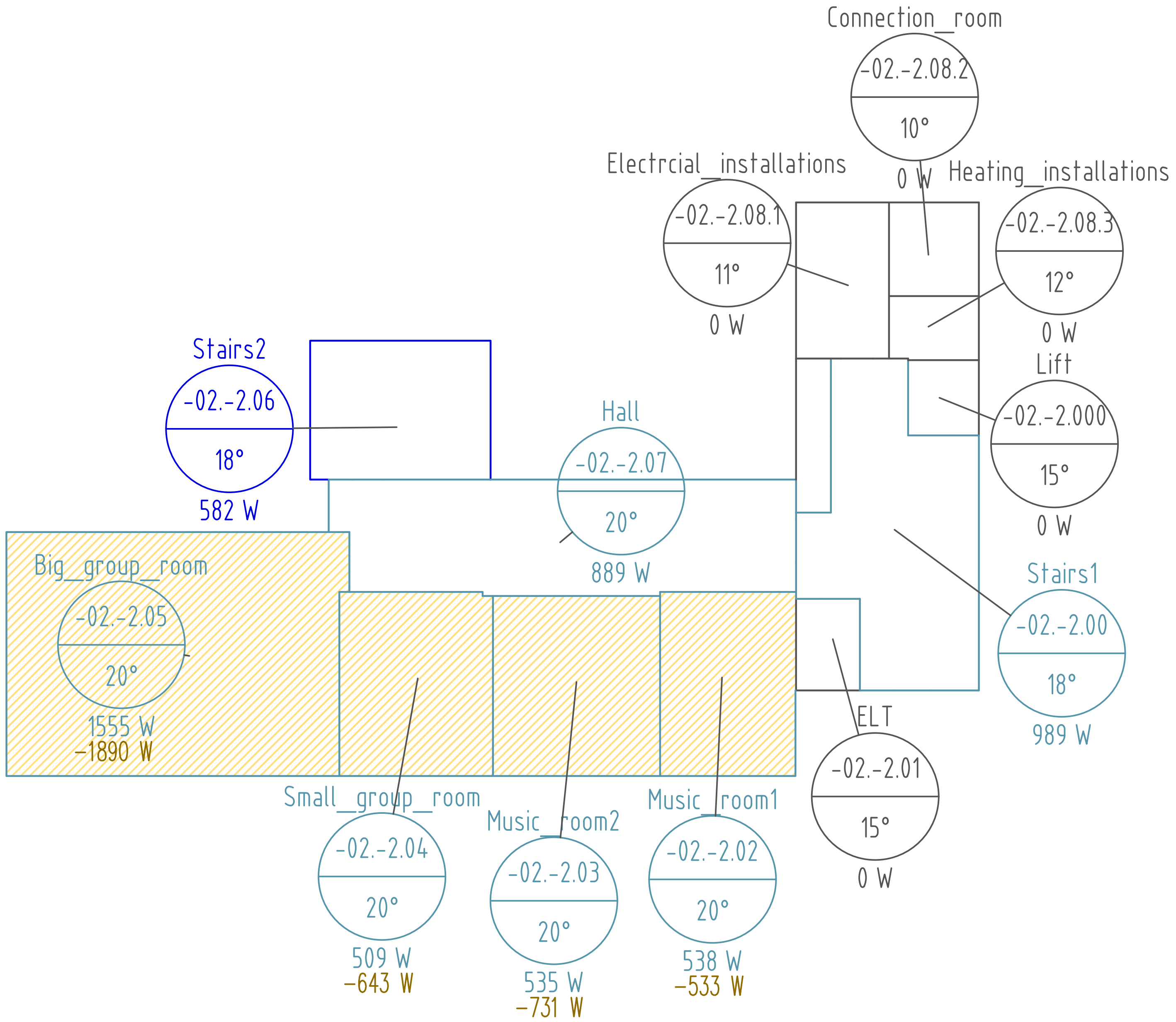
Plan: Heating and cooling load of each room of floor level -1

Author: Luise Kleideiter

Date: November 2023

Scale: 1:200

Plan No.: 11



Legend:

⬛ Unheated rooms
🟦 Heating load of 0 - 40 W/m²
🟦 Heating load of 40 - 80 W/m²
🟪 Heating load of 80 - 120 W/m²
🟥 Heating load of 120-170 W/m²
▨ Cooling load of 0 - -20 W/m²
▨ Cooling load of -20 - -40 W/m²
▨ Cooling load of -40 - -60 W/m²
▨ Cooling load of -60 - -80 W/m²

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

Plan: Heating and cooling load of each room of floor level -2

Author: Luise Kleideiter

Date: November 2023

Scale: 1:200

Plan No.: 12

Legend:

- ⬜ Non-conditioned rooms
- 🟦 Radiators
- 🟫 Radiant floor
- 🟥 Radiant ceiling panels
- 🟨 Chilled beams

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

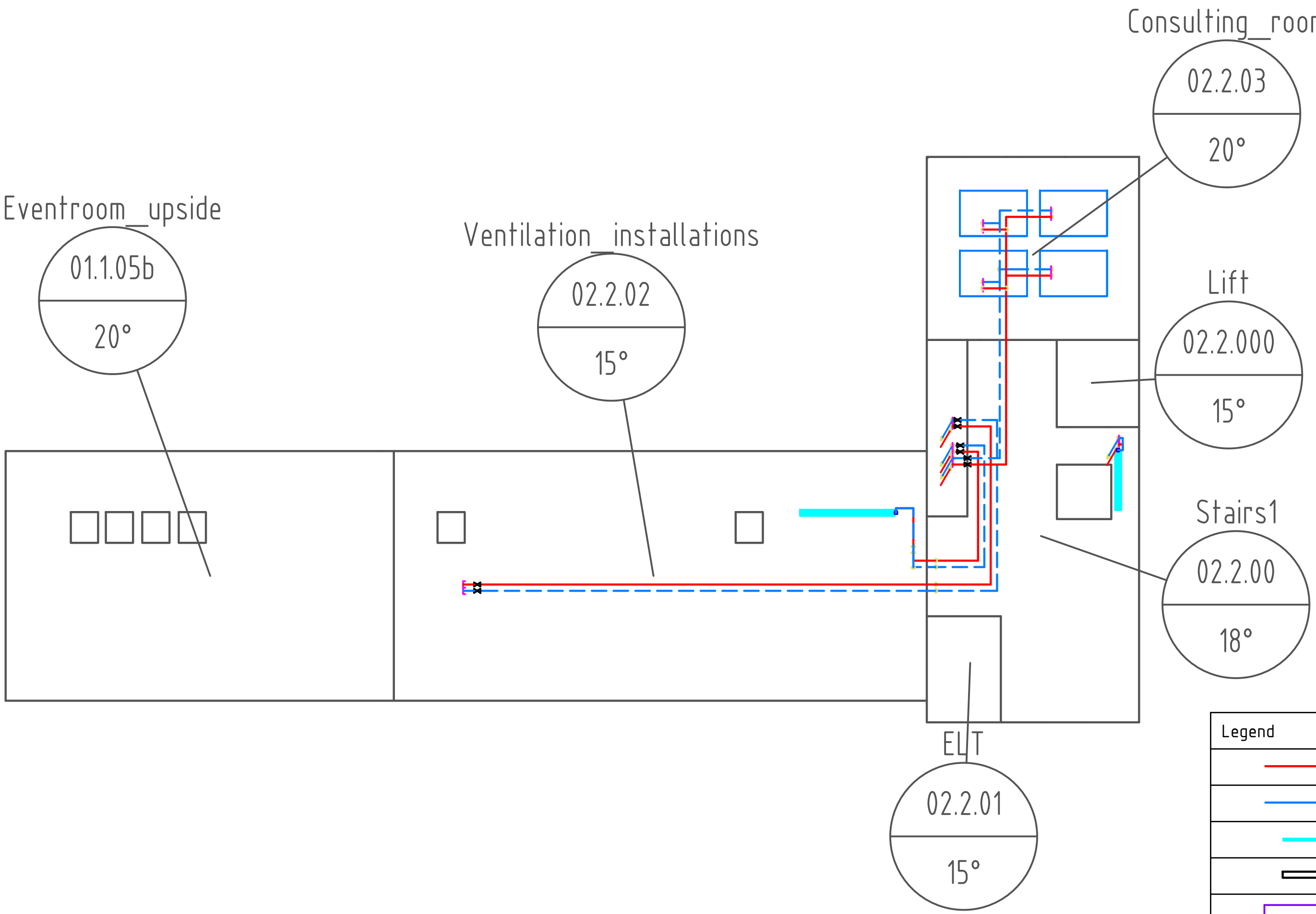
Plan: Illustration of terminal unit selection for each room

Author: Luise Kleideiter

Date: November 2023

Scale: 1:400

Plan No.: 13



Legend	
🟥	Heating – Supply
🟦	Heating – Return
🟦	Radiator
▭	Radiant floor heating – manifold
▭	Radiant floor heating areas
▭	Radiant ceiling heating panels
▭	Heated beams
⋈	Gate and control valves
⟋ ⟋	Direction: from bottom to top going through

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

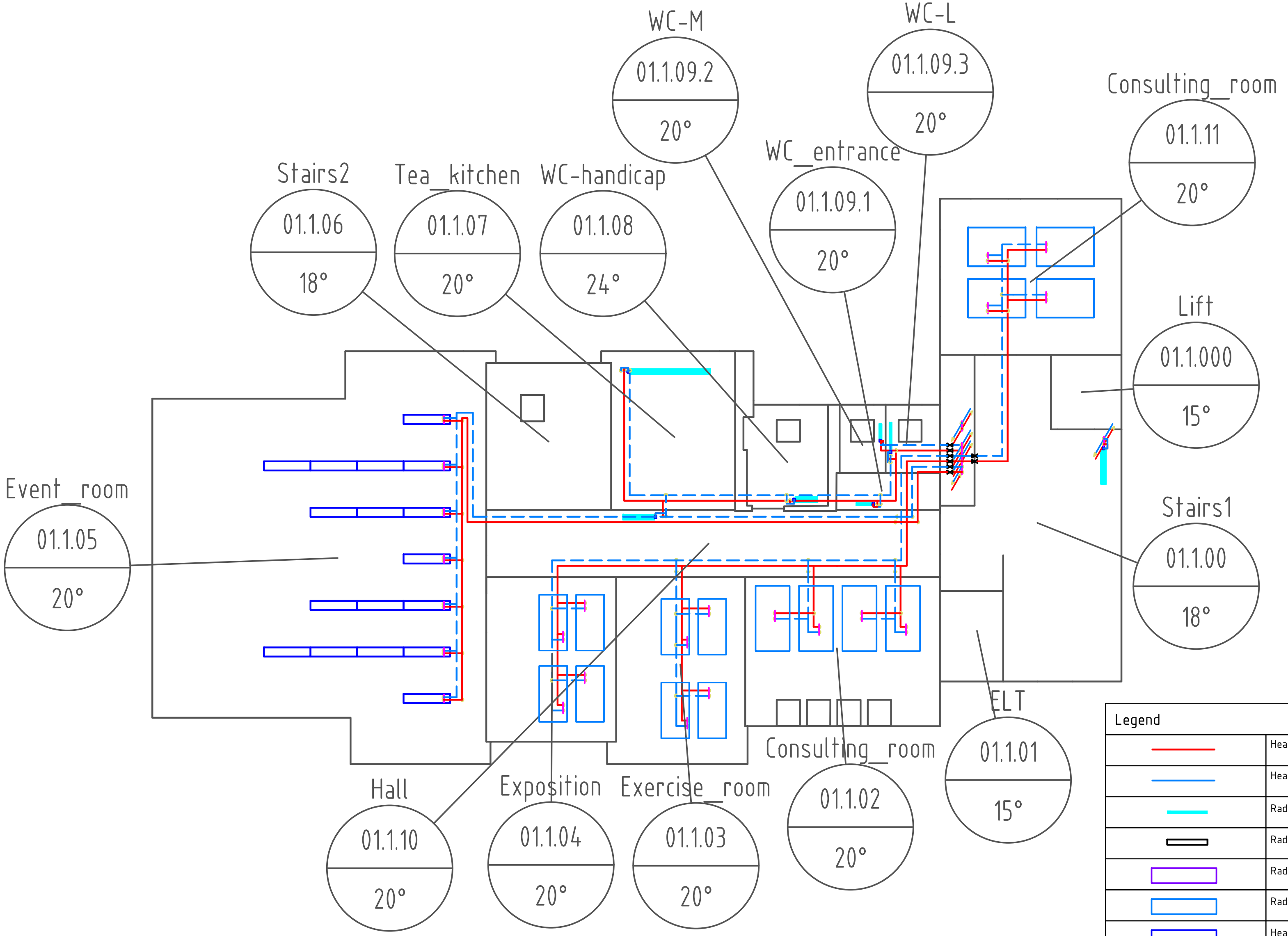
Plan: In-room terminal systems and distribution network in heating mode (floor level 2)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 14



Legend

—	Heating – Supply
—	Heating – Return
—	Radiator
▭	Radiant floor heating – manifold
▭	Radiant floor heating areas
▭	Radiant ceiling heating panels
▭	Heated beams
⋈	Gate and control valves
	Direction: from bottom to top going through

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

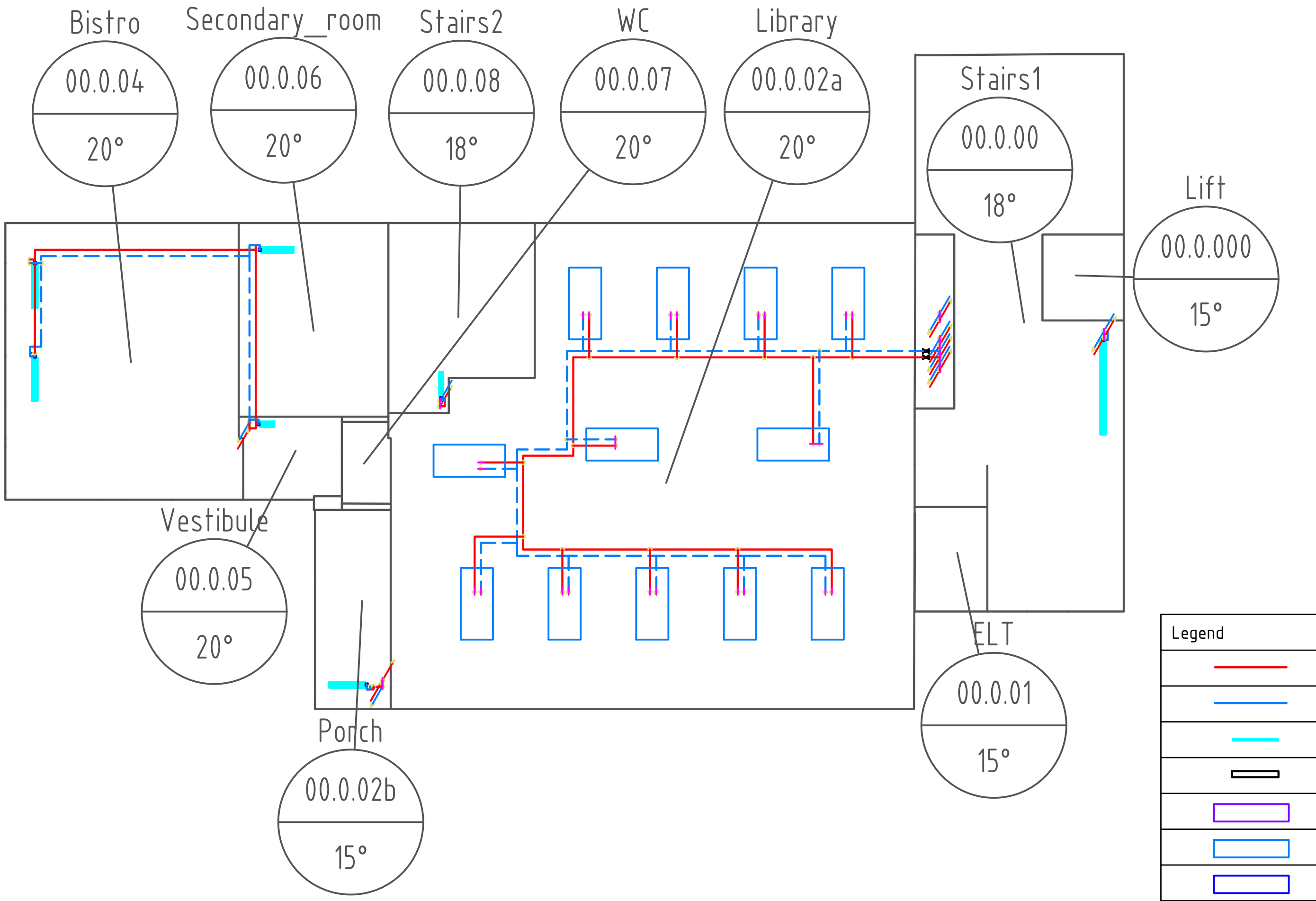
Plan: In-room terminal systems and distribution network in heating mode (floor level 1)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 15



Legend

—	Heating – Supply
—	Heating – Return
▬	Radiator
▭	Radiant floor heating – manifold
▭	Radiant floor heating areas
▭	Radiant ceiling heating panels
▭	Heated beams
⋈	Gate and control valves
/	Direction: from bottom to top going through

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

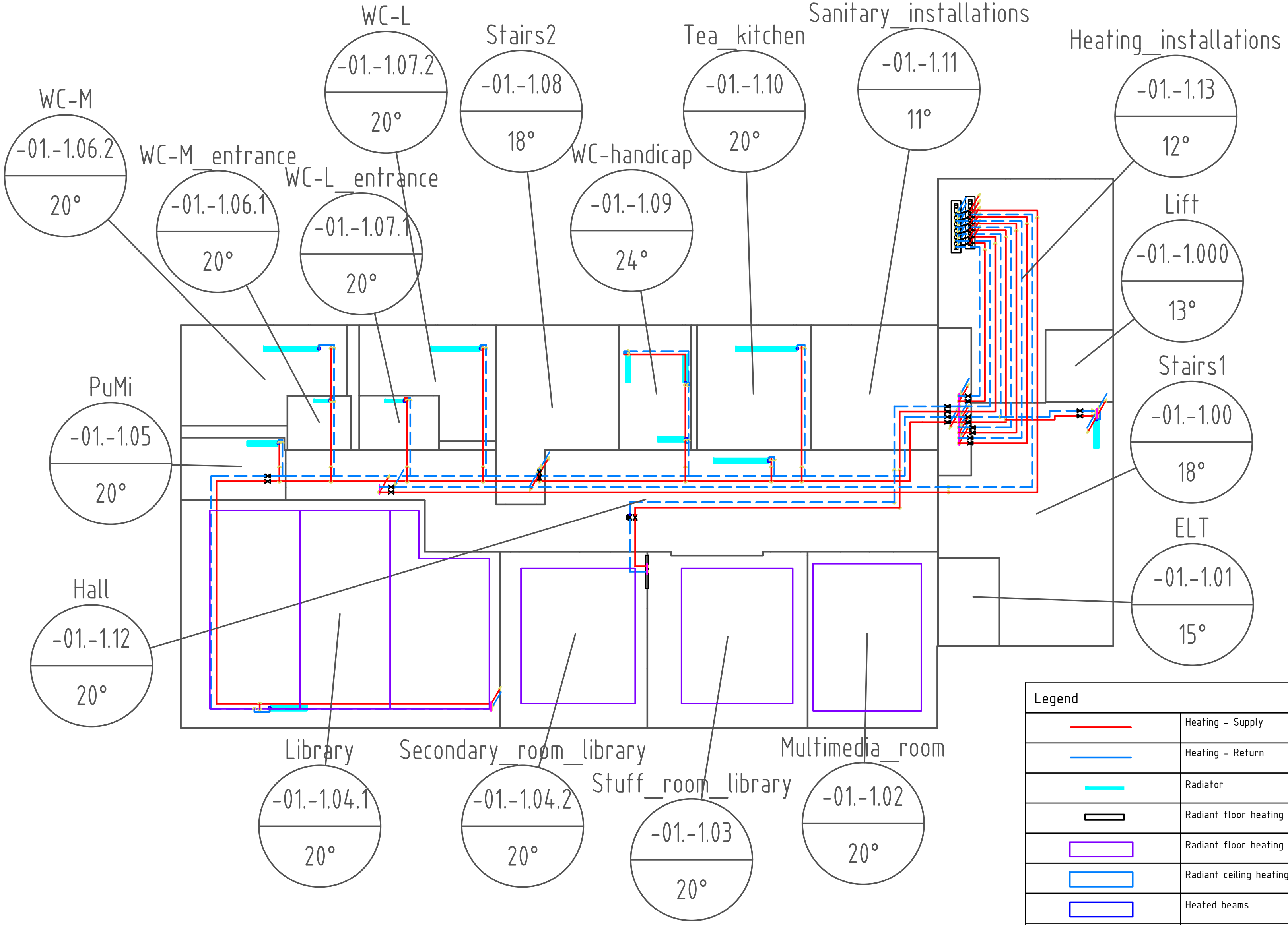
Plan: In-room terminal systems and distribution network in heating mode (floor level 0)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 16



Legend

━	Heating – Supply
━	Heating – Return
━	Radiator
▭	Radiant floor heating – manifold
▭	Radiant floor heating areas
▭	Radiant ceiling heating panels
▭	Heated beams
⋈	Gate and control valves
⫽	Direction: from bottom to top going through

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

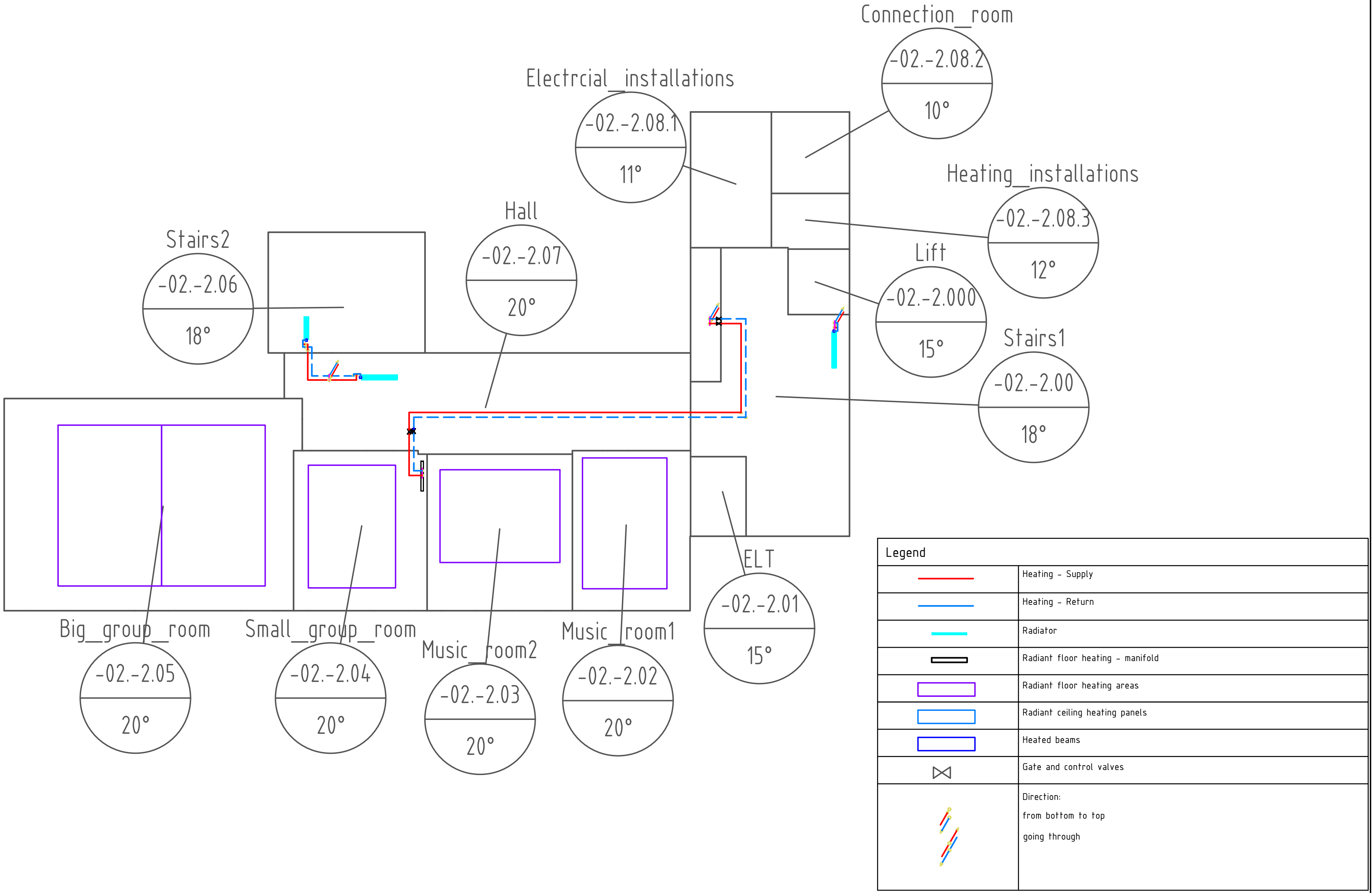
Plan: In-room terminal systems and distribution network in heating mode (floor level -1)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 17



MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

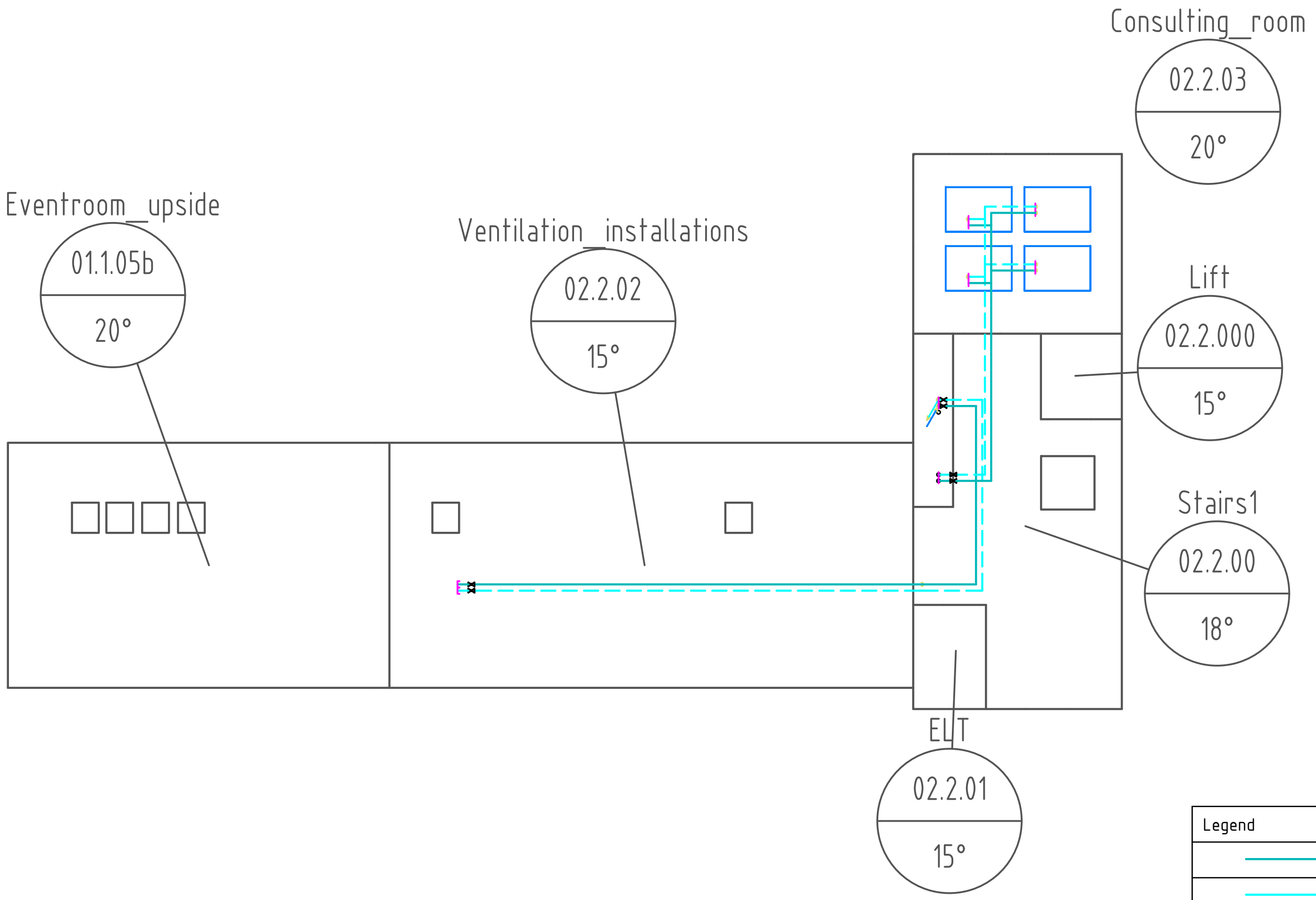
Plan: In-room terminal systems and distribution network in heating mode (floor level -2)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 18



Legend

—	Cooling - Supply
—	Cooling - Return
▭	Radiant ceiling cooling panels
▭	Chilled beams
⋈	Gate and control valves
⫽	Direction: from bottom to top going through

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

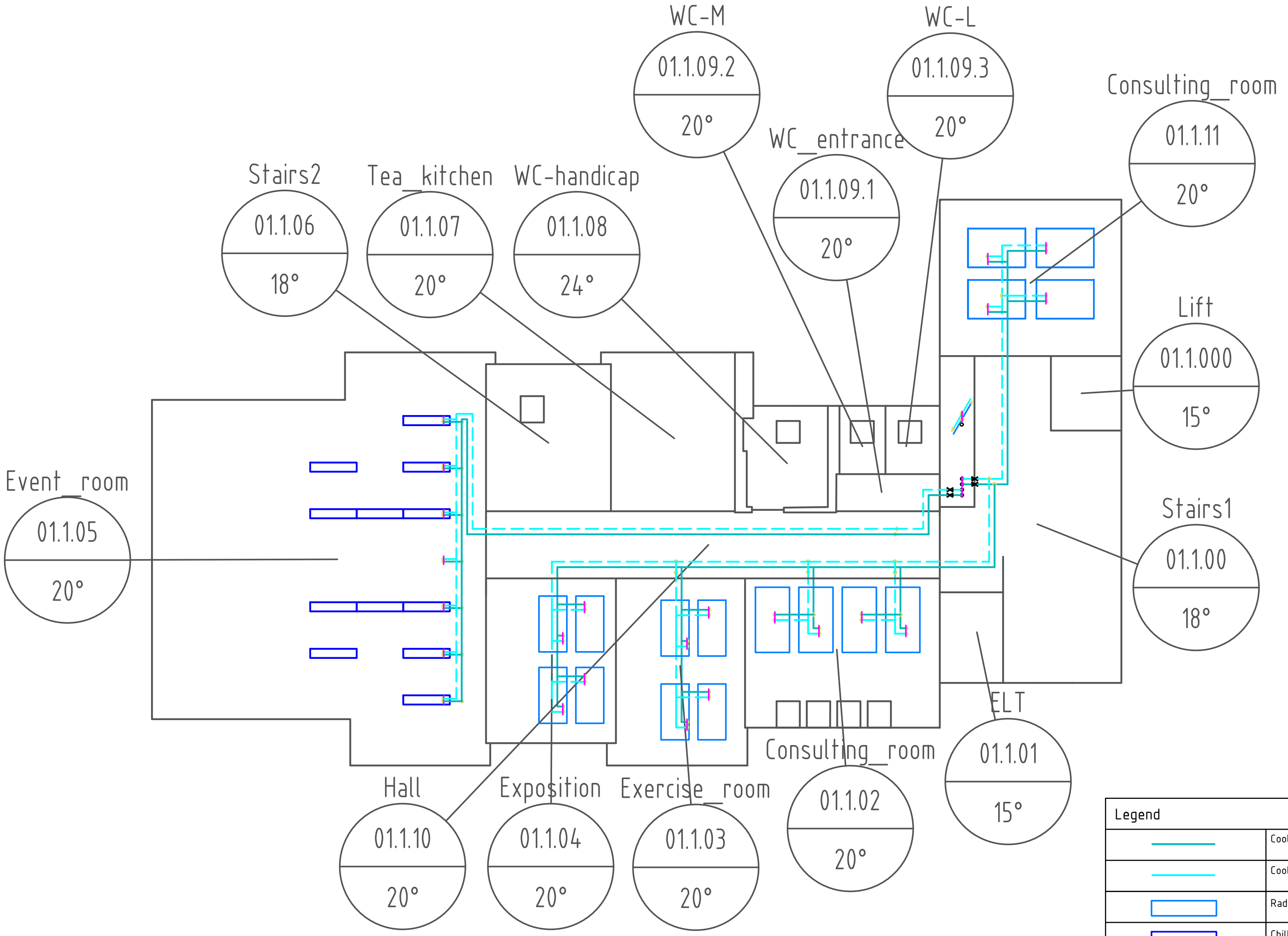
Plan: In-room terminal systems and distribution network in cooling mode (floor level 2)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 19



Legend	
—	Cooling - Supply
—	Cooling - Return
▭	Radiant ceiling cooling panels
▭	Chilled beams
⋈	Gate and control valves
	Direction: from bottom to top going through

MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

ESCUELA
TÉCNICA
SUPERIOR
INGENIERÍA
INDUSTRIAL
VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

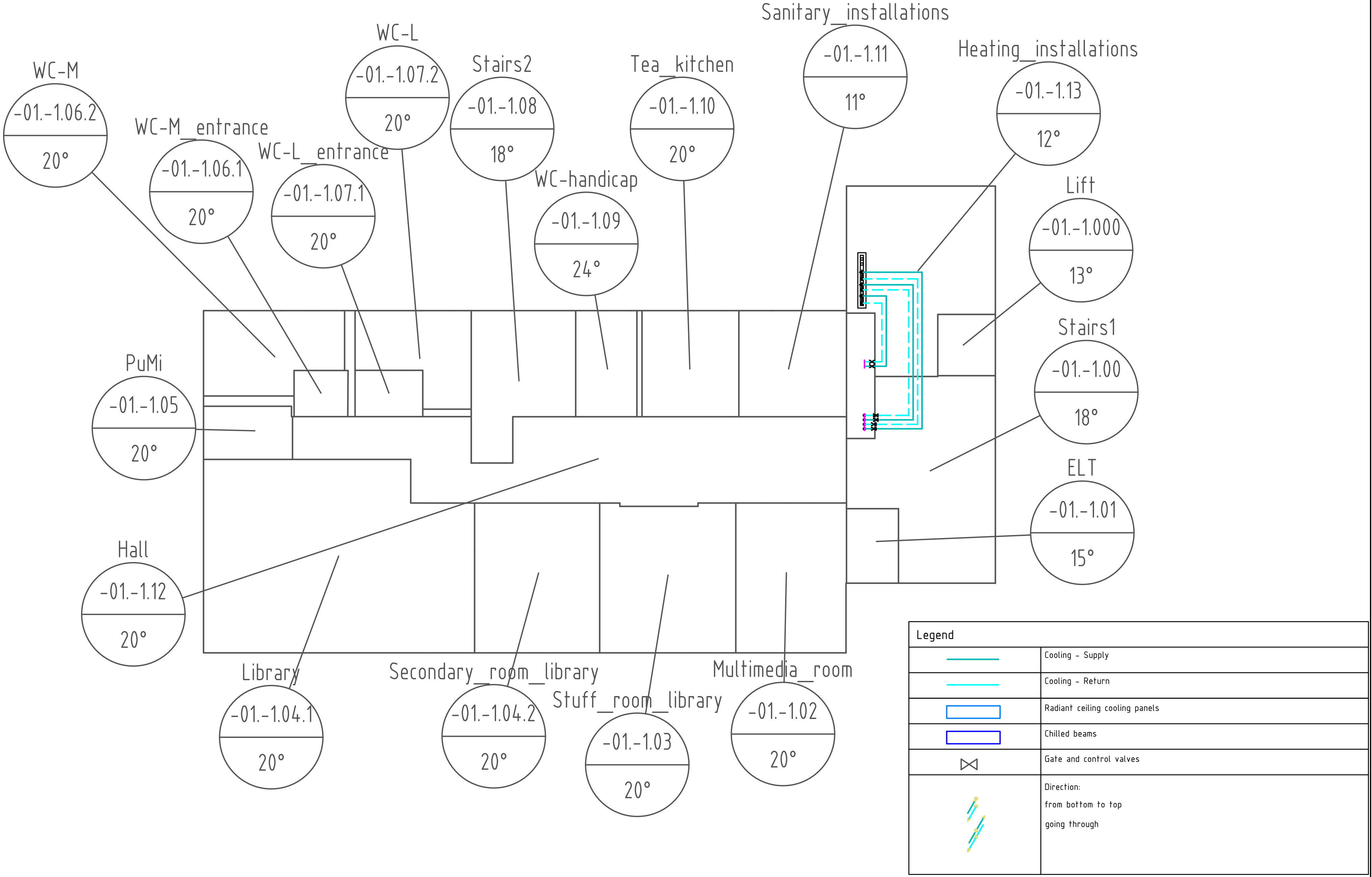
Plan: In-room terminal systems and distribution network in cooling mode (floor level 1)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 20



MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

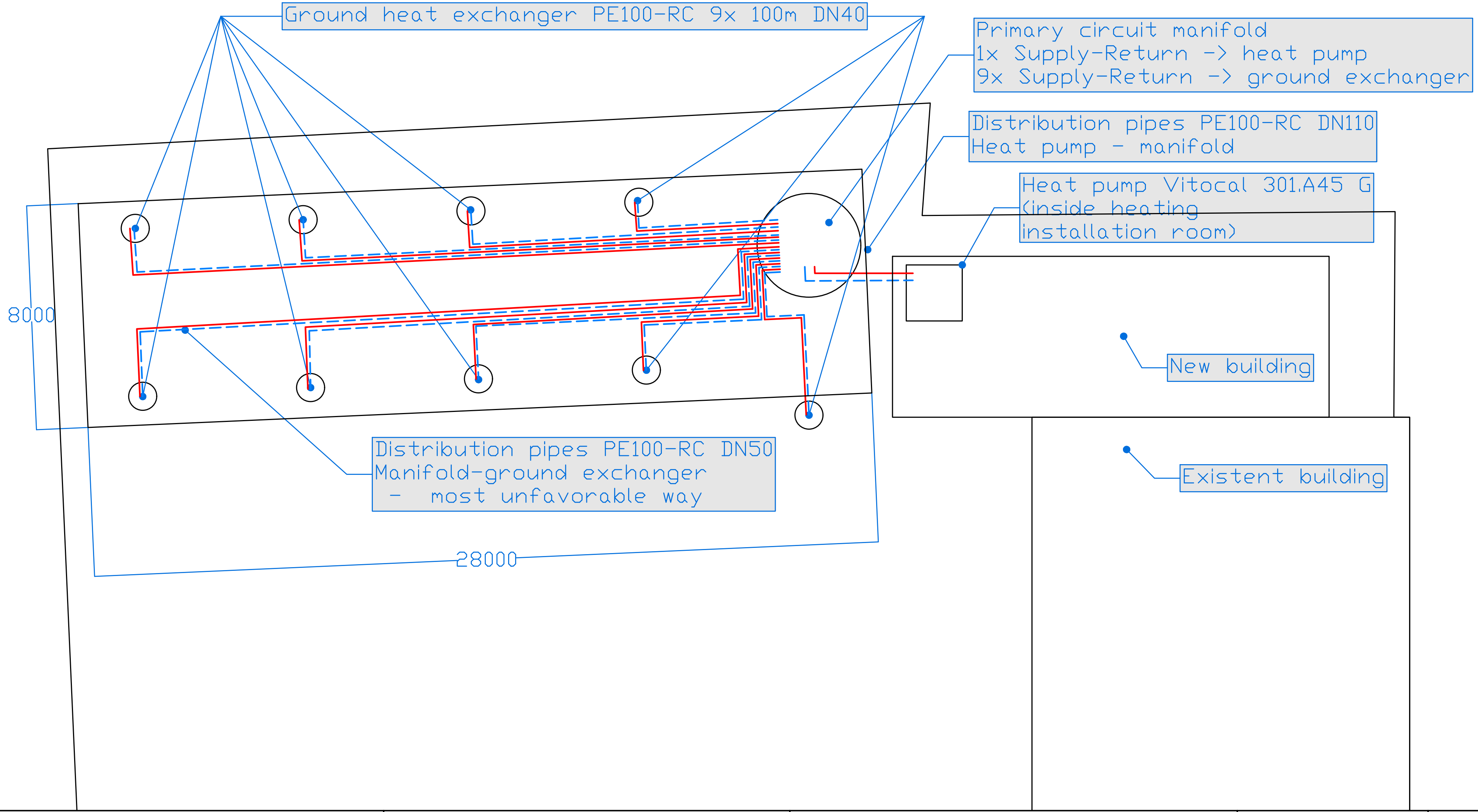
Plan: In-room terminal systems and distribution network in cooling mode (floor level -1)

Author: Luise Kleideiter

Date: January 2024

Scale: 1:200

Plan No.: 21



MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

Plan: Illustration of primary circuit location and its elements

March 2024

Author: Luise Kleideiter

Scale: 1:400

22

Pump data Heating

P 01	Name	HL 01: Air handling unit	
	Mass flow	0.37	m^3/h
	dp	165	mbar
	Voltage	230	V
	Power input	0.08	kW
P 02	Name	HL 02: Radiant floor	
	Mass flow	0.64	m^3/h
	dp	298	mbar
	Voltage	230	V
	Power input	0.08	kW
P 03	Name	HL 03: Radiators	
	Mass flow	1.08	m^3/h
	dp	383	mbar
	Voltage	230	V
	Power input	0.13	kW
P 04	Name	HL 04: Radiant ceiling	
	Mass flow	1.28	m^3/h
	dp	400	mbar
	Voltage	230	V
	Power input	0.13	kW
P 05	Name	HL 05: Chilled beams	
	Mass flow	1.61	m^3/h
	dp	431	mbar
	Voltage	230	V
	Power input	0.13	kW
P 06	Name	HL 06: Radiators Rent	
	Mass flow	0.14	m^3/h
	dp	170	mbar
	Voltage	230	V
	Power input	0.08	kW
P 10	Name	Secondary pipes	
	Mass flow	5.11	m^3/h
	dp	303	mbar
	Voltage	230	V
	Power input	0.27	kW
P 12(H)	Name	Heat pump circulation	
	Mass flow	5.11	m^3/h
	dp	154	mbar
	Voltage	230	V
	Power input	0.27	kW
P 13	Name	Condensing gas boiler	
	Mass flow	2.03	m^3/h
	dp	19	mbar
	Voltage	230	V
	Power input	0.13	kW
P 14(H)	Name	Primary circuit pump	
	Mass flow	18	m^3/h
	dp	882	mbar
	Voltage	230	V
	Power input	1.29	kW

Pump data Cooling

P 07	Name	CL 01: Air handling unit	
	Mass flow	3.28	m^3/h
	dp	278	mbar
	Voltage	230	V
	Power input	0.80	kW
P 08	Name	CL 02: Radiant Ceiling	
	Mass flow	0.94	m^3/h
	dp	498	mbar
	Voltage	230	V
	Power input	0.13	kW
P 09	Name	CL 03: Chilled beams	
	Mass flow	2.22	m^3/h
	dp	363	mbar
	Voltage	230	V
	Power input	0.13	kW
P 11	Name	Secondary pipes	
	Mass flow	4.90	m^3/h
	dp	306	mbar
	Voltage	230	V
	Power input	0.27	kW
P 12(C)	Name	Heat pump	
	Mass flow	4.90	m^3/h
	dp	163	mbar
	Voltage	230	V
	Power input	0.27	kW
P 14(C)	Name	Primary circuit pump	
	Mass flow	18	m^3/h
	dp	701	mbar
	Voltage	230	V
	Power input	1.29	kW

Valve data Heating

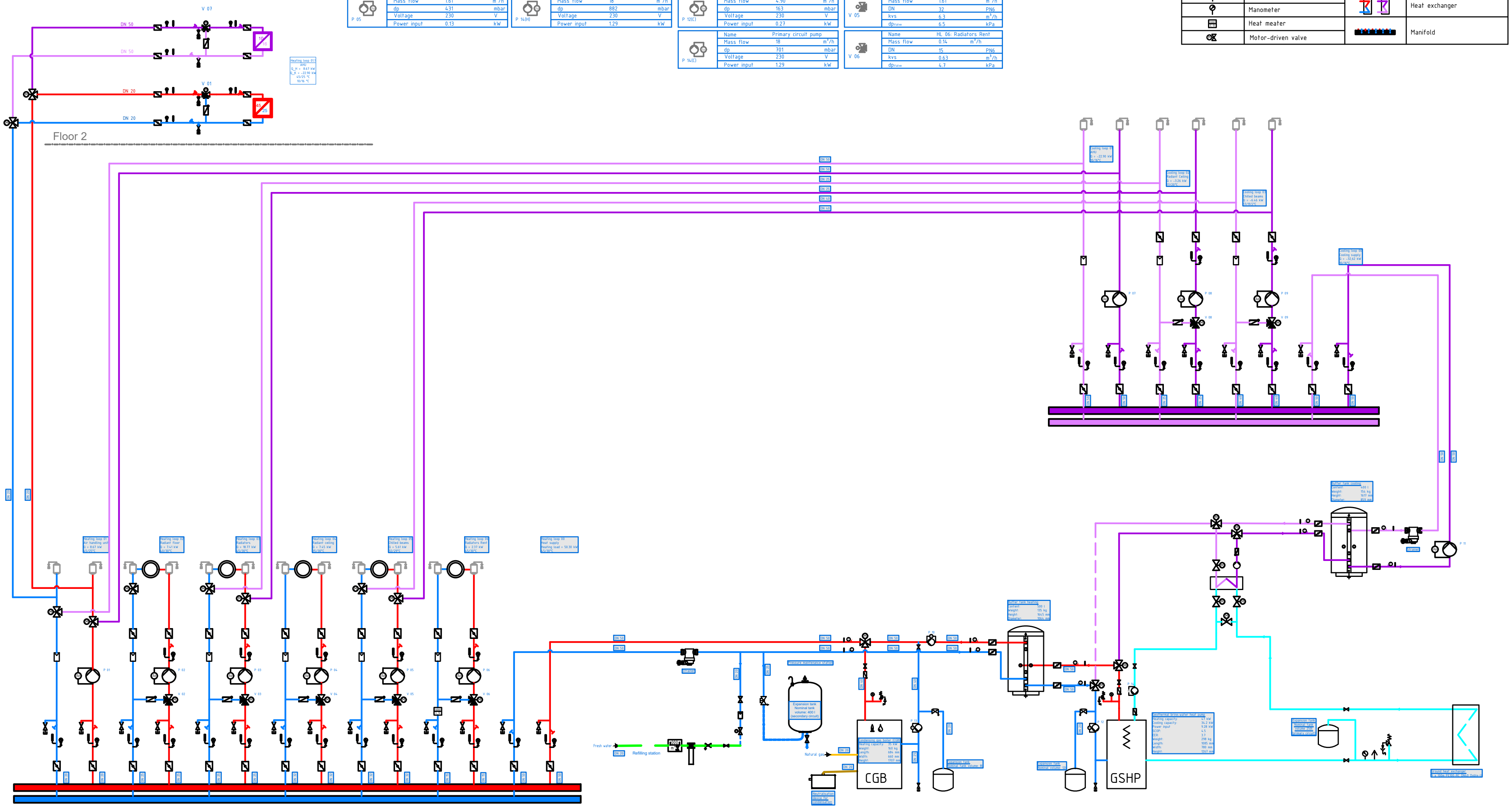
V 01	Name	HL 01: AHU	
	Mass flow	0.37	m^3/h
	DN	25	PN6
	kvs	2.5	m^3/h
	dp_{Valve}	6.5	kPa
V 02	Name	HL 02: Radiant floor	
	Mass flow	0.64	m^3/h
	DN	25	PN6
	kvs	2.5	m^3/h
	dp_{Valve}	6.5	kPa
V 03	Name	HL 03: Radiators	
	Mass flow	1.08	m^3/h
	DN	25	PN6
	kvs	4.0	m^3/h
	dp_{Valve}	7.2	kPa
V 04	Name	HL 04: Radiant ceiling	
	Mass flow	1.28	m^3/h
	DN	32	PN6
	kvs	6.3	m^3/h
	dp_{Valve}	4.1	kPa
V 05	Name	HL 05: Chilled beams	
	Mass flow	1.61	m^3/h
	DN	32	PN6
	kvs	6.3	m^3/h
	dp_{Valve}	6.5	kPa
V 06	Name	HL 06: Radiators Rent	
	Mass flow	0.14	m^3/h
	DN	15	PN6
	kvs	0.63	m^3/h
	dp_{Valve}	4.7	kPa

Valve data Cooling

V 07	Name	CL 01: AHU	
	Mass flow	3.28	m^3/h
	DN	50	PN6
	kvs	16.0	m^3/h
	dp_{Valve}	4.2	kPa
V 08	Name	CL 02: Radiant Ceiling	
	Mass flow	0.94	m^3/h
	DN	25	PN6
	kvs	4.0	m^3/h
	dp_{Valve}	5.5	kPa
V 09	Name	CL 03: Chilled beams	
	Mass flow	2.22	m^3/h
	DN	40	PN6
	kvs	10.0	m^3/h
	dp_{Valve}	4.9	kPa

Legend

🟥	Heating - Supply	🟦	Heating - Return
🟪	Cooling - Supply	🟪	Cooling - Return
🟦	Brine	🟧	Natural gas
⋈	Check valve		Manometer
	Anti-tamper valve	✓	Gauge connection
	Three-way-valve - switching		Temperature sensor
	Three-way-valve - mixing		Evacuation
	Non-return valve	↑	Vent
	Strainer		Safety valve sping-loaded
	Throttle valve		
	Venting device	◎	Heat consumer
○	Circulation pump		
	Thermometer		Heat exchanger
	Manometer		
	Heat meater		Manifold
	Motor-driven valve		



MASTER THESIS IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

ESCUELA
TÉCNICA
SUPERIOR
INGENIERÍA
INDUSTRIAL
VALENCIA

Project: DESIGN OF A GEOTHERMAL HEAT PUMP AND CONSENDING BOILER HYBRID SYSTEM FOR PROVIDING HEATING AND COOLING TO A BUILDING IN HOHEN NEUENDORF

Plan: Hydraulic scheme with GSHP, condensing gas boiler and consumers

Author:
Luise Kleideiter

March 2024

Scale:
-

23