Thermal Optimization of 70 Residential Units in Ennetbürgen by Means of Building Energy Simulation

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Semester	spring semester 20
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Bachelor's thesis at the Lucerne School of Engineering and Architecture

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Abstract German

Der Gebäudesektor ist stark von nicht erneuerbaren Energiequellen abhängig und verantwortlich für einen Großteil der klimaschädlichen CO_2-Emissionen in der Schweiz. Es ist davon auszugehen, dass die Umgebungstemperatur während der Lebensdauer eines heute entworfenen, geplanten und gebauten Gebäudes deutlich ansteigt. Dies bringt die Notwendigkeit energieeffizienter Gebäude in Bezug auf die Heizenergie sowie den Schutz vor Überhitzung mit sich. Gebäudeenergie-Simulationen ermöglichen Vorhersagen über verschiedene Aspekte eines Gebäudes. Einzelne Parameter und Maßnahmen können analysiert und die Erfüllung der Anforderungen an das Innenraumklima und die thermische Behaglichkeit nachgewiesen werden.

In Ennetbürgen, Kanton Nidwalden, wird derzeit ein Gebäudepark mit 10 Gebäuden und 70 Wohneinheiten geplant. Der Bauherr dieses Projektes, die Vereinigung BIZUN, setzt auf die thermische Behaglichkeit im Sommer ohne aktive Kühlung sowie auf umweltfreundliche Baustoffe.

Die vorliegende Studie analysiert den Einfluss verschiedener Parameter auf die thermische Behaglichkeit einer Wohneinheit in diesem Gebäudekomplex. Die kritischsten Maßnahmen, die mit einer parametrischen Gebäudeenergiesimulation identifiziert wurden, sind Sonnenschutz und Nachtlüftung. Dieser Bericht zeigt die Bedeutung dieser Maßnahmen im Hinblick auf die Elimination der Überhitzung einer Gebäudeeinheit auf. Die Machbarkeit einer Leichtbauweise ohne kritische Überhitzung im Sommer konnte mit der Umsetzung geeigneter Maßnahmen und Parameter nachgewiesen werden. Dieser Bericht enthält zudem mehrere Empfehlungen für die Vereinigung BIZUN, um eine hohe thermische Behaglichkeit im Sommer zu gewährleisten.

Abstract English

The building sector is heavily dependent on non-renewable energy sources and is responsible for a large share of climate-damaging CO_2 emissions in Switzerland. The environmental air temperature over the lifetime of a building designed, planned and constructed today is foreseen to increase significantly. This implies the necessity of energy efficient buildings in terms of heating energy as well as protection against overheating.

Building energy simulations enable predictions on several aspects of a building's performance. Single parameters and measures can be analyzed and the fulfillment of requirements for interior room climate and thermal comfort can be proven.

A building park with 10 buildings holding 70 residential units is currently being planned in Ennetbürgen, canton of Nidwalden. The client of this project, the association BIZUN, emphasizes the thermal comfort in summer without active cooling as well as the implementation of environmentally friendly building materials.

This study analyzes the impact of several parameters on the thermal comfort of a residential building unit in this building complex. The most critical measures identified with a parametric building energy simulation are solar protection and nighttime ventilation. This report demonstrates the importance of these measures to eliminate overheating of a building unit. The feasibility of a lightweight construction without critical overheating in summer could be proven with the implementation of appropriate measures and parameters. Furthermore, this report holds several recommendations to provide high thermal comfort for the association BIZUN.

Horw, 08.06.2020

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Abbreviations and Acronyms

BES	Building Energy Simulation
BIM	Building Information Modelling
CFD	Cumulative Frequency Distribution
clo	Thermal Resistance of Clothing
CO_2	Carbon Dioxide
DIN	German Institute for Norms (Deutsches Institut für Normung)
EN	European Norm
EPS	Expanded Polystyrene
HVAC	Heating, Ventilation and Air Condition
NCCS	National Centre for Climate Services
OSB	Oriented Strand Board
PJ	Petajoules
ppm	Particles per million
PUR	Polyurethane
SES2050	Swiss Energy Strategy 2050
SFOE	Swiss Federal Office of Energy
SIA	Swiss Association of Engineers and Architects (Schweizerischer Ingenieur- und Architektenverein)
TCY	Temperature Course of the Year
TMY	Typical Meteorological Year
WUFI	Heat and Humidity non-steady state (Wärme und Feuchte instationär)

1. Introduction

In 2017, the Swiss citizens voted to accept several revisions of the nationwide energy law. These revisions were merged to build the Swiss Energy Strategy 2050 (SES 2050) (Moser, 2017). The main objectives of the SES 2050 are the implementation of energy reduction measures, increasing energy efficiency, increasing the share of renewable energy sources and phasing out nuclear energy. Currently, the building sector is highly dependent on nonrenewable energy sources, such as oil and gas in heating systems, causing 1/3 of the all Carbon Dioxide (CO_2) in Switzerland (Swiss Federal Office of Energy SFOE, 2020). Therefore, the building sector needs great considerations to meet the objectives of the SES 2050.

In the year 2016, the total final energy consumption in Switzerland was 842.5 Petajoules (PJ). Space heating, with an amount of 250.3 PJ accounts for a share of 29.7% of this total energy consumption and this is the largest sector (Catenazzi et al., 2017). This and the objectives of the SES2050 demonstrate the necessity for energy efficient buildings with a decreased heat demand.

In a long-term perspective considering future temperature forecasts, also the overheating of buildings must be considered in the planning, designing, and construction phase of modern buildings. The National Centre for Climate Services NCCS (2019) created several scenarios for future temperature development in Switzerland. The scenarios include predictions for temperatures in close future, the middle of the 21st century and the end of the 21st century. For these timespans, optimistic (with climate protection measures) and pessimistic (without climate protection measures) forecasts were established. Buildings have a relatively long lifetime of up to 80 years and their physical and thermal characteristics must fulfil the requirements of thermal comfort over the entire lifespan (Gross, Hermann, & Krause, 2016). For a building designed and constructed today, this would result in a timeframe closing at the end of the 21st century. In the optimistic scenario, an increase of 0.6°C to 1.9°C in temperature was predicted for the end of the century, whilst the pessimistic scenario predicts an increase of 3.3°C to 5.4°C (National Centre for Climate Services NCCS, 2019). The worst-case scenario of a temperature increase of 5.4°C would cause severe complications for buildings, which are designed and constructed on the base of current temperatures. This leads to the urgency to apply measures to protect buildings against overheating.

Currently, a building park with a total of 10 buildings holding 70 residential units is being planned in Ennetbürgen, canton of Nidwalden. The project is currently in the early stage of the reference project (Richtprojekt), which is developed and processed by the architectural office Unit Architekten. In cooperation with the building complex owner, the association BIZUN, the thermal comfort properties of the buildings were analyzed in this report based on various scenarios.

The first section of the report (section 1) covers the required background knowledge associated with the involved stakeholders, building energy modelling, as well as how the weather data is achieved. Furthermore, the processes and industry standards applied are briefly described. Section 2 Methodology focuses on the fundaments of the simulation process. This includes the applied simulation tool, the requirements on the indoor room climate, the simulation model and the various simulation cases. The results of the conducted simulations are presented in section 3. These results are discussed, analyzed and interpreted in the same section, as parts of the results base on the discussion of previous results. The report is completed with a conclusion along with recommendations for the association BIZUN as well as an outlook in section 4.

1.1. Project Aim

The aim of this Bachelor Thesis is to analyze the impact of certain parameters on the thermal comfort and energy demand of a residential building unit. These parameters include three different construction types, solar protection (shading devices), night-time ventilation, additional windows and the glazed area of the unit. A parametric building energy simulation study shall provide a basis of decision-making for the association BIZUN for the planned building park in Ennetbürgen.

1.2. Association BIZUN

In 1949 the company SIGRIST Photometer AG was founded by Dr. Ing. Willi Sigrist and his wife Paula Sigrist (Sigrist, 2016). Today the company SIGRIST-Photometer AG is leading around the world in development, production and selling measuring instruments, which work in the principle of photometry. These measuring instruments are used in the range of drinking water and drinks, tunnel ventilation, fire call and industrial processes.

Willi and Paula did not have any children and such no successors. Nevertheless, they wanted the company to hold on to their fundamental ideas of sustainability, independence and social considerations. Therefore, they founded the association BIZUN in 1978 (Sigrist, 2016). Until today, the association BIZUN continues to maintain these fundamental ideas. BIZUN furthermore owns buildings, properties and land parcels. The members of the association BIZUN are employees from the company SIGRIST Photometer AG as well as external people. The land parcel in Ennetbürgen where the building complex is intended to be built belongs to the association BIZUN. (personal information, Andreas Odermatt, association BIZUN)

From the association's point of view, one of the most important requirements for the building complex is the thermal comfort in summer without any active cooling measures. Further requirements are to use environmentally friendly building materials wherever possible as well as a low annual energy consumption.

1.3. Building Energy Simulation

Building simulations are mathematical, computer-based models, which replicate several aspects of a building's characteristics and performance (Yang, 2008). They are a subcategory of the contemporary process of Building Information Modelling (BIM) today. BIM is an intelligent, 3D based process, which connects architecture, planning, engineering and construction of buildings. This process evolved due to the inefficiencies of this sector such as the high amount of waste, excessive duplication of processes and poor project coordination. Because BIM is a relatively new approach in this sector it is not yet fully implemented in the industry. BIM faces several barriers such as the complex planning processes, the currently established work practices and legal and contractual issues (Dastbaz, Gorse, & Moncaster, 2017, p. 48).

Common applications for building simulations are:

- Thermal simulations
- Humidity simulations
- Lightning simulations
- Acoustical simulations
- Air flow simulations

Building Energy Simulations (BES) can give crucial information about the analyzed aspects for planners and engineers such as heating and cooling demand of a building. With these simulations, the feasibility and performance of the planned projects can be investigated and verified at an early stage of a project. During the simulation process, the influence of different parameters can be analyzed, and they can be optimized resulting in best possible solution. BES enable the design and planning of energy efficient buildings as well as the development and dimensioning of the required energy system (Bazjanac, Fischer, & Maile, 2007).

1.4. Weather Data used for Building Simulations

Spread over the whole world, meteorological stations collect weather data such as temperature, irradiation, rainfall, pollen and many other parameters. In remote locations, the technology of satellites is used to obtain the data. Using this grid of measurement stations, the satellites and interpolation, reliable weather data for every location can be generated (Meteonorm, 2020, p. 2). Measurement periods of 25 up to 30 years for temperature and radiation are used to generate a Typical Meteorological Year (TMY). A TMY does not represent the daily, hourly or minute average values over the measurement period but rather provides data for a realistic year in which extreme values are accounted for (Remund, 2015). This data is crucial for planners and engineers in the building sector in order to predict for example heating and cooling demand as well as ventilation measures.

1.5. SIA-Standards

The Swiss Association of Engineers and Architects (SIA) is a union of Swiss engineers and architects, which serves as a multidisciplinary network throughout the entire building sector (Bolliger & Ruhstaller, 2013). This association provides a significant set of norms, standards, guidelines, and recommendations, which are widely applied in the industry. These norms include for example the average consumption of electricity per person in a residential or industrial environment or the average heat radiation per person. In terms of building energy simulations these standards enable a more unified performance which makes the solutions from different companies more comparable (Haus, Müller, & Tami, 2013)

Furthermore, the SIA guidelines enable rough estimations and give planners and engineers a perception of the scale during the early stages of a project. This simplifies the further steps in large projects drastically.

The SIA guidelines provide standard, target and current values for building envelope and Heating, Ventilation and Air Conditioning (HVAC) aspects. The standard values describe typical figures used in planning processes and the target values refer to optimal planning quantities. The current values represent average figures for unfurnished buildings constructed before 1980 (SIA 2024, 2015).

In this report the SIA standard and target values for heating demand, internal loads, insulation characteristics and others are referred to.

2. Methodology

This section covers in detail the sequence of tasks and the methods applied this project. In a first step background knowledge, covered in the previous section (section 1), was obtained in a thorough literature review. A profound understanding of the client, origin of data and industry norms are a crucial fundament for a successful execution of such a project. In a second step, a basic simulation model is defined. This simulation model serves as a base model for the following simulation cases. Variables such as location and climate, geometry and internal loads are defined because these stay unchanged for the following scenario analyses. The subsequent simulation cases are defined and carried out in order to estimate and demonstrate the influence of different parameters on the thermal comfort of the residential unit. The methodology process is graphically represented in Figure 1. The grey ellipses show the processes and methods applied while the blue ellipses cover the chapters of this report.

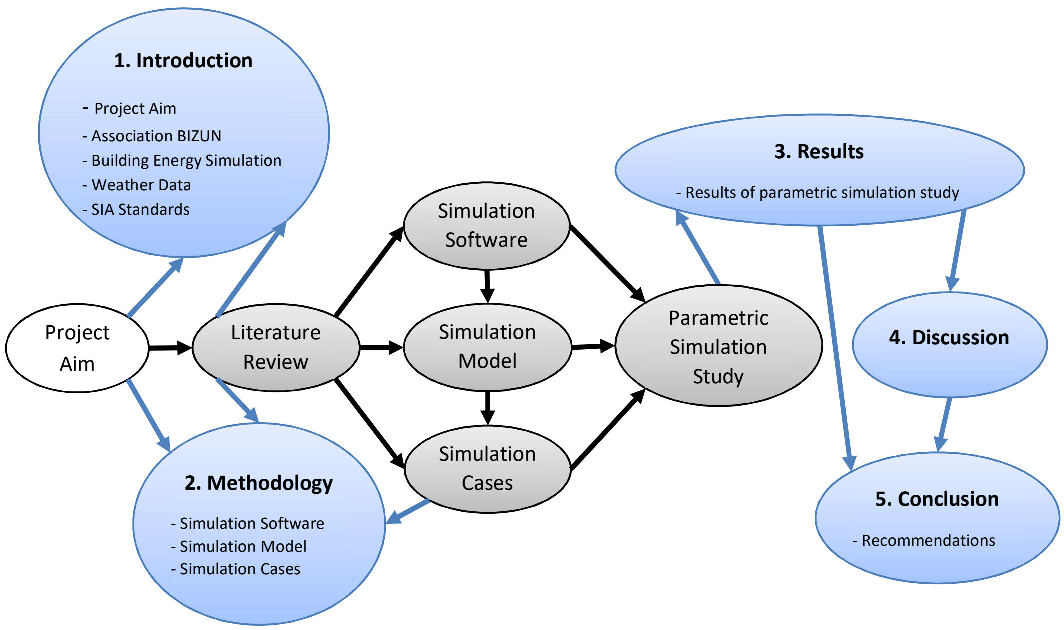

Figure 1: Methodology Process Flow Diagram

2.1. Simulation Software WUFI

The simulation software used in this project is WUFI (heat and humidity non-steady state) ®PLUS. It is developed, maintained and serviced by the Fraunhofer institute. This simulation tool has rather limited functionalities but fulfils all the required needs of this project. This software enables the hygrothermal (movement of heat and moisture) simulation of a building or a building unit. As such, the WUFI ®PLUS software enables predictions of indoor room climate as well as of the magnitude of the heating and cooling demand (Antretter et al., 2017). The simulation is based on input values such as exterior climate, wall layer structures, internal loads, ventilation, and solar protection. However, in this project only the thermal simulation and assessment of a building unit are of interest. WUFI ®PLUS is a two-dimensional simulation software. Therefore, some limitations exist. For example, for walls only continuous layers can be simulated, and frames, grates or grids cannot be modelled. This means that constructions such as support structures or ventilation channels in walls cannot be simulated. However, in most cases these constructions only have a minor impact on the thermal assessment and can therefore be neglected. Usually the empty space in these structures is filled with insulation material, which can be assumed to be distributed uniformly over the area of the wall. This insulation layer can easily be implemented in the software. (Antretter et al., 2017)

2.2. Indoor Room Climate

In this section, the reference values for a favorable indoor room climate are detailed. These reference values are based on standards and can be used to verify the simulation results. These values serve as guidelines and should, if possible, be complied with.

2.2.1. Indoor Room Temperature

Thermal comfort depends on seasons and can therefore not be described with a specific temperature or temperature range. In summertime, generally higher indoor air temperatures are accepted than in wintertime. Defined by SIA 180 (1999) these comfort temperature range between 23.5°C and 26°C in summer and between 19°C and 24°C in winter. The thermal comfort of a person depends on the thermal resistance of clothing (clo). The comfort temperature ranges defined by SIA correspond to a clo 0.5 in summer and clo 1 in winter. Clo 1 corresponds to a shirt and sweater with long sleeves, trousers, socks and shoes and clo 0.5 to a shirt with short sleeves, light trousers and socks as well as shoes. The metabolic rate (or level of activity) also influences the thermal comfort of a person. The temperature ranges defined by SIA are valid for a metabolic rate of 1.2, which stands for sedentary activity or relaxed standing.

The German Institute for Norms (DIN) suggests more specific acceptable temperatures of thermal comfort. According to DIN EN 15251 (2012, p. 27) these ranges for an acceptable indoor air temperatures are depending on the exterior air temperatures. A graphical representation of this norm is presented in Figure 2. The mean outer air gliding temperature (also called running mean temperature) is an exponentially weighted and time-dependent calculation of the exterior air temperature.

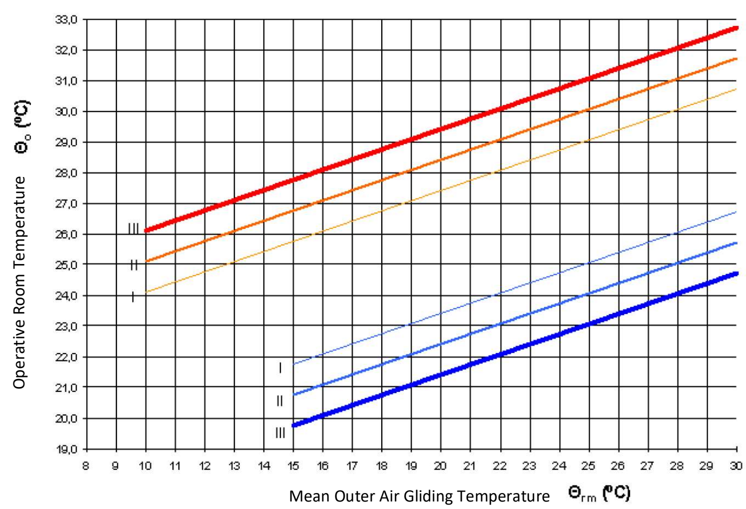

Figure 2: Acceptable Indoor Room Temperatures (DIN EN 15251, 2012, p. 27)

The lines in the Figure 2 indicate the boundaries for three different categories for an acceptable operative room temperature. According to the DIN EN 15251 norm, these lines can be horizontally extended at their bottom ends. The categories are explained in Table 1.

Table 1: Categories of Acceptable Operative Room Temperatures (DIN EN 15251, 2012, p. 13)

Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

2.2.2. CO_2-Concentration

The interior CO_2 concentration is a crucial indicator of air quality. A low CO_2 concentration indicates a high rate of exchange between interior and exterior air. Furthermore, high CO_2 concentrations can lead to health issues such as headaches and decreased performance levels as well as lower concentration (Jarosch, 2019). The concentration of CO_2 is usually measured in particles per million (ppm). Table 2 shows the classification of different air quality levels. The high air quality level is to be targeted in terms of CO_2 concentration for applications such as residential units.

Table 2: CO_2 Concentration and Air Quality Levels (Jarosch, 2019)

CO_2 Concentration in PPM	CO_2 in %	Quality Level
Below 800	<0.08%	High air quality
800-1000	0.08-0.1%	Medium air quality
1000-1400	0.1-0.14%	Moderate air quality
Over 1400	>0.14%	Low air quality

2.2.3. Humidity

Besides the CO_2 concentration, also the indoor humidity level indicates the quality of interior air. Too low levels of humidity lead to dry and rough throats, dry eyes as well as dry and itchy skin. On the other hand, too high levels of humidity facilitate an increased propagation of fungus and bacteria. According to the SIA 382/1 (2014) guidelines, humidity levels in a range of 40-70% are acceptable for interior air.

2.3. Simulation Model

The association BIZUN assigned the architecture office Unit Architekten with the development and design of the concept for the building park planned in Ennetbürgen. The project is in the phase of the reference project (Richtprojekt) which means that there are still many dimensions and design aspects undefined. The floor plans and layout plans used in this report were provided by Unit Architekten and are at the state of this reference project. Figure 3 shows the layout plan for the building park, which can be found in a larger scale in Annex A.

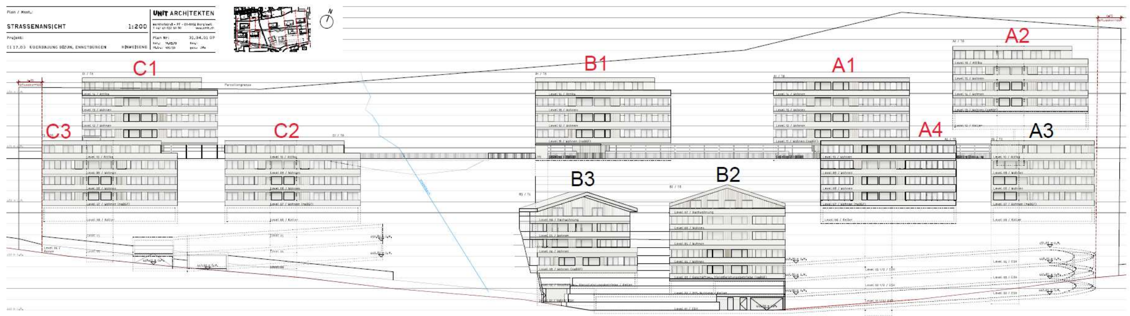

Figure 3: Layout Plan Building Park Ennetbürgen (Unit Architekten)

In general, it can be said that attic residential units are most exposed to the environment, which makes them the most critical units in a building regarding heat demand and overheating. Therefore, the unit analyzed in this report was chosen to be the attic residential unit, which is planned in 7 of the total 10 buildings of the building park. In Figure 3, the buildings with this attic unit are labeled red. The orientation of the building park is slightly tilted, but the inclination on which it is planned to be built is facing south.

2.3.1. Location and Climate

The building park holding the residential unit is planned to be built in Ennetbürgen, canton of Nidwalden in central Switzerland. The weather data used for the simulations was obtained from Meteonorm for the location Ennetbürgen. Meteonorm is a webservice initiated by the Swiss Federal Office of Energy (SFOE) in 1985 which provides a broad pool of meteorological datasets for locations all over the world (Remund, 2015).

The utilized data describes a TMY and is an interpolation from the measured values of the surrounding meteorological stations in Luzern, Altdorf, Wädenswil and other stations further away from the building site. Furthermore, a small share (3%) of satellite data is used for the interpolation. The measurement period for the temperatures is from 2000 to 2009 and for the radiation from 1991 to 2010. The full meteorological report is provided in Annex B and includes data for exterior air temperature, irradiation and humidity, which are applied in the simulations. The exterior CO_2 concentration in the environmental air remains constant and was set to a value of 400ppm according to the Bundesgesundheitsblatt (2008).

2.3.2. Geometrical Model

Because the planning of this residential building park is still in a very early stage, not all aspects of the architectural plans are yet defined. The measurements for the windows as well as the area of the interior walls had to be estimated. These estimations and calculations can be found in Annex C (window measurements) and Annex D (calculation of interior walls). In WUFI ®PLUS, the interior of a unit is simulated as one zone leading to one temperature output. The interior walls however still have an impact on the temperature regarding their thermal mass. Therefore, they need to be included in the simulation.

The attic residential unit which is analyzed in this report holds four bedrooms, one living room including the kitchen and two bathrooms. The total of $192.5m^2$ living space and the floor height of 2.9m are already defined. Figure 4 shows the floor plan of this unit (measurements in meters). For simplification purposes it is assumed that the top of the floor plans displayed in this report is oriented north as displayed in Figure 4.

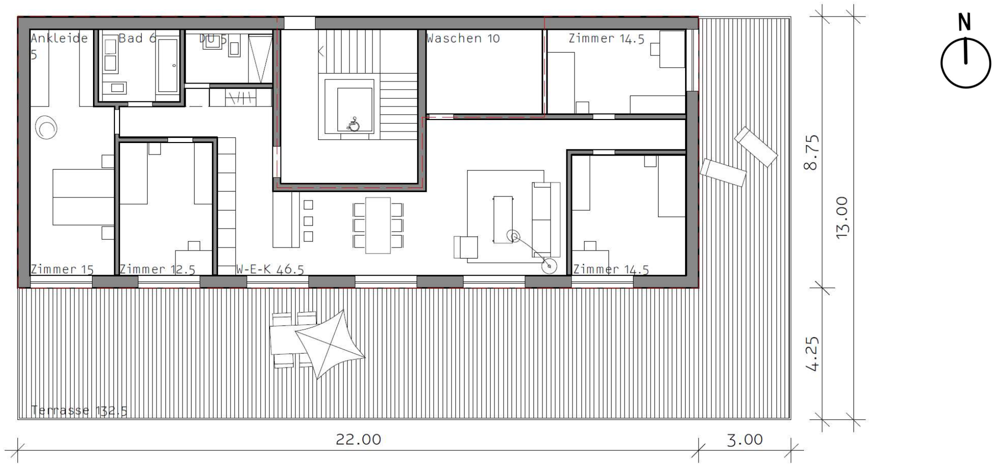

Figure 4: Floor Plan Attic Residential Unit (Unit Architekten)

2.3.3. Internal Loads

The residential unit analyzed in this report is supposed to hold a four-person household. In the WUFI ®PLUS software, the influence of internal loads for heat emissions, moisture and CO_2 emissions can be assessed. As it is a residential unit, it is assumed that the residents are present for 12 hours each day from 8PM to 8AM (SIA 380/1, 2016, p. 29).

According to the SIA 380/1 (2014, p. 33) datasheet for heating-, moisture protection and room climate in buildings, a person emits approximately 70 Watts of heat in a seated activity. The seated activity was chosen because the residents of the unit will be sleeping and living in the present time. In a four-person household, this leads to a total of 280 Watts heat release.

As stated by the SIA 380/1 (2014, p. 33) datasheet, a person emits 60 g/h moisture during a seated activity. This leads to a total of 240g/h for four residents.

The SIA 380/1 (2014, p. 33) datasheet suggests a standard value of 16l/h CO_2 excess per person. For a four-person household this leads to 64l/h CO_2.

PanGas (2015) states a density of 1.528g/l for CO_2 under atmospheric pressure. This then leads to:

$$CO_2\ emissions \left[\frac{g}{h}\right] = CO2\ emissions\ \left[\frac{l}{h}\right] * density\ \left[\frac{g}{l}\right] = 64\ \frac{l}{h} * 1.528\frac{g}{l} =\ 97.79\frac{g}{h}$$

These values of internal loads for heat, moisture and CO_2 emissions of residents were integrated in the simulation for each of the scenarios in section 2.4.

2.3.4. Window Parameters

The window parameters remain unchanged for all the simulation cases and therefore are part of the basic simulation model. One of the most common specifications of insulation characteristics is the thermal transmittance, here referred to as the U-value. This value describes the amount of heat which passes through one square meter of a building component per temperature difference of one kelvin. (Krause, Nowoswiat, & Steidl). The SIA 2024 (2015) target U-value for windows is 0.9 W/m^2K while the window manufacturer Glaströsch (n.d.) provides a value of 0.4 W/m^2K. The U-value chosen for the windows is 0.6 W/m^2K is a mean of those and corresponds to excellent insulation characteristics. The full report on the window parameters can be found in Annex E.

2.4. Simulation Cases

In this section, the design and the input variables of all simulation cases are collected and described. Figure 5 shows the chronological and coherent sequence of the various cases, which were conducted. Based on the simulation model, described in the previous section (section 2.3), three base cases with different construction types were developed. In Figure 5, these base cases are colored in green. Subsequently, the influence of various parameters on the thermal comfort was simulated on one of the base cases (hybrid construction). These parameters analyzed in a sensitivity analysis are shown in red in Figure 5. The hybrid construction case was chosen for this because it is a combination of the heavy- and lightweight construction type. This means in the hybrid construction aspects of the other two construction types are present. Conducting the sensitivity analyses with the other two construction types as well would exceed the scope of this project. The last three simulation cases represent a realistic combination of the parameters evaluated in the sensitivity analysis and serves as a base for decision making for the client. This last set of simulations was carried out for all three construction types.

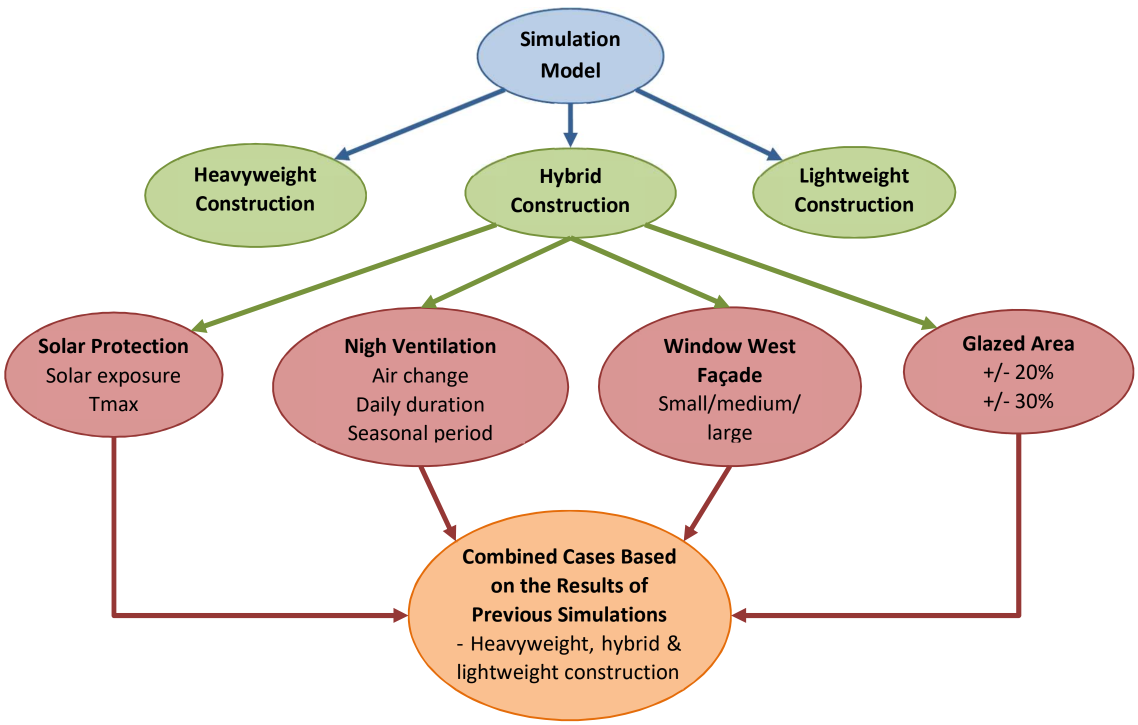

Figure 5: Overview of Simulation Cases

2.4.1. Base Cases (Construction Types)

The first set of simulations regards the different wall layer structures of the three construction types, heavyweight construction, hybrid construction and lightweight construction. In order to be able to compare these different structures, all need to have the same U-values, which assesses the quality of the insulation. This value is the reciprocal of the thermal resistance (R-value). The unit's envelope elements and the aspired U-values are shown in Table 3. Because the ceiling and the exterior walls are in exchange with the environment of the building, they need the highest thermal insulation and therefore the lowest U-values. This value of 0.1 W/m^2K corresponds with the target value of the SIA 2024 (2015, p. 30) datasheet.

Table 3: Envelope Elements and Corresponding U-values

Envelope element	**U-value** $\left[\frac{W}{m^2K}\right]$
Floor	0.33
Ceiling	0.10
Exterior walls	0.10
Interior walls	2.79

The architecture office Unit Architekten provided detailed information about typical wall structures for all three construction types, which served as guidelines in this project. These guidelines can be found in Annex F (heavyweight construction), Annex H (hybrid construction) and Annex I (lightweight construction.

For the first set of simulations, no nighttime ventilation as well as no solar protection are applied, to most decisively demonstrate the characteristics of each construction type.

The second set of simulations was conducted with nighttime ventilation as well as solar protection (shading device). For the nighttime ventilation, the standard value of an air change rate of 3 times of the unit's interior air per hour was chosen. The ventilation lasts from 8PM to 8AM over a period from June 1st to September 30st, as the maximum temperatures are of interest in this report. For the shading device, a solar exposure of 0.1 was chosen with a maximum temperature of 27°C. These parameters are further explained in Section 2.4.2 of solar protection.

Heavyweight Construction

As suggested by the architecture office Unit Architekten, for this type of construction the exterior walls are built only from a single layer of bricks with interior and exterior plaster. The suggested type of brick is called monobrick produced by the company Schumacher Ziegelei AG which has a very low lambda value of 0.074W/mK. The lambda value describes the thermal conductivity a material and is used to determine the U-value of a series of layers. Because the lambda value is proportional to the U-value, a low lambda value is desired. A data sheet of this specific brick can be found in Annex G. The ceilings and the floors of this construction type mainly consist of concrete and insulation. For the interior walls, one single layer of bricks with interior plaster on both sides is used. Table 4 shows all the envelope elements with their structures and layer thicknesses. The suggestions from Unit Architekten for the design of the heavyweight construction can be found in Annex F. The full material report with the resulting U-values and R-values can be found in Annex J.

Table 4: Heavyweight Construction, Structure of Envelope Elements

Envelope element	**Material**	**Thickness [m]**	$\lambda\left[\frac{W}{mK}\right]$
Floor	Interior Plaster	0.015	0.2
	Concrete	0.29	1.6
	EPS	0.055	0.04
	Isover Isoconfort	0.04	0.031
	Screed	0.073	1.6
	Hardwood	0.01	0.13

Ceiling	Grass	0.08	0.2
	Filter mat	0.05	0.035
	Polyurethane (PUR) Insulation	0.16	0.025
	Expanded Polystyrene (EPS)	0.084	0.029
	Vapor Barrier	0.001	2.3
	Concrete	0.26	1.6
	Interior Plaster	0.015	0.2
Exterior walls	Exterior Plaster	0.02	0.87/0.25
	Monobrick	0.73	0.074
	Interior Plaster	0.015	0.2
Interior walls	Interior Plaster	0.015	0.2
	Solid Brick	0.125	0.6
	Interior Plaster	0.015	0.2

Hybrid Construction

For this construction type, Unit Architekten proposed exterior walls with cellulose insulation, fiberboards, and an airspace. The layer sequence and thicknesses are shown in Table 5. For simplification, the air gap and the exterior plasterboard are not included because they do not affect the thermal insulation aspects, only the irradiation. In order to counterbalance this measure, the irradiation on the exterior walls was set to zero. The floors, ceilings and interior walls for this type of construction have the same structure as the ones from the heavyweight constriction type. The design suggestions from Unit Architekten can be found in Annex H and the full material report from WUFI ®PLUS with the resulting U-values and R-values in Annex K.

Table 5: Hybrid Construction, Structure of Envelope Elements

Envelope element	**Material**	**Thickness [m]**	$\boldsymbol{\lambda \left[\frac{W}{mK}\right]}$
Exterior walls	Gypsum fiberboard	0.015	0.32
	Cellulose fiber insulation	0.28	0.036
	Oriented Strand Board (OSB) plate	0.015	0.0964
	Mineral wool	0.06	0.04
	Plywood	0.05	0.13
	Interior gypsum board	0.013	0.16
	Interior gypsum board	0.013	0.16
	Interior plaster	0.015	0.2

Lightweight Construction

Based on the suggestions of Unit Architekten, the exterior walls of the lightweight construction have the same structure as the exterior walls of the hybrid construction type. The ceilings and floors consist of a wooden grid with insulation, which cannot be modeled in WUFI ®PLUS. However, the thermally significant layers such as mineral wool, insulation boards and cellulose insulation are implemented in the simulation model as listed in Table 6. The interior walls for this construction type consist of two fiberboards with a layer of interior plaster and an air space in between. The suggestions for this construction type from Unit Architekten can be found in Annex I. The WUFI ®PLUS material report with the resulting U-values and R-values for the lightweight construction can be found in Annex L.

Table 6: Lightweight Construction, Structure of Envelope Elements

Envelope element	**Material**	**Thickness [m]**	$\lambda\left[\frac{W}{mK}\right]$
Floor	Plywood board	0.025	0.1
	Mineral wool	0.03	0.04
	Gravel	0.05	0.7
	Softwood	0.015	0.09
	Isover Isoconfort	0.04	0.031
	Isover Isoconfort	0.013	0.031
	Anhydrite screed	0.045	1.2
	Hardwood	0.01	0.13
Ceiling	Gravel	0.088	0.7
	Flumroc insulation board	0.075	0.035
	Spruce	0.019	0.09
	Cellulose fiber insulation	0.265	0.036
	Plywood	0.027	0.13
Interior walls	Interior plaster	0.014	0.2
	Fermacell gypsum fiberboard	0.01	0.32
	Air layer	0.092	0.59
	Fermacell gypsum fiberboard	0.01	0.32
	Interior plaster	0.014	0.2

2.4.2. Solar Protection

The solar gain through windows has a significant impact on the interior thermal comfort, especially in summertime. In WUFI ®PLUS, shading devices can be simulated, in order to reduce this solar gain. The two main parameters for this shading device are the solar exposure and the maximum temperature. To receive the most conclusive results, there was no nighttime ventilation included in the simulations.

Solar Exposure

The value of solar exposure describes how much of the sunlight reaches the interior of the unit. For example, a solar exposure of 0.1 means that 10% of the irradiation is transmitted through the windows and the shading device into the unit. A solar exposure of 1 means a full exposure to the sunlight and is equal to no shading device. In order to estimate the influence of the solar exposure on the interior climate simulations with a solar exposure of 0.1, 0.2, 0.5 and 1 were conducted.

Maximum Temperature

WUFI ®PLUS offers several options to control the shading device. It can be activated in order to reduce overheating (maximum temperature), if the irradiation exceeds a limit value or by schedule. Because the association BIZUN is concerned about the thermal comfort in summer and does not want to integrate active cooling of the units, this option to reduce overheating was chosen. This means, the shading device is active if the interior room temperature exceeds this maximum temperature. The simulations were conducted with a maximum temperature of 25°C and 27°C.

2.4.3. Nighttime Ventilation

A second measure to prevent overheating of a building is nighttime ventilation during the warm summer months. The building, which was heated up during the hot day, can be cooled down with cooler air from the environment during the night by opening the windows. This measure is also called natural ventilation. The most important parameters for this measure are the air change rate, the daily duration and the seasonal period. For all these simulations, the solar protection was omitted such that the effects on the results are more distinguishable.

Air Change Rate

The air change rate describes the amount of air, which passes through the building per hour. An air change rate of 1 means that all the interior air is exchanged with environmental air once per hour. For the simulations in this report, air change rates of 1 time, 3 and 6 times per hour were applied.

Daily Duration

This parameter describes at which time the ventilation starts in the evening and when it stops in the morning. In the base case simulations, the duration from 8PM until 8AM were applied. To analyze the impact of nighttime ventilation on the interior thermal comfort, simulations with starting and ending the nighttime ventilation two hours earlier and later were conducted.

Seasonal Period

Because the overheating of a building in Switzerland is only critical in summer, the definition of the start and end date of the ventilation period is crucial. In the base case simulations, a start date of June 1st and an end date of September 31st was applied. Simulations with a 1-month extension and ½-month shortening were conducted in order to evaluate the impact of the seasonal period on the interior thermal comfort. For the long period, this resulted in a start date of May 1st and end date of October 31st, for the short period in June 15th and September 15th respectively.

2.4.4. Window West Façade

Based on the floor plan from the reference project provided by Unit Architekten, there is no window planned on the west façade for the largest of the bedrooms. As this room is rather large and only has one window, it is possible that a window will be added in the future development process. To analyze the impact of an additional window at the west façade, three simulations were conducted; one with the same window size as the remaining windows (1.9mx2m), one with a small window (1mx1.5m) and one with a large window (2.5x2m). In order to highlight the effects of these measures, the nighttime ventilation was not included in the simulation and the base case values for the solar exposure (0.1) were used. A maximum temperature of 25°C was assumed, such that the effects are more visible.

2.4.5. Glazed Area

The solar gain through windows can also be modified with the area of the windows. Table 7 shows the glazed area from the base cases as well as scenarios with modifications of 20% and 30% of the window area. In order to make the impacts of these measures stand out, the nighttime ventilation was omitted and the solar exposure value (0.1) from the base cases was applied. A maximum temperature of 25°C was assumed.

Table 7: Glazed Area Case Overview

Case	North Façade	East Façade	South Façade	West Façade	Total
Base case	1.6 m²	3.8 m²	22.8 m²	0	28.2 m²
+ 30%	2.08 m²	4.94 m²	29.64 m²	0	36.66 m²
+ 20&	1.92 m²	4.56 m²	27.36 m²	0	33.84 m²
- 20%	1.28 m²	3.04 m²	18.24 m²	0	22.56 m²
- 30%	1.12 m²	2.66 m²	15.96 m²	0	19.74 m²

2.4.6. Combined Cases Based on Results from Previous Simulations

The last set of simulations were conducted in order to provide realistic scenarios for the three construction types. These scenarios include heating and mechanical ventilation. Mechanical ventilation is necessary in order to provide the required interior air quality standards. The source of the heating energy is assumed to be a district heating grid, based on information received from Unit Architekten. The input variables for these scenarios are based on the findings of the analyzed parameters above and are therefore further described in section 3.11. These input variables must be identical among the three construction types to make them comparable.

3. Results and Discussion

This section collects all the data output from the simulations carried out. To display the results, the output data from the WUFI ®PLUS software is presented in Cumulative Frequency Distribution (CFD) curves and Temperature Course of the Year (TCY) curves. For the horizontal axis, 12 sections were chosen, such that they represent the months of the year in a TCY. In WUFI ®PLUS an initial value for temperature to start the simulations can be set. In the cases where no heating source is applied, the TCY starts with this initial temperature, which was set to 20°C. Therefore, in some of the TCY curves there are temperature peaks in the first hours of the year until the building is cooled down. As stated in section 2.4, the hybrid construction type was applied for the sensitivity analyses presented in section 3.3 to section 3.10.

Furthermore, after each subchapter of results, a discussion of the presented graphs is given. These discussion subchapters aim to assess and interpret the results displayed. Consequential explanations for peaks, deviations and inconsistencies are given. Additionally, the results are compared to the guidelines and norms of requirement for indoor room climate introduced in section 2.2.

3.1. Results of Base Cases (Construction Types)

The first set of simulations was conducted in order to compare the three different construction types described in section 2.4.1. In order to highlight the effects of the three different construction types, nighttime ventilation and solar protection were excluded from the simulation. Figure 6 shows the CFD curve of the three construction types heavyweight, hybrid and lightweight construction. The lightweight construction reaches the highest temperatures in summer and the lowest in winter. The maximal temperature reached was 46.71°C and the minimal 10.13°C for the lightweight construction. The curves for the heavyweight and hybrid construction types are almost identical. The hybrid construction reached temperatures from 15.66°C to 42.76°C and the heavyweight construction from 16.00°C to 42.99°C.

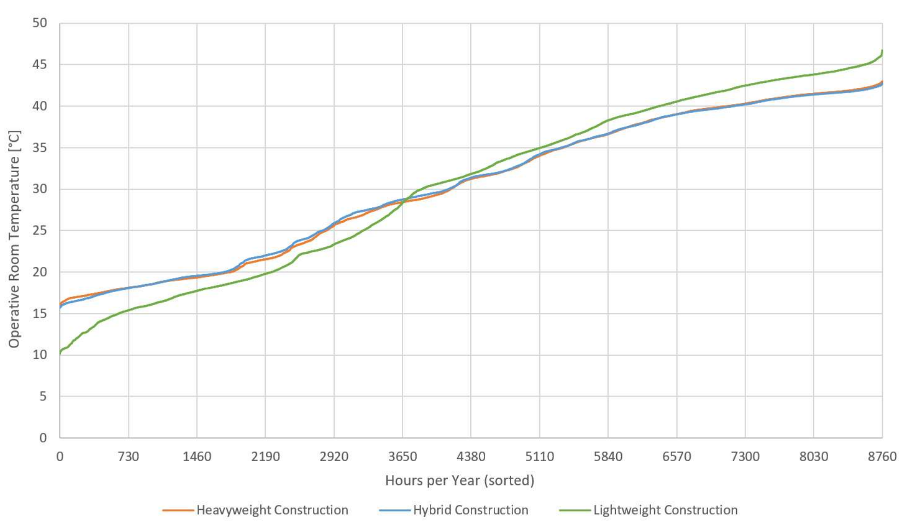

Figure 6: CFD of Construction Types without Solar Protection and Nighttime Ventilation

In Figure 7, the TCYs curves for the three construction types are displayed. It is visible that high temperature fluctuations for lightweight construction occur (green line). Equal to Figure 6, the heavyweight and hybrid construction curves show minimal deviations.

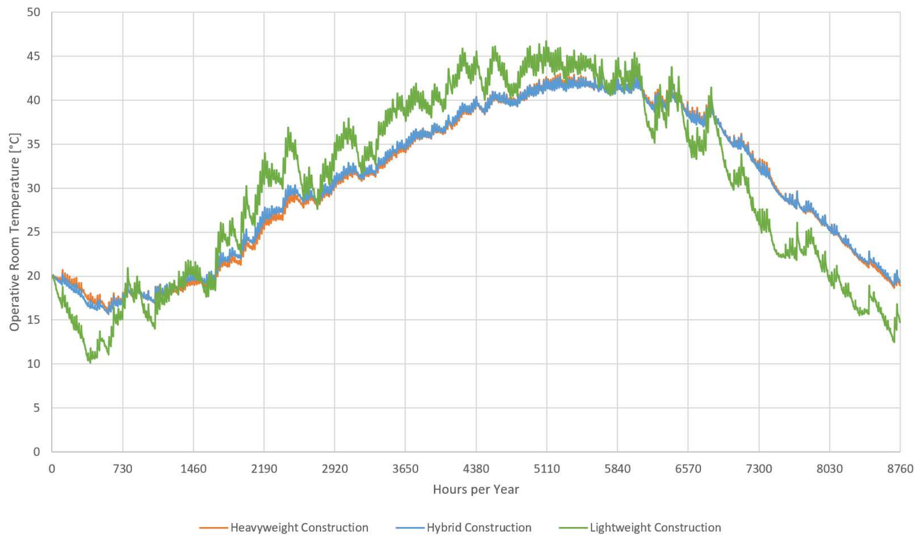

Figure 7: TCY of Construction Types without Solar Protection and Nighttime Ventilation

The second set of simulations was conducted including the measures nighttime ventilation and solar protection. The CFD curve of this simulation set is shown in Figure 8. The minimal temperatures were not affected by these two measures. However, in summer the maximum temperatures for the three construction types are nearly identical in a range between 27.01°C and 27.05°C.

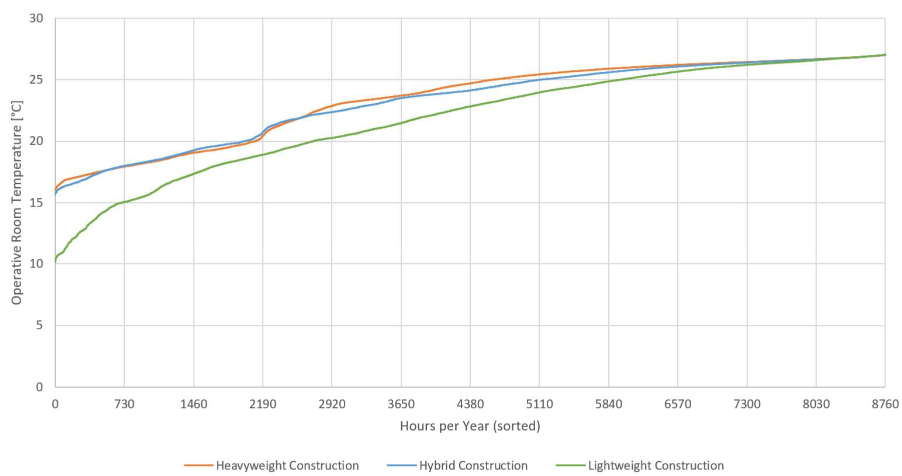

Figure 8: CFD of Construction Types with Solar Protection and Nighttime Ventilation

Figure 9 shows the TCY of the same simulation data as presented in the Figure 8. It can be deduced that for none of the construction types the maximum temperature of 27°C is exceeded significantly. The TCY shows distinctively the effects of the solar protection and nighttime ventilation. The maximum temperature of 27°C is visible as a bar, which cuts of the temperature curves. The seasonal period is clearly identifiable between the two low temperature gaps in summertime (3650h and 6570h).

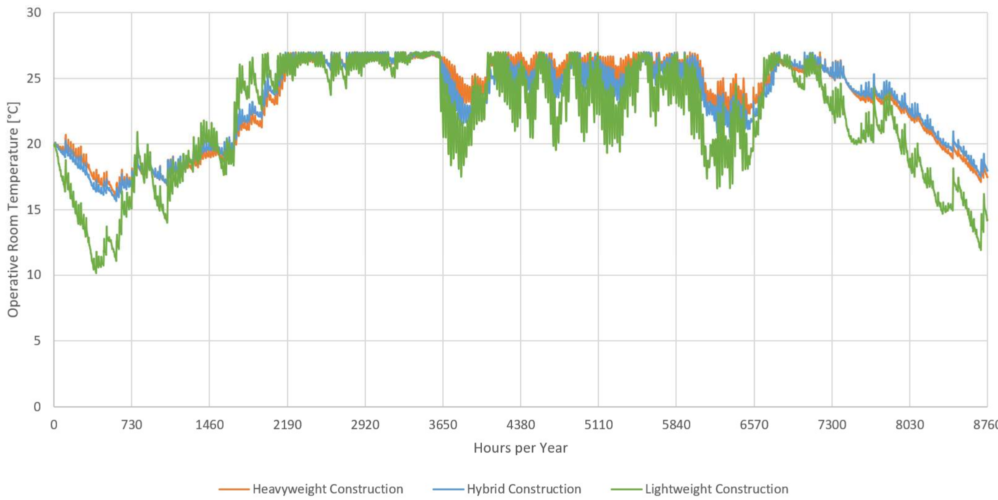

Figure 9: TCY of Construction Types with Solar Protection and Nighttime Ventilation

3.2. Discussion of Base Cases (Construction Types)

The first set of simulations without solar protection and nighttime ventilation lead to almost identical results for the heavyweight and hybrid construction. This occurs due to the minor differences of the wall layer structures from the heavyweight and the hybrid construction types. All three construction types resulted in unreasonably high interior temperatures for an acceptable indoor room climate.

The high fluctuations of the lightweight construction case visible in Figure 7 can be justified with the lower thermal mass of this construction type. This leads to a shorter adjustment time between the interior and the exterior temperature as well as the appearing severe differences in maximum and minimum temperature.

The results of the second set of simulations shows clearly that only with good solar protection and nighttime ventilation the maximum temperature can be kept in a reasonable range for all three construction types. As seen in Figure 9, the temperature of none of the construction types overshoots the defined maximum temperature of 27°C. The greatest differences lay between the lightweight construction and the two other construction types. This is a comprehensible result due to the minor changes between the heavyweight and hybrid construction types.

3.3. Results of Solar Protection

The first measure investigated with a sensitivity analysis is the solar protection with the two parameters solar exposure and maximum temperature. The CFD curve of these cases is shown in Figure 10. As a reference, one case with no solar protection was included. The effect of this measure is noticeable due to the large differences between the colored curves (different solar exposure values and maximum temperatures) and the grey curve for solar exposure 1 (no shading device).

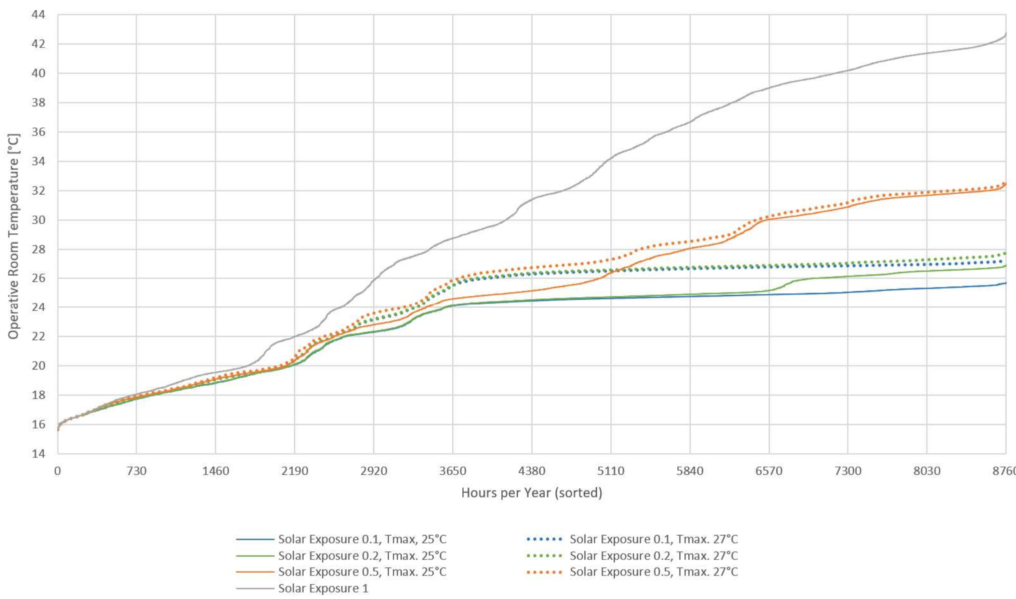

Figure 10: CFD of Solar Protection

Figure 11 shows two TCYs for the solar exposure of 0.1 with maximum temperatures of 25°C and 27°C. The overshoots of the maximum temperatures are minimal, especially for the maximum temperature of 27°C.

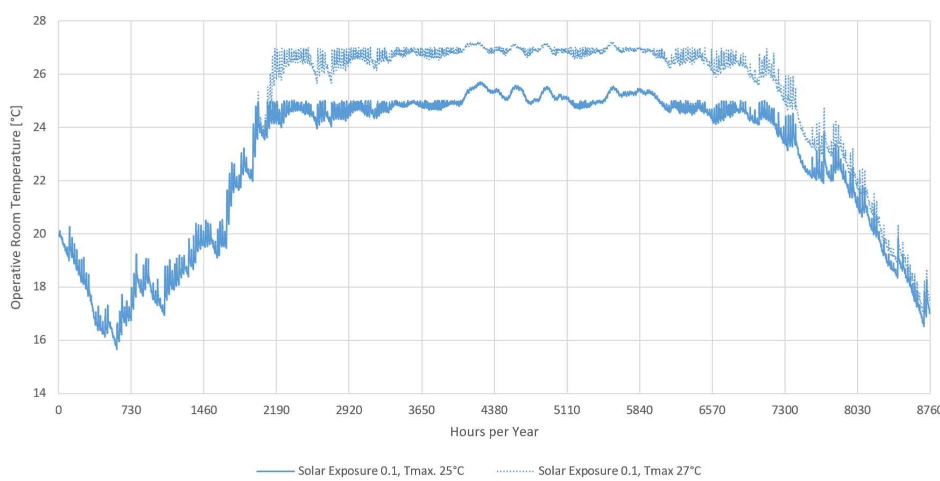

Figure 11: TCY of Solar Exposure 0.1

In Figure 12 the simulation outputs with a solar exposure of 0.2 for the two maximum temperatures of 25°C and 27°C are displayed as TCYs. Here, the overshoots of the maximum temperatures are larger compared to Figure 11. Additionally, the difference between the curves of the two maximum temperatures is considerably smaller.

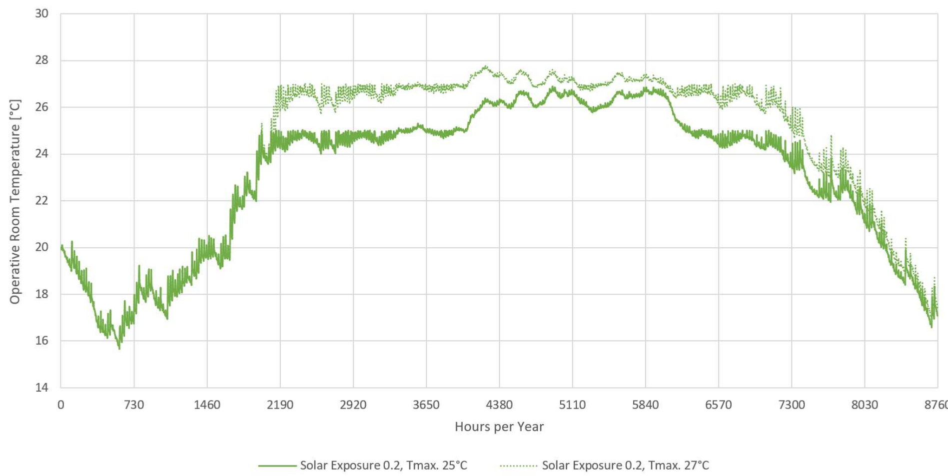

Figure 12: TCY of Solar Exposure 0.2

The same simulations were carried out with a solar exposure value of 0.5. The simulation outputs for these cases are shown in a TCY representation in Figure 13. Overshoots of the maximum temperature of 7°C occur for this solar exposure value for both maximum temperatures. The two curves for the different maximum temperatures show almost no difference during the warmest months.

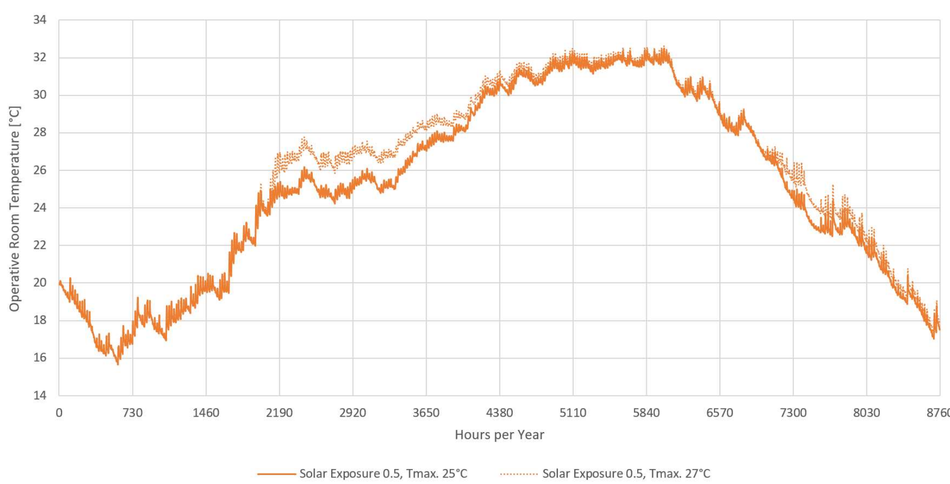

Figure 13: TCY of Solar Exposure 0.5

3.4. Discussion of Solar Protection

Comparing the results of the case solar exposure 1 (no solar protection) with the other cases with solar exposure values of 0.1, 0.2 and 0.5 in Figure 10, results in a difference of maximal temperatures of 10°C to 16°C. This leads to the perception, that solar protection in form of a shading device has a significant impact on the thermal comfort in summer.

The curves of the three Figures with different solar exposure values (Figure 11, Figure 12 and Figure 13) show clearly the influence of the parameters of solar protection. The worse the solar exposure, the larger the overshooting of the maximum temperature. Also visible from these three figures is that the difference between the two curves (maximum temperature 25°C and 27°C) of each figure decreases for higher solar exposure values. The same is visible in Figure 10 when comparing the dotted and continuous lines of each color. This demonstrates the significant effect of a good (low) value for solar exposure. Deductible from these analyses is that with the worse solar exposure value the more critical the controlling of the maximum temperature appears. For the value of solar exposure of 0.5, controlling the maximum temperature is unachievable.

3.5. Results of Nighttime Ventilation

The analyses of the nighttime ventilation included the parameters of the air change rate, the daily duration and the seasonal period of the ventilation. The results of these simulations are collected in this section of the report.

3.5.1. Air Change Rate

The first parameter assessed was the air change rate. Figure 14 shows the CFD of three different air change rates including a reference case without any nighttime ventilation. The three cases describe the air change rate of 1x, 3x, and 6x the volume of the residential unit.

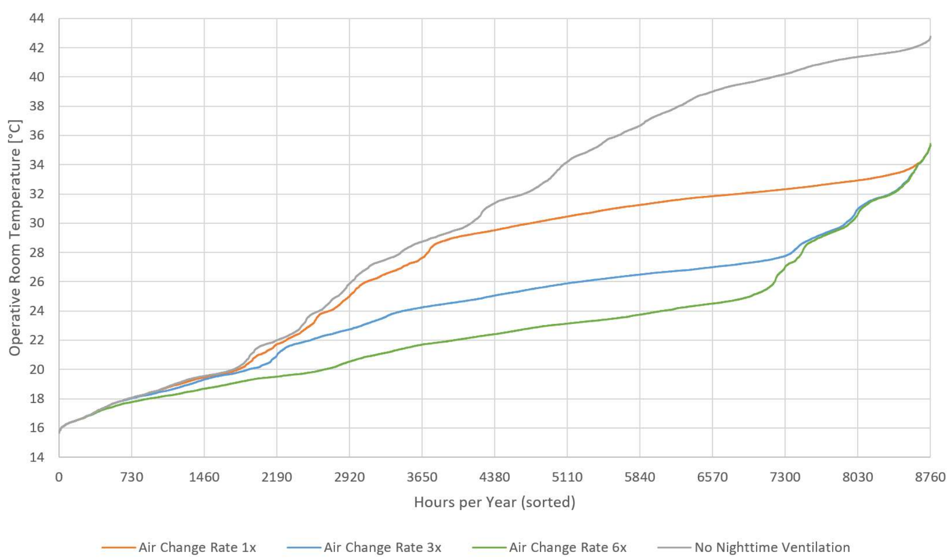

Figure 14: CFD of Nighttime Ventilation, Air Change Rates

In Figure 15 the same data is displayed as a TCY including the reference case without nighttime ventilation. It can be seen that the nighttime ventilation leads to significantly lower temperature developments in summer, however also to slightly lower temperatures in the last months of the year from October (6570h) to end of December (8760h).

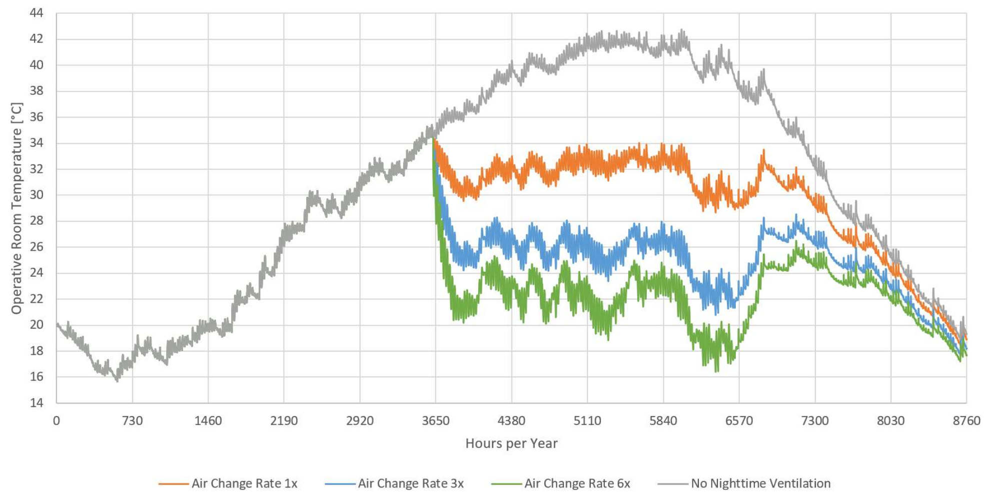

Figure 15: TCY of Nighttime Ventilation, Air Change Rates

3.5.2. Daily Duration

The second parameter analyzed from the nighttime ventilation is the daily duration of the nighttime ventilation. Figure 16 shows the CFD for three different durations from 6PM to 6 AM, 8PM to 8AM and 10PM to 10AM. The duration from 6PM to 6AM shows slightly higher temperatures while the durations from 8PM to 8AM and 10PM to 10AM lead to identical results.

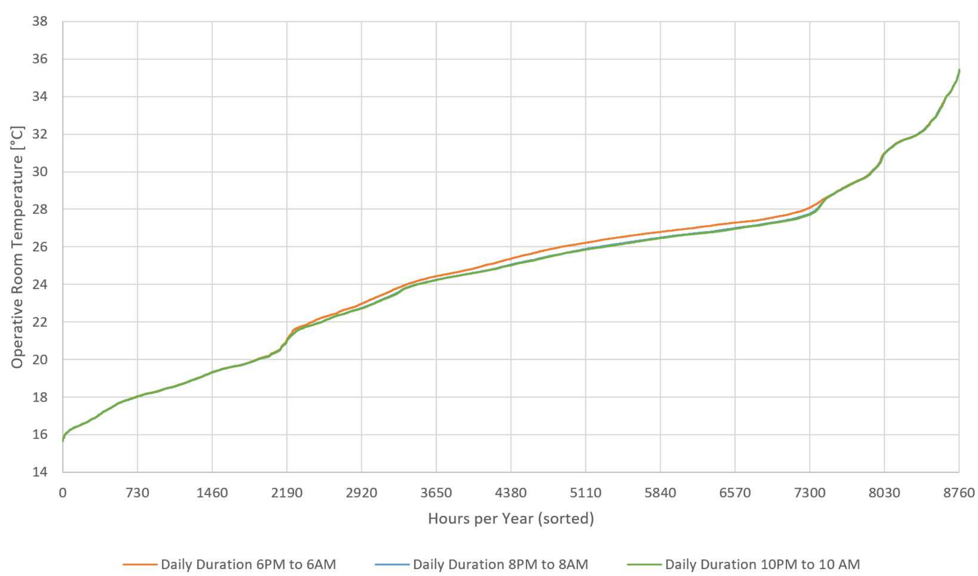

Figure 16: CFD of Nighttime Ventilation, Daily Duration

In Figure 17 the same data is displayed in a TCY representation. Comparable to Figure 16, in this representation the three curves show little difference and the durations from 8PM to 8AM and 10PM to 10AM are identical.

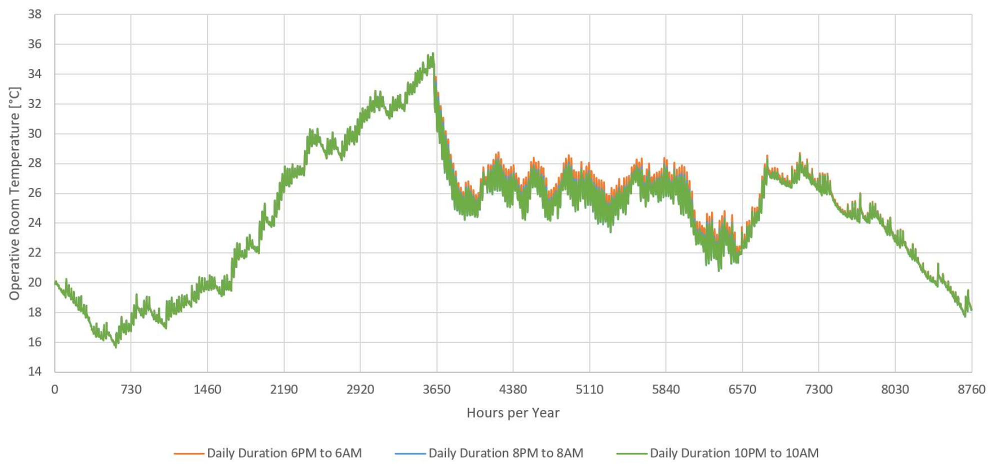

Figure 17: TCY of Nighttime Ventilation, Daily Duration

3.5.3. Seasonal Period

The last parameter analyzed form the nighttime ventilation is the seasonal period. In Figure 18 the TCY of three different ventilation periods, long, medium and short are displayed. The base case period from June 1st (3'650h) to September 31st (6'570h) corresponds to the medium duration. The long period lasts from May 1st (2'920h) until October 31st (7'300h), the short from June 15th (3'680h) to September 15th (6'200h) respectively. The start and end dates of these durations are observable at the peaks and gaps of the TCY curves.

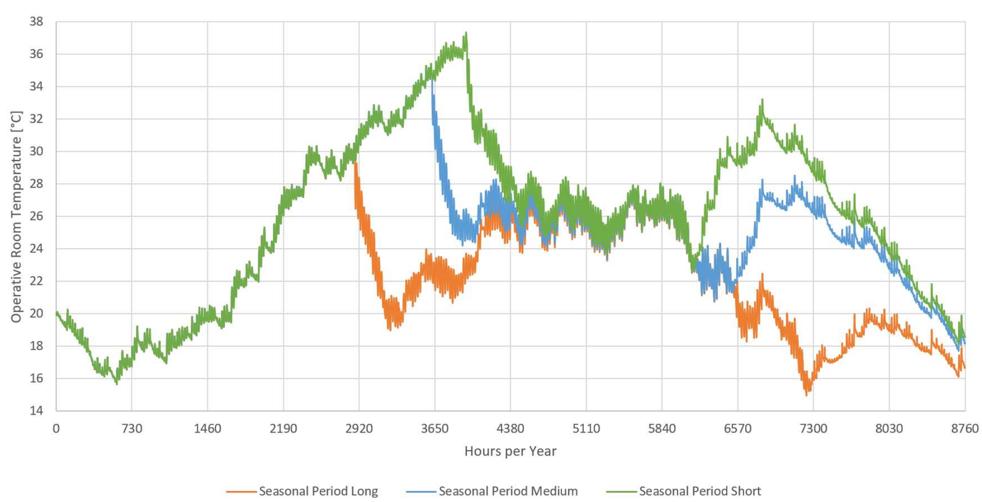

Figure 18: TCY of Nighttime Ventilation, Seasonal Period

3.6. Discussion of Nighttime Ventilation

The sensitivity analysis of the three different parameters air change rate, daily duration and seasonal period for the nighttime ventilation are discussed in this section.

3.6.1. Air Change Rate

A comparison of the case with no nighttime ventilation to the cases with different air change rates in Figure 15 implies the great effectiveness of this measure. The high temperature peaks in summer can be eliminated, even with the lowest of the simulated air change rates.

The similar maximum temperatures of each air change rate simulation visible in Figure 14 occur at the temperature peaks just before the nighttime ventilation period starts in June (2650h). The TCYs of air change rate 1x and 3x result in a significant shift downwards of the temperature curve. This shift appears distinguishably smaller from air change rate 3x to 6x. This implies that the higher the air change rate, the smaller the effect of reducing the high temperatures. Therefore, an air change rate of 3x is ideal.

3.6.2. Daily Duration

The exterior air reaches its lowest temperatures just before the sun rises in the morning. In summertime, this occurs at around 6AM. This implies the general assumption, that nighttime ventilation is most effective in the morning hours. The results presented in Figure 16 and Figure 17 show only minor differences. Therefore, the simulation model is not very sensitive to a change in this parameter. The slightly higher temperatures for the duration from 6PM to 6AM origin from the higher temperatures in the early evening hours when the nighttime ventilation starts.

3.6.3. Seasonal Period

The beginning of the three simulated seasonal periods is clearly visible in Figure 18. The peak in June (3650h) of the short and medium seasonal periods imply that the ventilation must start earlier. The very low temperatures in the beginning of May (2920h) reached with the long seasonal period, show that the start on May 1st is too early. Based on these simulations a start date of May 15th is suitable. The end of the ventilation period shows temperature drops for all three simulations in Figure 18. Therefore, the end dates of the simulated ventilation periods were chosen too late and an end date of August 31st emerges to be appropriate.

3.7. Results of Window West Façade

As stated in section 2.4.4, a sensitivity analysis on an additional window on the west façade was conducted. Four simulation cases to analyze the impact of an additional window were carried out. In order to highlight the influence of an additional window, the nighttime ventilation was not included in these simulations. The CFD of the four cases large, medium, small and no window are shown in Figure 19. The maximum temperatures reached with these simulations are in a range from 25.71°C (no window) to 25.79°C (large window).

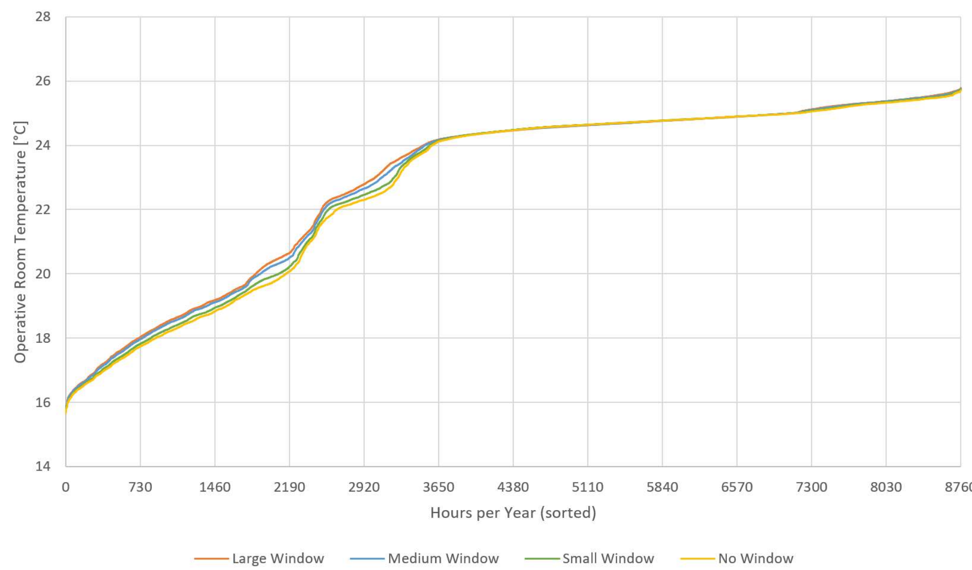

Figure 19: CFD of Window West Façade

Figure 20 shows results from the same simulation cases in a TCY representation. The main temperature differences occur in wintertime, and the differences in summertime are minor.

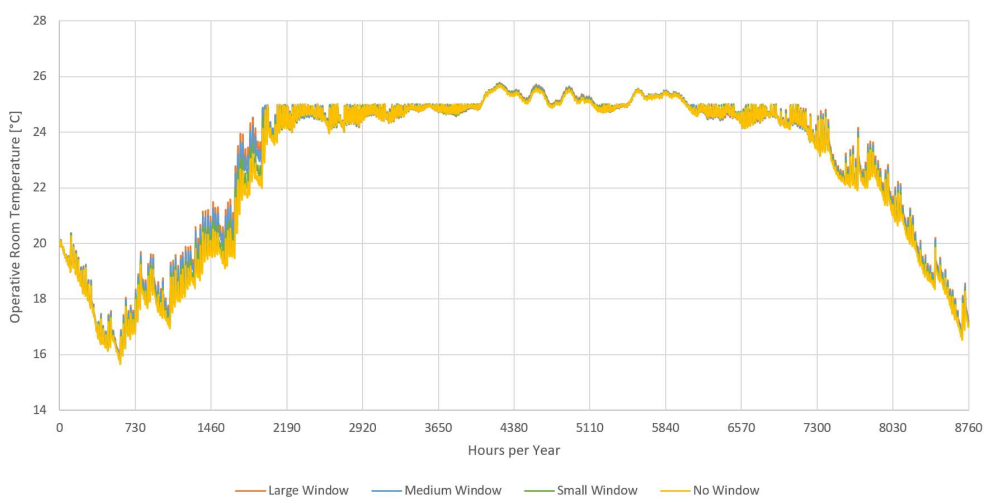

Figure 20: TCY of Window West Façade

3.8. Discussion of Window West Façade

As seen in Figure 19 and Figure 20 the impact of a single additional window is only minor. The main temperature differences occur in the colder season, where solar gain is desired. The larger the window, the larger the solar gains and therefore also the higher temperatures in wintertime. Hence, with an additional window, the heating demand can be reduced. With a good shading device with a solar exposure value of 0.1, the additional solar gains can be counterbalanced in summer. The differences in the overshoots of the maximum temperature of 25°C are negligibly small for the four cases.

The differences of these simulations are so minimal because the entire unit is simulated as a single temperature zone. Therefore, the solar gain of the additional window is distributed over the whole unit resulting in only small temperature deviations. For the room facing west this could however lead to temperatures, which exceed the guidelines and norms of thermal comfort. Simulations for the increased temperatures of the west facing room can not be given due to the limitations of the WUFI ®PLUS software.

3.9. Results of Glazed Area

As the window measurements are not defined by Unit Architekten, four cases for a sensitivity analysis of these measurements was conducted. These four cases differ in plus and minus 20% and 30% of glazed area. In Figure 21 the temperature CFD of these simulation results are displayed. The differences in maximum temperatures reached in summer are minimal and range from 25.59°C (-30% glazed area) to 25.82°C (+30% glazed area). The differences in minimum temperatures are slightly larger and range from 15.15°C for -30% glazed area to 16.10°C for + 30% glazed area.

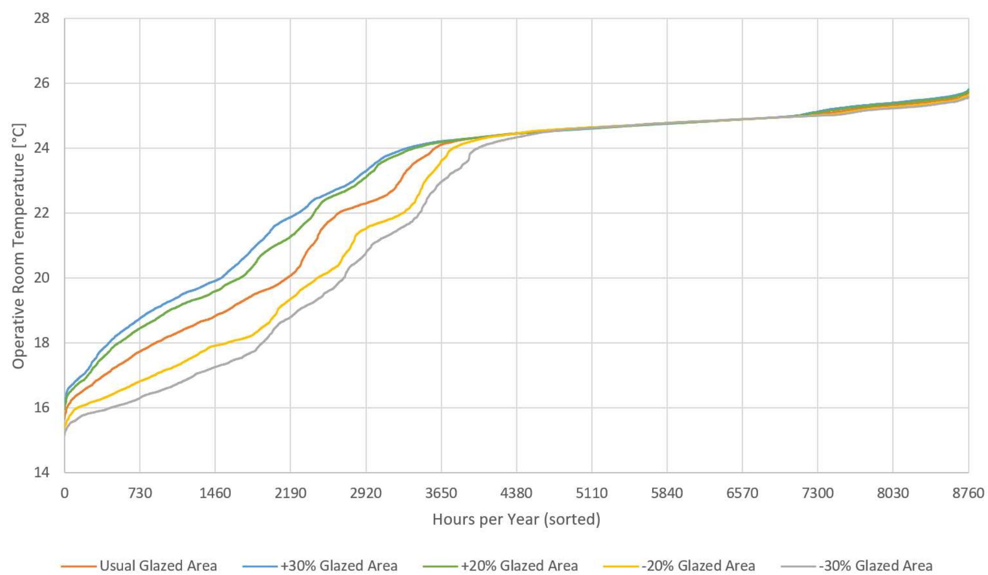

Figure 21: CFD of Glazed Area

Figure 22 shows the same data set in a TCY representation. It is visible that a change of the glazed are has a major impact on the temperature in wintertime but only a minor impact in summertime. This results in higher temperatures for cases with a larger glazed area in summertime and lower temperatures for cases with a smaller glazed area in wintertime.

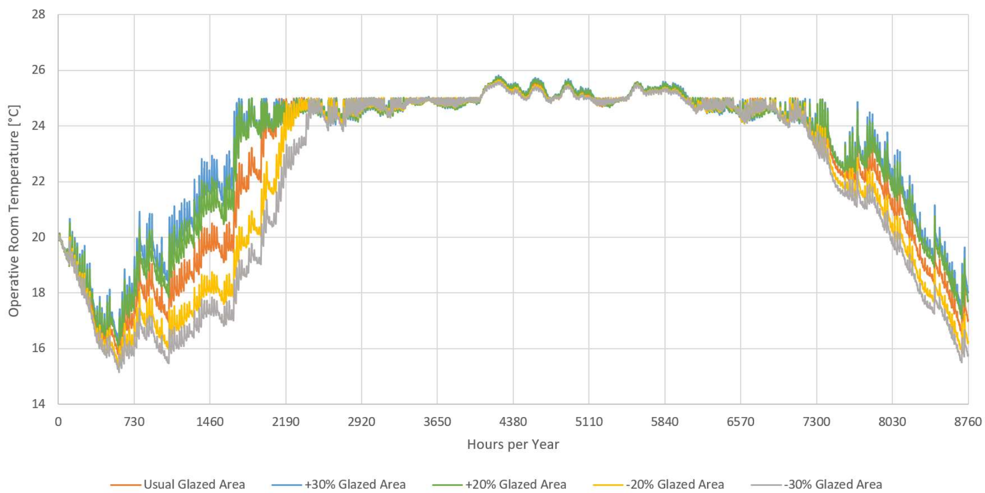

Figure 22: CTY of Glazed Area

3.10. Discussion of Glazed Area

The results from the glazed area simulation cases presented in Figure 21 and Figure 22 show similar characteristics to the cases with an additional window. However, the temperature differences are slightly higher in summertime as well as in wintertime. This is due to the larger changes in glazed area, which lead to larger changes in solar gains compared to only one additional window. For this parameter, a compromise between the reduction of heating energy and thermal comfort in summer is mandatory. Because the impact on the temperature in wintertime is much larger, intuitively increasing the glazed area would be plausible. However, the association BIZUN is mainly concerned about the thermal comfort in summertime and hence caution with increasing the glazed area is required.

3.11. Input Variables for Combined Cases Based on Results from Previous Simulations

For the last set of simulations, the previously analyzed parameters were evaluated and adjusted in order to match the requirements for this residential unit. Three simulations were conducted with the same input variables for the heavyweight, hybrid and lightweight construction type. The simulations include mechanical ventilation as well as heating, such that predictions about the heating demand can be established. An additional window on the west façade was not included. Based on the requirements of the association BIZUN, there was no active cooling in summertime included in the simulations.

3.11.1. Solar Protection

Based on the previously presented results, the value for solar exposure of 0.1 was chosen. The maximum temperature of 25°C was applied because the association BIZUN is concerned about overheating of the residential units in summertime. With this value of solar exposure and maximum temperature it can be proven, whether eliminating overheating without active cooling is possible or not.

3.11.2. Nighttime Ventilation

From Figure 14 it can be deduced, that the initially chosen air change rate of 3x is appropriate, this value was also applied for the last set of simulations. Because the impact of the change in daily duration of the nighttime ventilation was only minor (Figure 16), this data remained unchanged from the base cases. As shown in Figure 18 the start and the end dates of the seasonal period chosen in the base cases were both too late. The period which was chosen for the last set of simulations lasts from May 15th to August 31st.

3.11.3. Mechanical ventilation

As already mentioned above, the last set of simulations includes mechanical ventilation. An air volume flow rate of $600\frac{m^3}{h}$ over the whole year was chosen. The efficiency for the heat recovery is assumed to be 0.8 according to the target value of SIA 2024 (2015).

3.11.4. District heating

The last set of simulations also includes the planned district heating. A heating capacity of 1.925 kW is assumed which corresponds to the standard value of $10W/m^2$, which is applicable for a low energy consuming building. The heating period was set from October 15th to April 1st. The heating is controlled with a minimum temperature for the residential unit, which was set to 20°C. This activates the heating whenever the temperature falls below 20°C.

3.12. Results of Combined Cases

The full reports on these simulation results can be found in Annex M for the heavyweight construction, in Annex N for the hybrid construction and in Annex O for the lightweight construction.

3.12.1. Temperature Curves

Figure 23 shows the CFD of the three construction types with combined and improved choice of input variables. The heavyweight and hybrid construction types still have very similar temperature curves. The temperature of the heavyweight construction ranges from 19.58°C to 25.26°C, the hybrid construction from 19.62 to 25.40°C and from 18.27°C to 26.25°C for the lightweight construction.

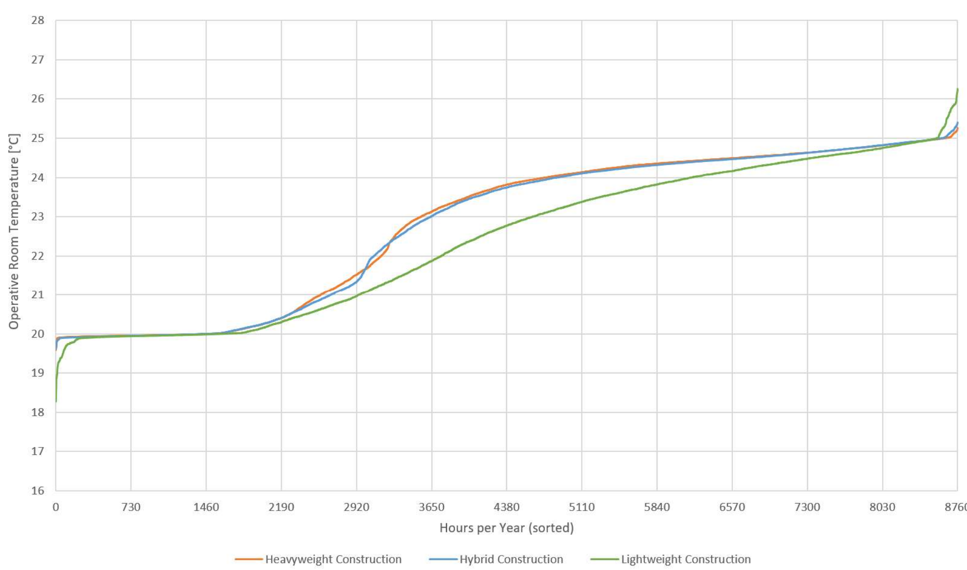

Figure 23: CFD of Combined Cases Construction Types

The TCYs of the three construction types are displayed in Figure 24 including the temperature of the exterior air (grey line). It is visible that the overshoots of the maximum temperatures align with the high temperatures of the exterior air.

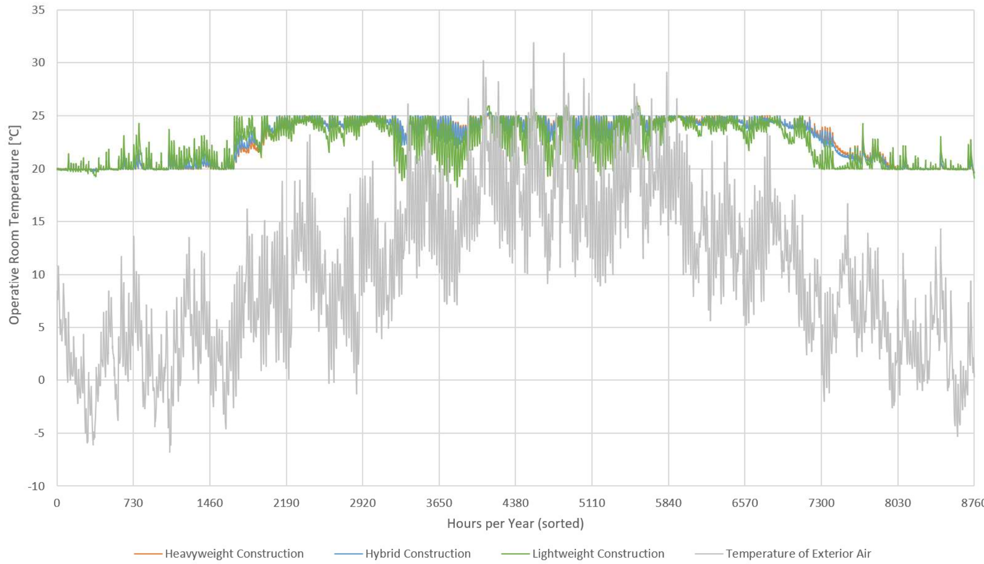

Figure 24: TCY of Combined Cases Construction Types Including Temperature of Exterior Air

In Figure 25 the TCYs of the same simulations are displayed enlarged without the temperature of exterior air. Here, the high fluctuations of the lightweight construction are clearly visible as well as its low temperatures in summertime. Some overshoots of the maximum temperature in summer are visible for all three construction types. The lightweight construction also results in detectable underruns of the minimum temperature in winter.

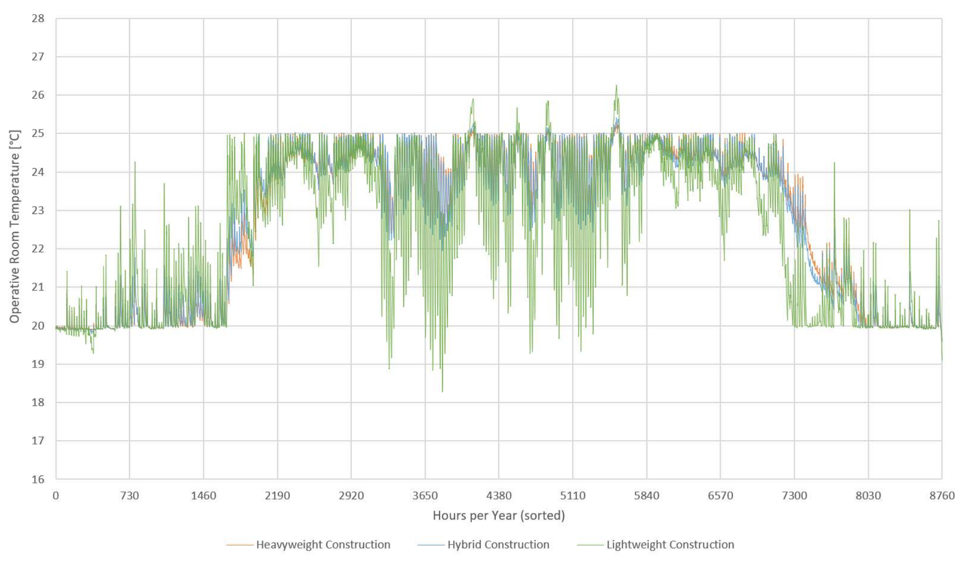

Figure 25: TCY of Combined Cases Construction Types

As stated in section 2.2.1 and according to DIN EN 15251 (2012) the values for an acceptable indoor room temperature are not absolute but dependent on the outside air temperature. The following graphs are directly exported from WUFI ®PLUS. Figure 26 shows the relation between the operative and the mean outer gliding temperature for the heavyweight construction and Figure 27 for the hybrid construction respectively.

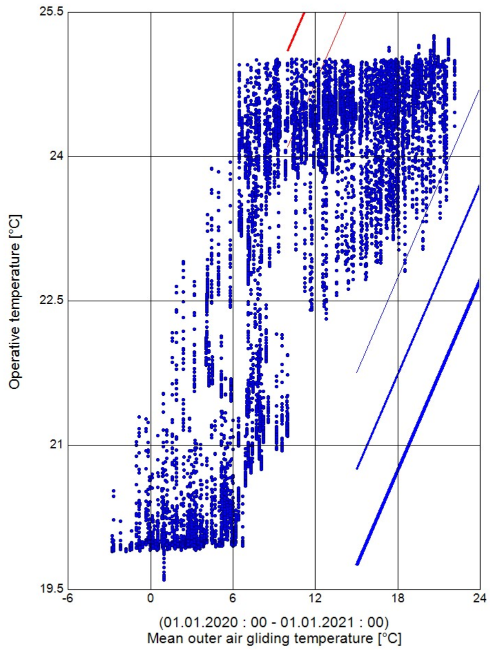

Figure 26: Heavyweight Construction, Operative vs. Mean Outer Air Gliding temperature

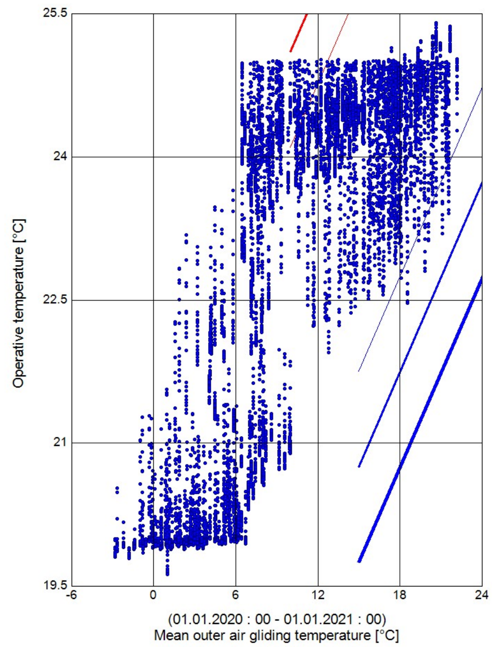

Figure 27: Hybrid Construction, Operative vs. Mean Outer Air Gliding temperature

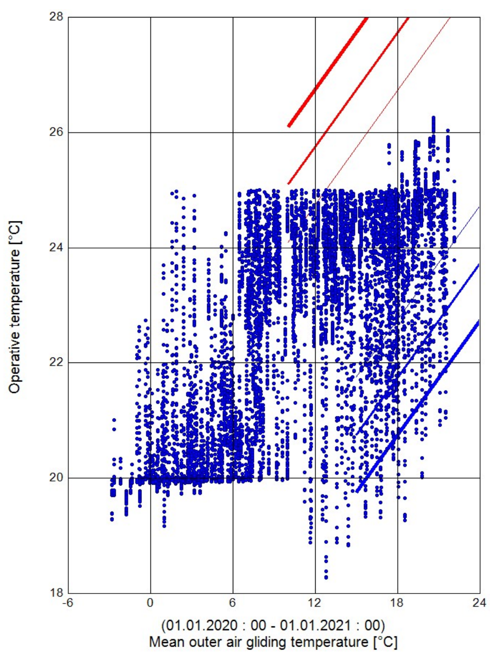

Figure 28: Lightweight Construction, Operative vs. Mean Outer Air Gliding temperature

The results of the operative and mean outer air gliding temperature for the lightweight construction are shown in Figure 28. The boundaries of the different categories from the DIN EN 15251 norm are described in Section 2.2 of this report and represented in red and blue lines. The thinnest line stands for category I and the thickest for category III.

3.12.2. Air Quality

The two factors evaluated in this report assessing the air quality are the relative humidity and the CO_2 concentration. In Figure 29 the TCY of the relative humidity for the three construction types including mechanical ventilation and heating are shown. The initial value for the relative humidity in WUFI ®PLUS is 55%. All the construction types, especially the lightweight construction, show very low values during the heating period in winter.

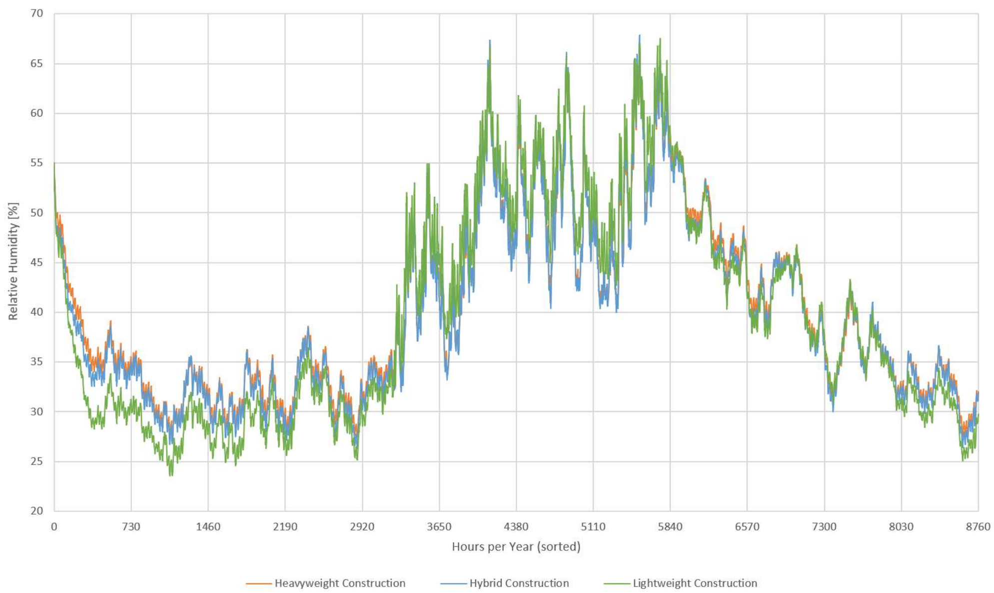

Figure 29: TCY of Relative Humidity of Construction Types

The TCY of the CO_2 concentration for the three construction types are displayed in Figure 30. The initial value for the CO_2 concentration is 400ppm. Because the CO_2 concentration is only dependent on the internal loads and the ventilation measures, the curves for all three construction types look the same.

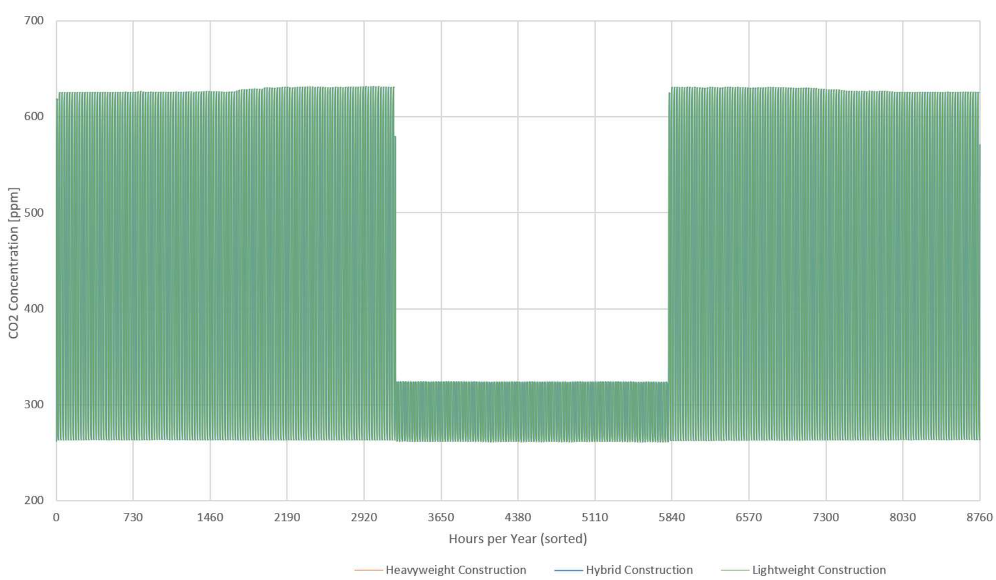

Figure 30: CO_2 of Concentration Course over the Year

3.12.3. Heating demand

WUFI ®PLUS also offers the possibility to calculate the heating demand of a simulated unit. The heating power of the residential unit over the period of a year for the three construction types is shown in Figure 31.

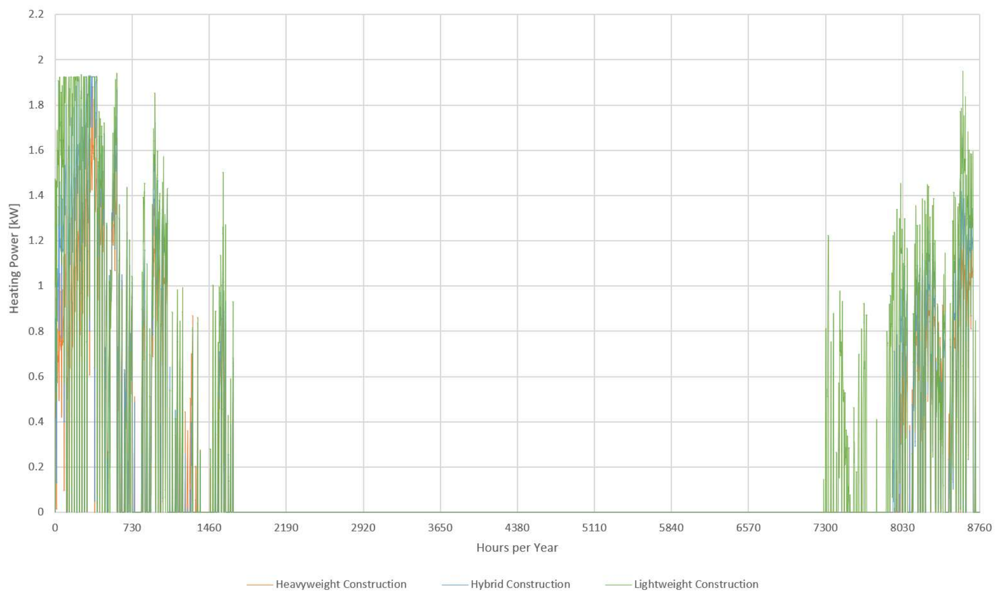

Figure 31: Heating Power Course over the Year of Construction Types

From Figure 32, which displays the CFD of the heating power, it can be deducted that the lightweight construction results in the highest heating energy demand and the heavyweight the least.

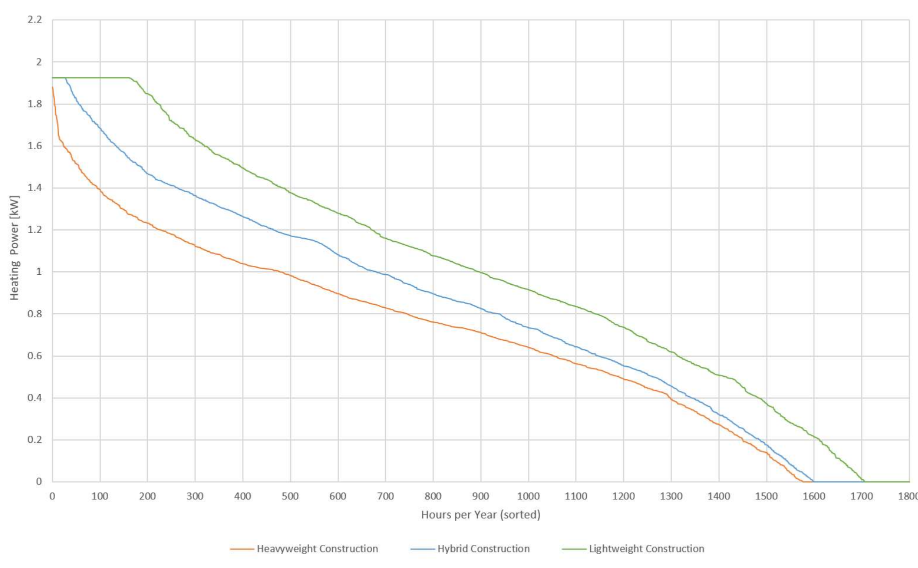

Figure 32: CFD Heating Power of Construction Types

In Table 8 the maximum heating power and heating energy output from the simulations are listed. The heating energy was calculated per square meter in order to make it comparable to other units.

Table 8: Simulation Heating Energy of Construction Types

Construction Type	Maximum Heating Power $[kW]$	Heating Energy $[\frac{kWh}{a}]$	Heating Energy $[\frac{kWh}{m^2 * a}]$
Heavyweight Construction	1.88	1’229.3	6.39
Hybrid Construction	1.925	1’462.6	7.60
Lightweight Construction	1.925	1’799.9	9.35

3.13. Discussion of Combined Cases

In this section, the results of the combined cases presented in section 3.12 are discussed. As mentioned above, the simulations include mechanical ventilation and heating, but no active cooling.

3.13.1. Temperature Curves

In Section 2.2.1 the acceptable temperatures according to SIA are described as the temperature range from 23.5°C to 26°C in summer and from 19°C to 24°C in winter. The temperature CFD of the three last cases in Figure 23 show that with the heavyweight and the hybrid construction types these limits of 26°C in summer and 19°C in winter can be fulfilled. The lightweight construction overshoots the limit in summer for only 13h and in winter the temperature remains higher than 19°C for the whole season.

In Figure 25, it can be seen that in summertime for all three construction types temperatures below 23°C arise temporarily. The temperature of the lightweight construction even falls below 20°C. These low temperatures occur due to the effectiveness of the nighttime ventilation. In the simulation, the nighttime ventilation is running over the entire seasonal period. These low temperatures can simply be eliminated by not opening the windows, shorten the ventilation duration or decrease the air change rate in the specific nights with low temperatures.

The temperature peaks visible in Figure 25 occur for all three construction types but for the lightweight construction, they are the greatest. The peaks for the heavyweight and hybrid construction do not overshoot the boundaries stated in SIA 180 (1999) of 26°C but the lightweight construction leads to one overshoot of this boundary. For this high temperature period, the simulated solar protection and nighttime ventilation are not sufficient. These temperature peaks could be reduced by increasing the air flow rate of the nighttime ventilation in the specific nights with high temperatures.

The two graphs of the operative and mean outer air gliding temperature for the heavyweight and hybrid construction (Figure 26 and Figure 27) appear almost identical. Minor differences at high temperatures due to the maximum temperature overshoots occur in summer. Taking the lines of the comfort categories of the DIN EN 15251 norm into account, it can be said, that these two construction types mostly fulfill category II of the norm. If the lines of this norm are horizontally extended to the left, it appears that the temperatures occurring in winter are too low for category II, rarely even for category III. The requirements for the moderate level of expectations (category III) and the normal level of expectation (category II) can therefore not be fulfilled temporarily. This violation of the norm could be eliminated with increasing the minimum temperatures for the heating in the simulations or increasing the heating power. However, this would lead to a significant increase in heating demand.

The graph for the lightweight construction (Figure 28) looks slightly different. The maximum temperature overshoots are more distinct but still lay within the boundaries of the DIN EN 15251 norm. At high exterior air temperatures, the operative temperature clearly falls below the limit of category III from the DIN EN 15251 norm. This mainly occurs for periods with high outer air gliding temperatures which appear in during summertime. As stated above, these low temperatures in summertime can be eliminated with excluding the nighttime ventilation at the specific low temperature nights. For the low temperatures reached in winter, the same measure as stated above for the heavyweight and hybrid construction could be applied.

3.13.2. Air Quality

As stated in section 2.2.3, the acceptable interior relative humidity levels are 40% to 70%. The low humidity levels occur in wintertime during the heating period as seen in Figure 29. For all three construction types the relative humidity falls below the boundaries of 40%. Especially the lightweight construction results in extremely low values due to the increased heating demand. During summer, none of the construction types exceeds the upper limit of 70% relative humidity.

The highest air quality level described in Section 0 has an upper limit of a CO_2 concentration of 800ppm. As seen in Figure 30, the CO_2 concentration for none of the construction types exceeds this limit. Clearly visible from this figure are the lower CO_2 concentrations during the nighttime ventilation period from May 15th (3’300h) until August 31st (5’840h). These occur due to the increased air exchange of interior and exterior air during this period. The wide span of CO_2 concentration from 270ppm to 620ppm results from the presence time of the inhabitants. During the day, when the residents are out, the concentration drops and during the night, when the residents are present, the concentration rises.

3.13.3. Heating Demand

The flat top of the heating power shown in Figure 32 for the hybrid and the lightweight construction occur due to the limited power output of the heating system applied in the simulation. This leads to the result, that the heating power for these two construction types is insufficient to maintain the minimum temperature of 20°C defined in the simulation. However, during wintertime the temperature for both construction types never falls below the 19°C, which was proposed as a minimum temperature in winter by SIA.

It must be noted that the heating demand is heavily dependent on the minimum temperature of the simulations. Increasing this minimum temperature in order to fulfil the temperature requirements for category II or III of the DIN EN 15251 norm would lead to a considerably higher heating demand.

The calculated heating energies per square meter in Table 8 of $6.39\frac{kWh}{m^2*a}$ for the heavyweight construction, $7.60\frac{kWh}{m^2*a}$ for the hybrid construction and $9.35\frac{kWh}{m^2*a}$, appear rather low due to the low minimum temperature of 20°C in winter. According to SIA 2024 (2015) the target heating demand for residential units is $11.2\frac{kWh}{m^2*a}$. With a large amount of glazed area, this heating demand can be reduced due to the solar gain in winter. As this report shows, this is possible without overheating of the unit in summer when applying the correct measures.

4. Conclusion

In this report, the influence and sensitivity of several measures and parameters on the thermal comfort in a residential building unit was analyzed. The greatest influence was achieved with the parameter of solar exposure of the solar protection (shading device) in summertime and the air change rate of the nighttime ventilation. The three different construction types also lead to large differences, especially the elaborated temperatures of the lightweight construction varied largely from the other two types. The temperature fluctuations as well as the maximum and minimum temperatures diverged widely from the other two construction types.

4.1. Recommendations

In this section, the recommendations based on the established results of this report are stated. These recommendations shall provide a basis of decision-making in the further designing steps for the association BIZUN. The various measures and their parameters are addressed below.

4.1.1. Construction Types

The results presented in section 3.12 confirm the feasibility of each of the three construction types. The achieved temperatures mostly lay within the boundaries of the norms for acceptable indoor room climate. With the appropriate exclusion of nighttime ventilation on cooler summer nights, the low temperatures for the lightweight construction in summertime can be eliminated. Even though the lightweight construction type leads to the least favorable temperature developments, the choice of this construction type will mostly fulfil the requirements of an acceptable indoor room climate. In order to completely fulfil the requirements of the DIN EN 15251 norm, a combination of lightweight and the other construction types is conceivable. This would lead to the elimination of the high temperature fluctuations and a reduction of divergence for the minimum and maximum temperatures of the lightweight construction.

4.1.2. Solar Protection

The results presented in section 3.3 demonstrate the importance of solar protection, as well as of the parameter solar exposure. A good solar exposure value, which means a shading device with low transmittance of irradiance, makes a low maximum controlling temperature possible. Because all three construction types show small overshoots of the maximum controlling temperature, a solar exposure value of 0.1 is highly recommended. This value enables a maximum controlling temperature of 25°C reasonably.

4.1.3. Nighttime Ventilation

The results of the conducted simulations show, that with a 3x air change rate an acceptable thermal comfort can be provided. Smaller air change rates would lead to higher temperature overshoots and larger ones to less change in impact.

The modification of the daily duration resulted in minimal temperature differences and therefore is not a critical parameter. A drastic adjustment of this parameter of several hours, however, could still lead to significantly larger temperature overshoots. The recommended duration lasts from 8PM to 8AM.

The seasonal period of the nighttime ventilation is heavily dependent on the exterior air temperature developments of each specific year. The proposed period lasts from May 15th until August 31st for the TMY applied in this report. The measure of nighttime ventilation must be controlled by the residents of the unit and therefore, these dates could only serve as a guideline.

4.1.4. Window West Façade

The sensitivity analysis on the additional window shows, that this measure is not critical for the overall operational temperature of the unit. A window can be added on the west façade, depending on the size, without severe influenced on the overall maximum interior temperatures of the unit in summer. Despite the results of this report, the influence of this measure on the single room facing west must be analyzed. Furthermore, an additional window would lead to a reduction of the heating demand of the residential unit.

4.1.5. Glazed Area

The simulations referring to the glazed area lead to similar results as the additional window. The differences in the resulting temperatures however were slightly higher. Therefore, the glazed area should not greatly exceed the values chosen for the simulations in this report.

4.1.6. Air Quality

In this report, the two indicators relative humidity and CO_2 concentration of air quality were assessed. The requirements of the relative humidity could not be met for any of the construction types. During the heating period, all construction types show too low levels of relative humidity. Due to the higher heating demand, the lightweight construction resulted in the lowest humidity levels. In order to meet these requirements, additional measures are necessary such as the implementation of air humidifiers in the mechanical ventilation system.

The requirements of the CO_2 concentration could be fulfilled by all the construction types. With the implementation of a mechanical ventilation system, this is not a critical indicator of air quality for this residential unit.

4.1.7. Heating Demand

The assessment in this report concludes that the chosen heating power of $10\frac{W}{m^2}$ is not sufficient to maintain the minimum temperatures of the DIN EN 15251. However, the underrun of the minimum temperatures is minimal and only occurs for a short period. If the minimum temperature in winter is a critical value for the association BIZUN, a higher heating power should be chosen for all of the construction types.

The low resulting heating energy of the simulations evolve due to the low minimum temperature of 20°C. Increasing this temperature in order to fulfill the requirements of certain categories of the DIN EN 15251 (2012) norm would result in a significant increase of heating demand.

4.2. Outlook

It must be noted that none of the investigated measures to fulfil the thermal comfort requirements will lead to a satisfying result on its own. The combination of various measures as well as the appropriate dimensioning of the parameters are essential in order to meet the needs of thermal comfort. This implies that also the other parameters and the additional windows as well as the glazed area must be considered in the further designing steps from Unit Architekten. In case a lightweight construction type is chosen, the parameters analyzed in this report should only be changed with great caution from the values applied in the last set of simulations. If a heavyweight or hybrid construction are chosen, these parameters are less critical.

Due to the limitations of the simulation software WUFI ®PLUS, the impact of an additional window on the west façade could only be assessed based on the overall operative temperature of the unit. For more precise temperature developments of this measure, further simulations with a 3D software are necessary. The same applies for the modification of the glazed area as the solar gain from the windows can not be distributed uniformly over the whole unit.

Because the overheating of the residential unit is of major interest for the association BIZUN, further simulations with predicted weather data for the end of the 21^{st} century are suggested. This would confirm the fulfillment of the requirements of thermal comfort over the whole lifespan of the building complex.

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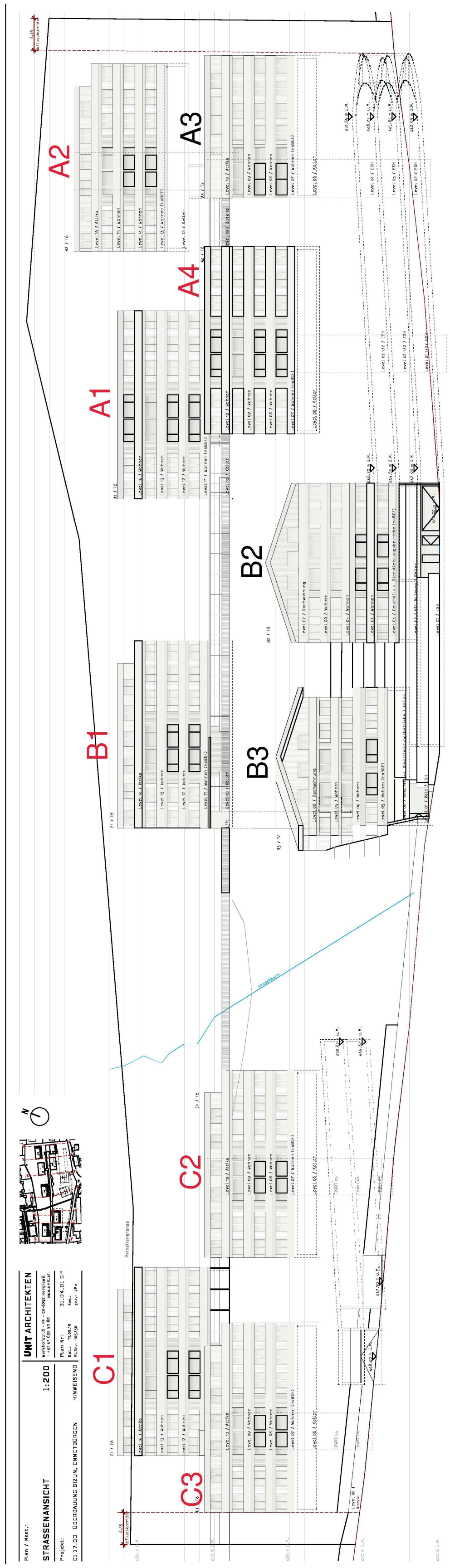
Annex A: Layout Plan of Building Park



Annex B: Report Meteonorm Ennetbürgen

Ennetbürgen
Location name

46.985
Latitude [°N]

8.415
Longitude [°E]

436
Altitude [m a.s.l.]

III, 3
Climate region

Standard
Radiation model

Standard
Temperature model

Perez
Tilt radiation model

2000–2009
Temperature period

1991–2010
Radiation period

Additional information

Uncertainty of yearly values: Gh = 3%, Bn = 7%, Ta = 0.8 °C
Trend of Gh / decade: 2.2%
Variability of Gh / year: 4.4%
Radiation interpolation locations: Luzern (1996-2015, 10 km), Altdorf (21 km), Waedenswil (33 km), Glarus (50 km), Zuerich-SMA (45 km), Reckenholz (50 km) (Share of satellite data: 3%)
Temperature interpolation locations: Altdorf (21 km), Waedenswil (33 km), Glarus (50 km), Wynau (56 km), Buchs-Suhr (51 km), Zuerich-Kloten (56 km)
P90 and P10 of yearly Gh, referenced to average: 95.5%, 106%

Month	H_Gh	H_Dh	N	Ta	RH	FF
	[W/m2]	[W/m2]	[Octas]	[°C]	[%]	[m/s]
January	41	27	5.8	2.0	70	3.2
February	75	46	5.3	3.0	67	3.4
March	125	63	4.9	5.6	68	3.4
April	174	92	4.4	9.6	64	4.0
May	200	120	5.0	14.0	67	3.7
June	222	129	4.6	17.3	70	3.2
July	218	113	4.5	18.4	71	3.2
August	185	107	4.7	18.3	73	2.9
September	139	69	4.6	15.0	74	3.0
October	85	50	5.5	11.3	74	2.9
November	50	32	5.8	6.3	72	3.2
December	34	25	6.4	2.9	72	3.1
Year	129	73	5.2	10.3	70	3.3

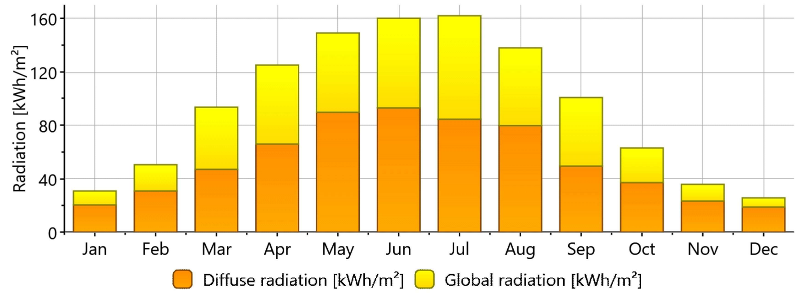
Meteonorm

Meteonorm V7.3.2.20780 1/4

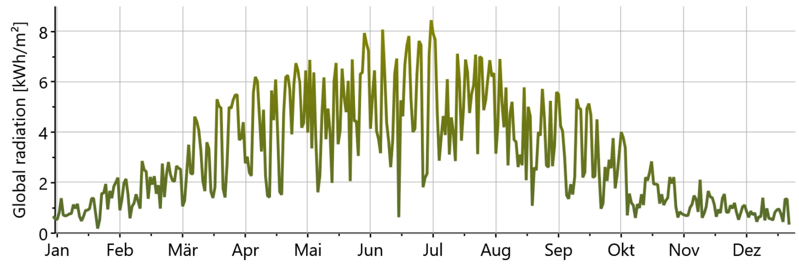
Month	DD	RR	G_Lin
	[grad]	[mm]	[W/m2]
January	259	53	268
February	281	46	269
March	277	60	282
April	286	77	298
May	302	131	325
June	300	152	344
July	299	154	352
August	270	160	353
September	276	113	335
October	277	84	319
November	274	73	292
December	269	68	274
Year	281	1171	309

Ta: Air temperature
H_Gh: Mean irradiance of global radiation horizontal
H_Dh: Mean irradiance of diffuse radiation horizontal
N: Cloud cover fraction
RH: Relative humidity
FF: Wind speed
DD: Wind direction
RR: Precipitation

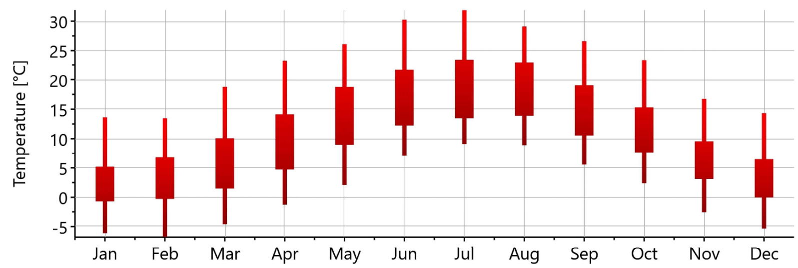
Monthly radiation



Daily global radiation



Monthly temperature



Meteonorm

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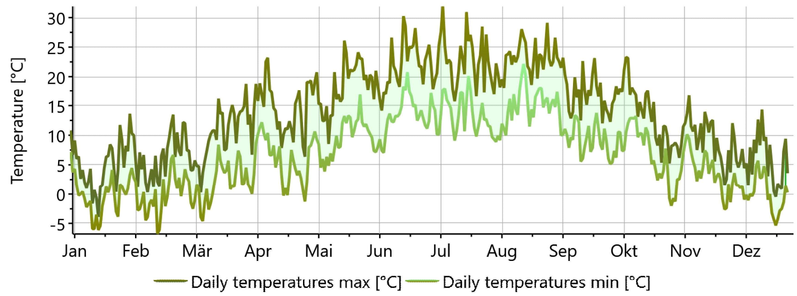
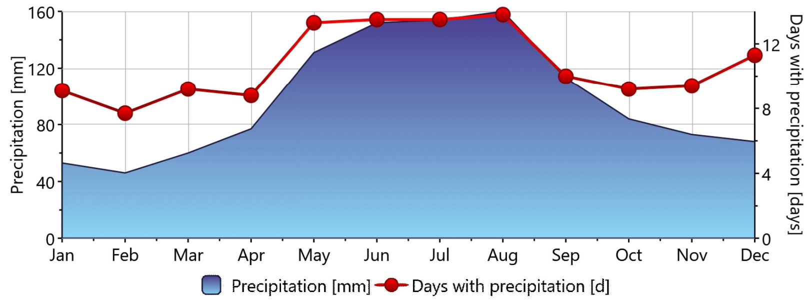
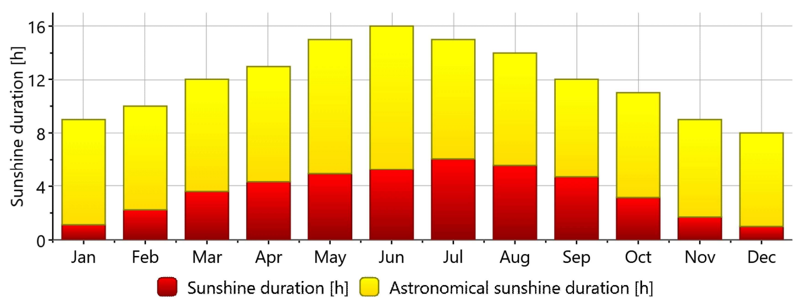
Daily temperature



Precipitation



Sunshine duration

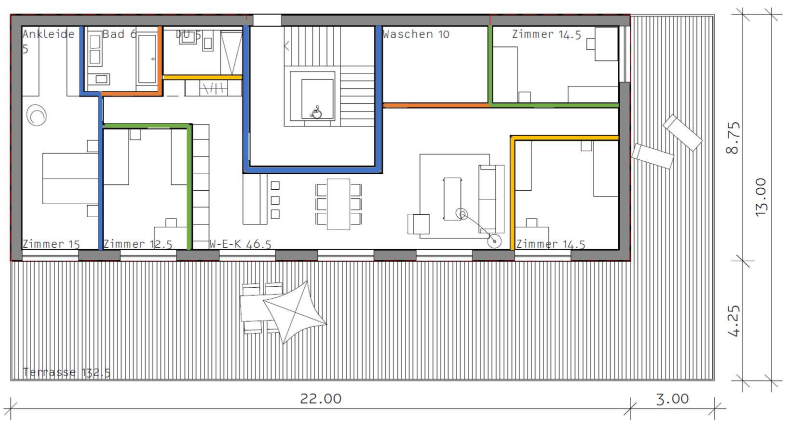


Annex C: Assumptions of Window Measurements

The figure below shows the assumptions for the window measurements added in blue (values in m). A window height of 2m was assumed for the windows of the south and east façade with an offset of 0.1m. For the window in the staircase in the north façade a window height of 1.6m with an offset of 1m was estimated.

Annex D: Calculation of Interior Walls Area

In order to integrate the data of the interior walls to WUFI ®PLUS, the total interior wall area is needed. To find this value, the interior walls were allocated to the rooms in the floor plan. The figure below shows the allocation with a color code.



In the table below, the allocated walls are listed and assigned an approximated length as well as summed up.

Room	Length [m]
Room 1	8.75m+0.50m
Room 2	5.00m+3.50m
Bathroom	2.00m+2.00m
Shower	4.00m
Staircase	6.50m+6.50m+5.00m
Laundry Room	4.00m
Room 3	3.50m+3.50m
Room 4	4.00m+5.00m
Total	63.75m

If the total interior wall length is multiplied with the floor height it results:

$$Interior\ Wall\ Area = Wall\ Lenght * Floor\ Height = \ 63.75m * 2.4m = 153m$$

This value can then be added in the simulation software and does not change for any of the cases.

Annex E: Window Parameters

Window type (Id 1): Window

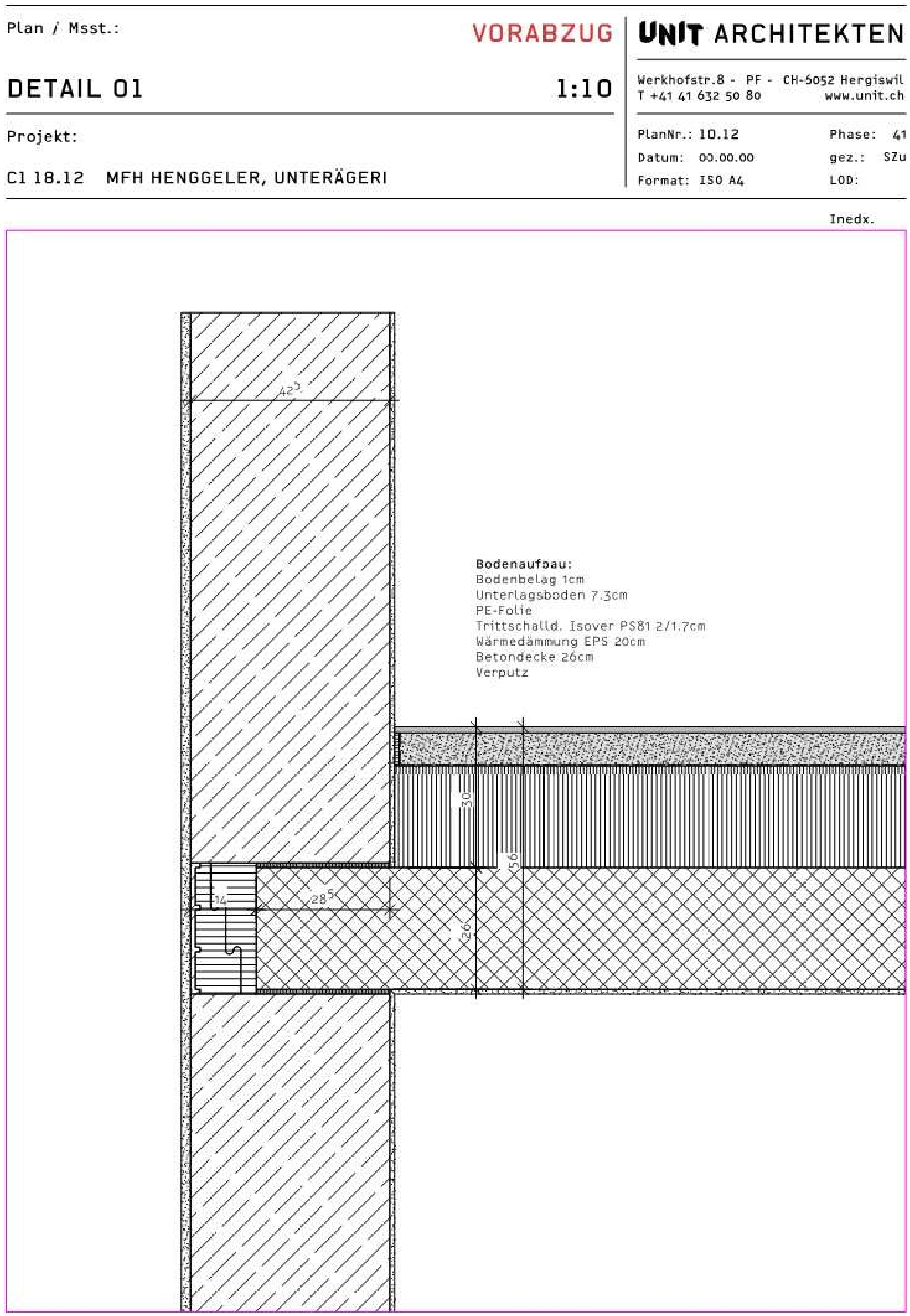
Basic data

Uw -mounted	[W/m²K]	0.6
Frame factor		0.8
Solar energy transmittance hemispherical		0.55
Long wave radiation emissivity (mean glazing/frame)		0.8

Solar radiation angle dependent data

Angle [°]	Total solar trans.
0	0.55

Annex F: Design Example Heavyweight Construction



Plan / Msst.: VORABZUG **UNIT** ARCHITEKTEN

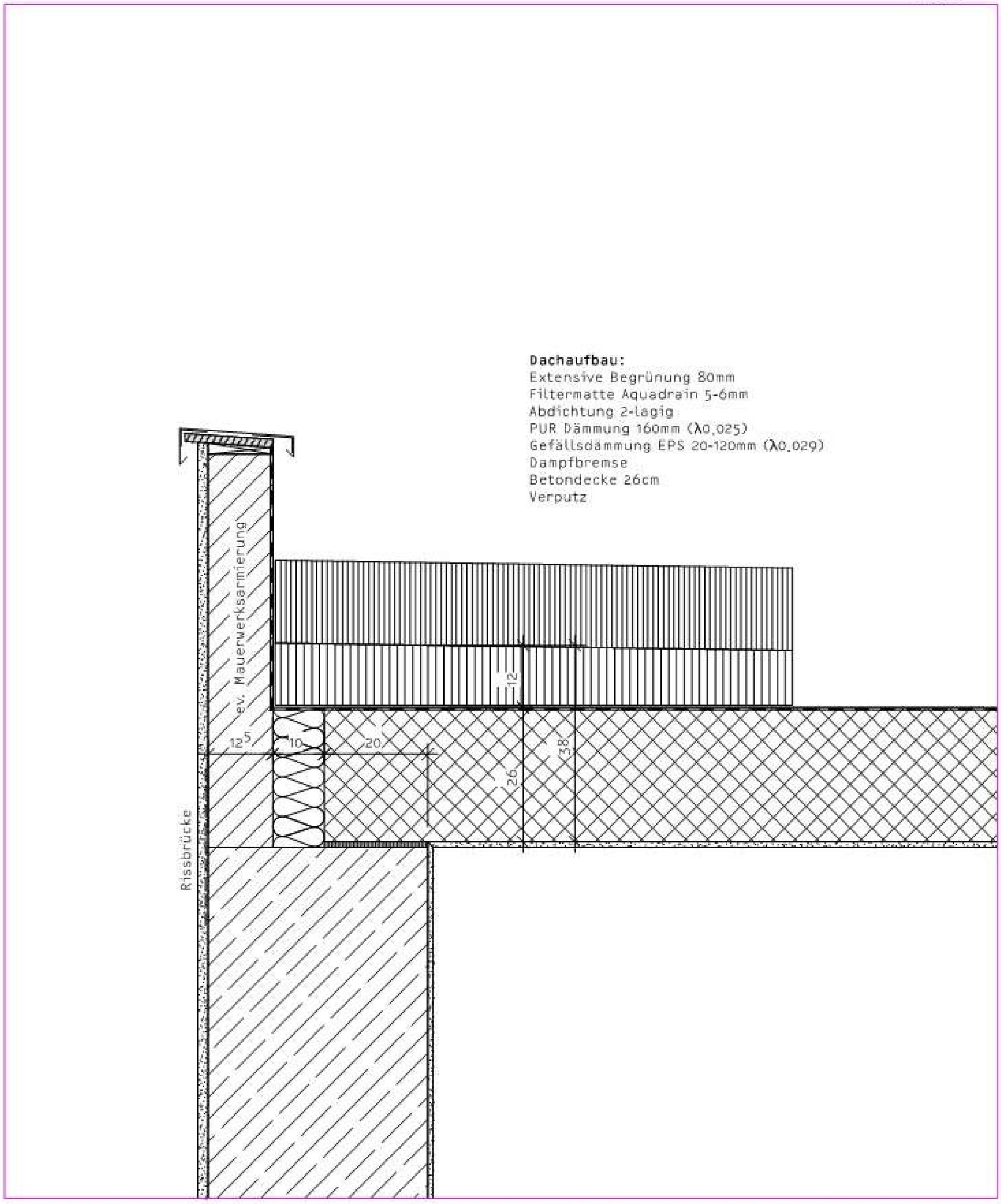
DETAIL 01 1:10

Werkhofstr.8 - PF - CH-6052 Hergiswil
T +41 41 632 50 80 www.unit.ch

Projekt:

C1 18.12 MFH HENGGELER, UNTERÄGERI

PlanNr.: 10.13	Phase: 41
Datum: 00.00.00	gez.: SZu
Format: ISO A4	LOD:
	Inedx.



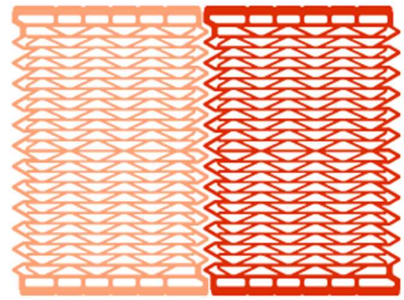
Annex G: Design Example Heavyweight Construction, Monobrick

MONOBRICK

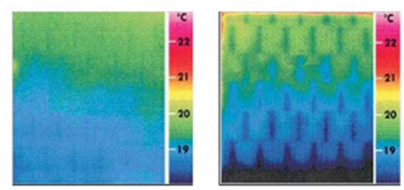
Die Effizienz des MONOBRICK - Mauersteins zeigt sich in einer sehr hohen Wärmedämmung bei gleichzeitiger Wärmespeicherung. Beide Eigenschaften zusammen ergeben ein Backstein-Mauerwerk mit optimal kombiniertem Wärmeschutz - wirksam im Sommer wie im Winter!

Grundlage ist eine feinporöse Keramik aus abgestimmten natürlichen Rohmaterialien. Der neue MONOBRICK - Mauerstein weist zudem ein besonderes, patentiertes Lochbild aus, welches die Wärmeleitfähigkeit und Wärmespeicherfähigkeit positiv beeinflusst. Die reissverschlussartige Stossfugenverzahnung verleiht dem MONOBRICK - Mauerwerk einen wärmebrückenfreien Wärmedurchgang bei optimaler Wärmespeicherung - ohne Unterbruch!

Materialkonzept, Steinlochbild, Stossfugenverzahnung und ein bewährtes Dünnbettmörtelsystem garantieren dauerhafte Wärmedämmung und Wärmespeicherfähigkeit. Das rein mineralische Konzept des MONOBRICK - Mauerwerks bietet Behaglichkeit, höchsten Brandschutz – und ein problemloses Recycling!



Auswirkung der Stossfuge auf den Wärmedurchgang in einer Backsteinwand



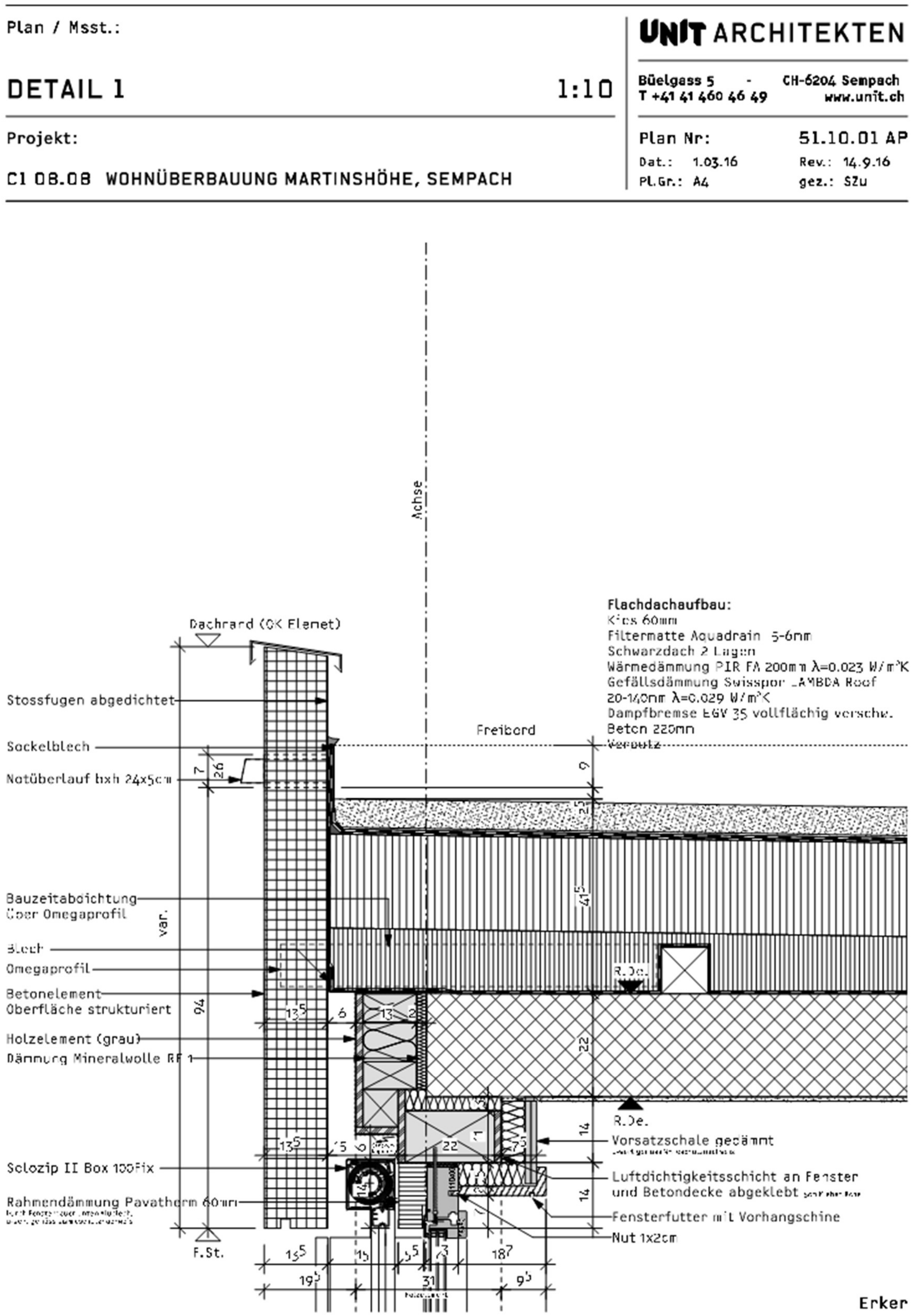
MONOBRICK - Mauerwerk mit wärmebrückenfreiem Wärmedurchgang dank der patentierten Stossfugenverzahnung; vertikale Stossfugen sind im Wärmebild kaum noch erkennbar.

Herkömmliches Mauerwerk aus wärmedämmenden Mauersteinen mit unverzahnten Stossfugen; der Wärmeverlust an der vertikalen Stossfuge ist im Wärmebild am dunklen Farbkontrast deutlich erkennbar.

WANDDICKEN				Minergiestandard
Länge x Breite x Höhe Bedarf Monobricksteine	mm Stk./m²	250 x 365 x 249 16	250 x 425 x 249 16	250 x 490 x 249 16
Steinrohdichte-Klasse	kg/m³	590	590	590
WÄRMESCHUTZ				
Lambda SIA 279 / EN 1745	W/mK	Lambda $_{10\,tr,\,Stein}$ = 0.072 / Lambda $_{design,\,Stein}$ = 0.074		
Wärmeleitfähigkeit Mauerwerk mit DBM	W/mK	Lambda $_{design,\,Mauerwerk}$ (Rechenwert) = 0.075		
U-Wert Mauerwerk	W/m²K	0.20	0.17	0.15
Wärmespeicherkapazität	Wh/Kg K	0.28	0.28	0.28
Diffusionswiederstandszahl	μ	3	3	3
BRANDSCHUTZ, STATIK				
Feuerwiderstand beids. verputzt	Klasse	F 180	F 240	F 240
Charakt. Mauerwerks - druckfestigkeit f_{xk}	N/mm²	1.8	1.8	1.8

https://www.ziegelei-schumacher.ch/admin/userfolder/it/subsubcat/1459929337Broschuere_Monobrick_19_11_2015.pdf

Annex H: Design Example Hybrid Construction



Plan / Msst.:

DETAIL 2 MIT LEIBUNG 1:10

Projekt:

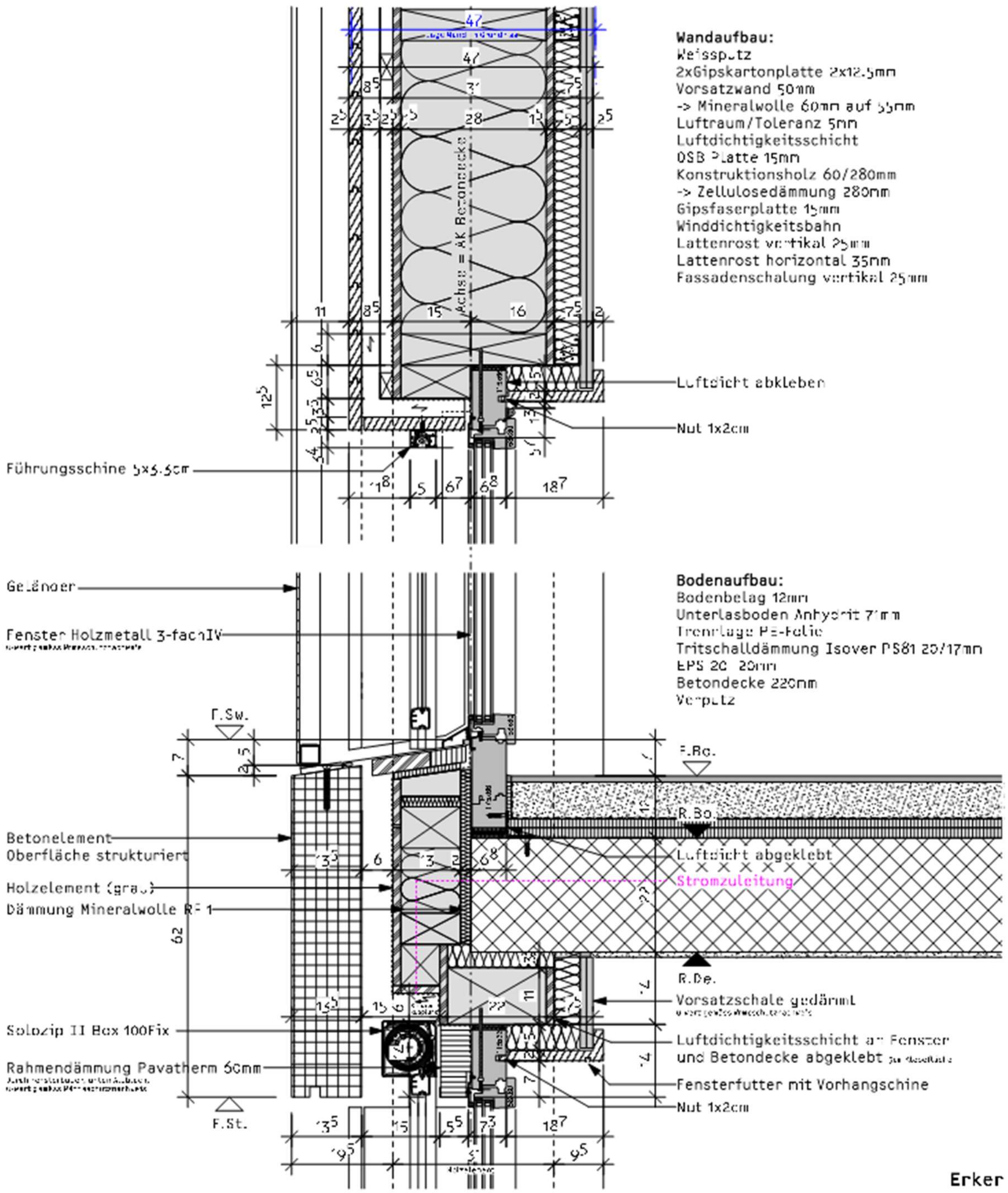
C1 08.08 WOHNÜBERBAUUNG MARTINSHÖHE, SEMPACH

UNIT ARCHITEKTEN

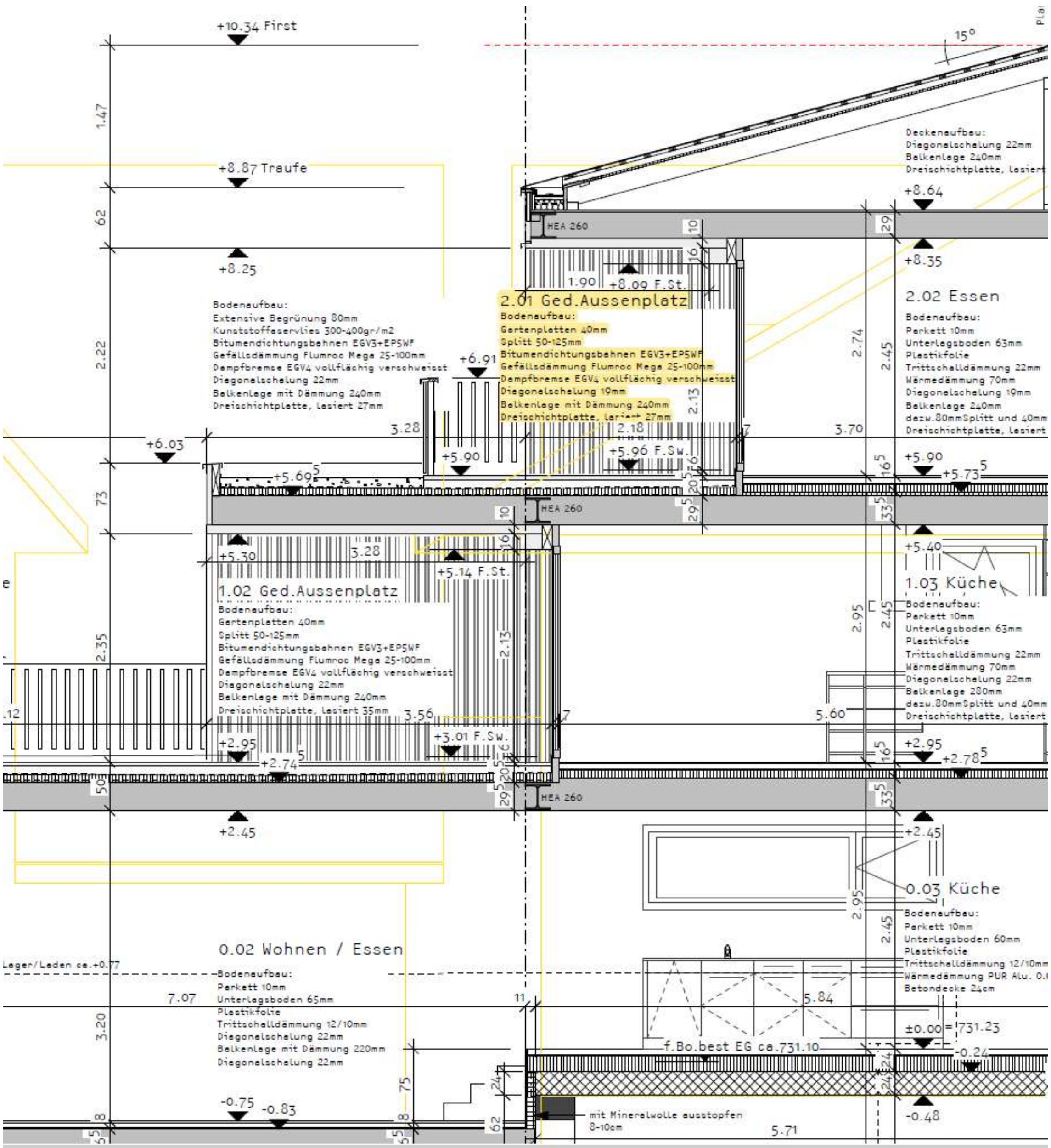
Büelgass 5 - CH-6204 Sempach
T +41 41 460 46 49 www.unit.ch

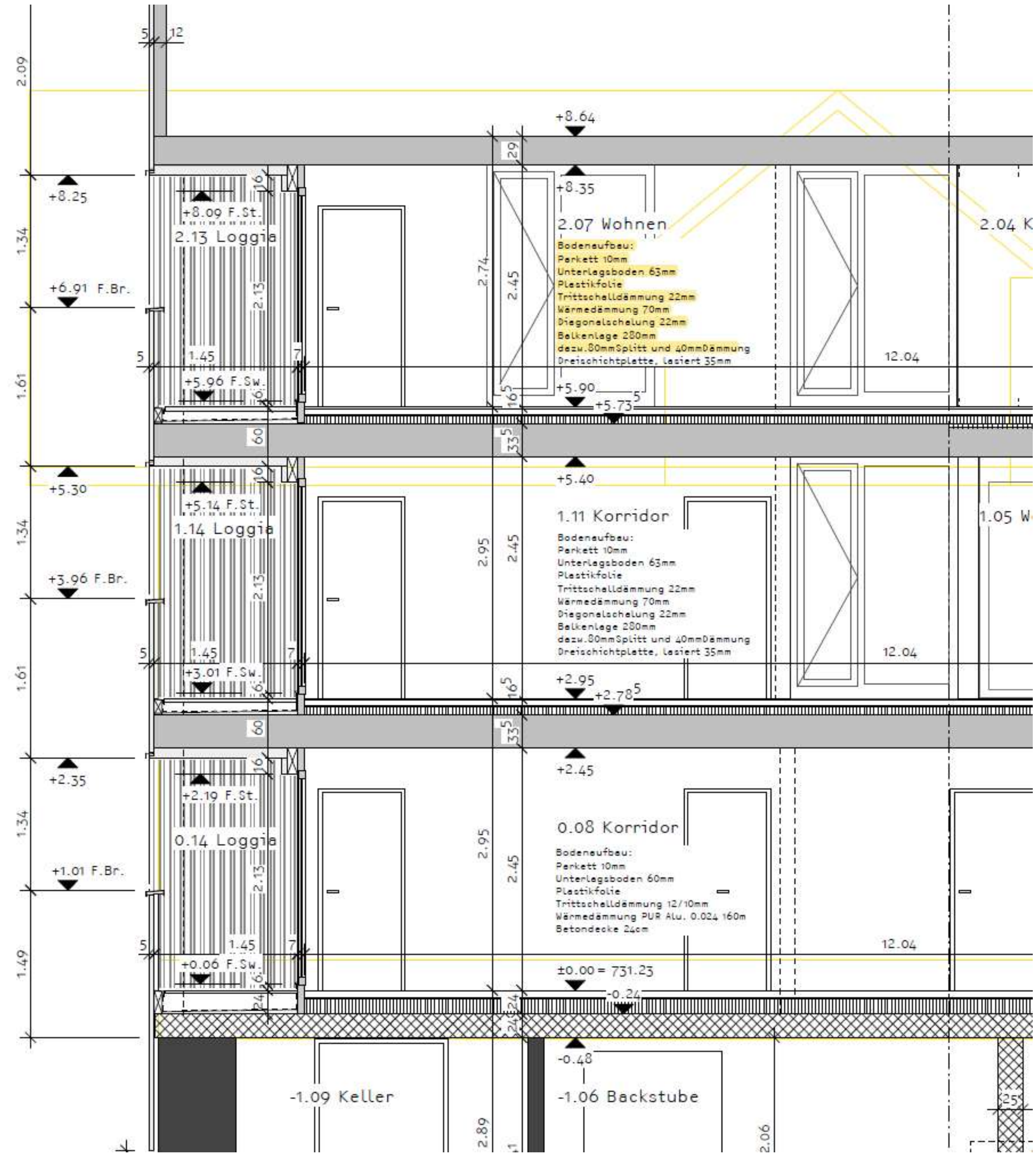
Plan Nr: 51.10.02 AP

Dat.: 1.3.16 Rev.: 14.9.16
Pl.Gr.: A4 gez.: SZu



Annex I: Design Example Lightweight Construction




+8.64
+8.35
2.07 Wohnen
Bodenaufbau:
Parkett 10mm
Unterlagsboden 63mm
Plastikfolie
Trittschalldämmung 22mm
Wärmedämmung 70mm
Diagonalschalung 22mm
Balkenlage 280mm
dazu.80mmSplitt und 40mmDämmung
Dreischichtplatte, lasiert 35mm
2.04 K
+8.25
+8.09 F.St.
2.13 Loggia
+6.91 F.Br.
+5.96 F.Sw.
+5.90
+5.73
+5.30
+5.40
+5.14 F.St.
1.14 Loggia
1.11 Korridor
Bodenaufbau:
Parkett 10mm
Unterlagsboden 63mm
Plastikfolie
Trittschalldämmung 22mm
Wärmedämmung 70mm
Diagonalschalung 22mm
Balkenlage 280mm
dazu.80mmSplitt und 40mmDämmung
Dreischichtplatte, lasiert 35mm
1.05 W
+3.96 F.Br.
+3.01 F.Sw.
+2.95
+2.78
+2.35
+2.45
+2.19 F.St.
0.14 Loggia
0.08 Korridor
Bodenaufbau:
Parkett 10mm
Unterlagsboden 60mm
Plastikfolie
Trittschalldämmung 12/10mm
Wärmedämmung PUR Alu. 0.024 160m
Betondecke 24cm
+1.01 F.Br.
+0.06 F.Sw.
±0.00 = 731.23
-0.24
-0.48
-1.09 Keller
-1.06 Backstube
12.04

Plan / Msst.:

DETAIL 2 MIT LEIBUNG 1:10

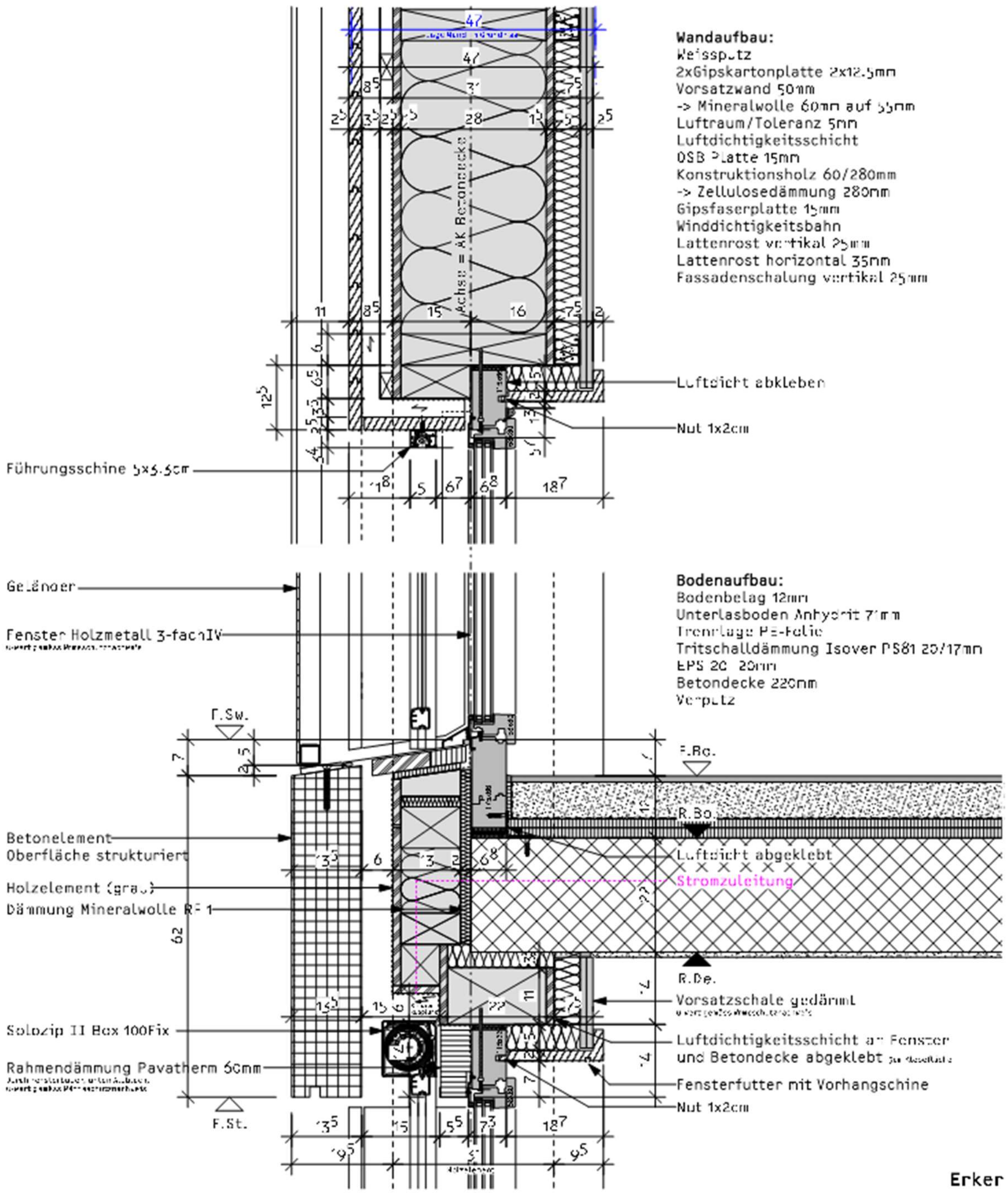
Projekt:

C1 08.08 WOHNÜBERBAUUNG MARTINSHÖHE, SEMPACH

UNIT ARCHITEKTEN

Büelgass 5 - CH-6204 Sempach
T +41 41 460 46 49 www.unit.ch

Plan Nr: 51.10.02 AP
Dat.: 1.3.16 Rev.: 14.9.16
Pl.Gr.: A4 gez.: SZu



Annex J: WUFI ®PLUS Report Base Case, Heavyweight Construction

WUFI®Plus

Assemblies/window types/solar protection

Assembly (Id.1): Floor

Homogenous layers

Thermal resistance: 3.044 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.307 W/m²K

Thickness: 0.483 m

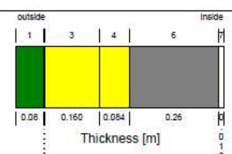
Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	
2	Concrete, C12/15	2200	850	1.6	0.29	
3	EPS (heat cond.: 0.04 W/mK - density: 15 kg/m³)	15	1500	0.04	0.055	
4	ISOVER ISOCONFORT 032 (Switzerland)	33	850	0.031	0.04	
5	CaSO4 Screed, top layer	1960	850	1.6	0.073	
6	Hardwood	650	1400	0.13	0.01	

Assembly (Id.2): Ceiling

Homogenous layers

Thermal resistance: 10.077 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.098 W/m²K



Thickness: 0.605 m

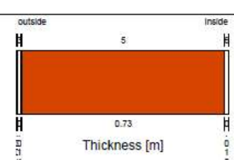
Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Optigreen Nature Roof 1 (grasses) 1-5	1500	1000	0.2	0.08	
2	Optigreen Nature Roof 1 (filter mat) 3-5	83	840	0.035	50E-4	
3	PU (heat cond.: 0,025 W/mK)	40	1500	0.025	0.16	
4	dena EPS (heat cond.: 0.03 W/mK - density: 30kg/m³)	30	1500	0.029	0.084	
5	vapor retarder (1perm)	130	2300	2.3	10E-4	
6	Concrete, C12/15	2200	850	1.6	0.26	
7	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	

Assembly (Id.3): Exterior Walls

Homogenous layers

Thermal resistance: 10.006 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.098 W/m²K



Thickness: 0.765 m

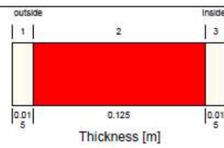
Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Exterior Plaster A - layer 1 of 4 (exterior)	1310	850	0.87	40E-4	
2	Exterior Plaster A - layer 2 of 4	1310	850	0.87	10E-4	
3	Exterior Plaster A - layer 3 of 4	1219	850	0.25	0.014	
4	Exterior Plaster A - layer 4 of 4 (interior)	1219	850	0.25	10E-4	
5	Monobrick	590	1008	0.074	0.73	
6	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	

Assembly (Id.6): Interior Walls

Homogenous layers

Thermal resistance: 0.358 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 1.617 W/m²K



Thickness: 0.155 m

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	
2	Solid Brick Masonry	1900	850	0.6	0.125	
3	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	

Window type (Id 1): Window

Basic data

Uw -mounted [W/m²K]	0.6
Frame factor	0.8
Solar energy transmittance hemispherical	0.55
Long wave radiation emissivity (mean glazing/frame)	0.8

Solar radiation angle dependent data

Angle [°]	Total solar trans.
0	0.55

Annex K: WUFI ®PLUS Report Base Case, Hybrid Construction

WUFI®Plus

Assemblies/window types/solar protection

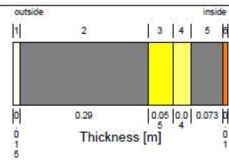
Assembly (Id.1): Floor

Homogenous layers

Thermal resistance: 3.044 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.307 W/m²K

Thickness: 0.483 m



Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	
2	Concrete, C12/15	2200	850	1.6	0.29	
3	EPS (heat cond.: 0.04 W/mK - density: 15 kg/m³)	15	1500	0.04	0.055	
4	ISOVER ISOCONFORT 032 (Switzerland)	33	850	0.031	0.04	
5	CaSO4 Screed, top layer	1960	850	1.6	0.073	
6	Hardwood	650	1400	0.13	0.01	

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Optigreen Nature Roof 1 (grasses) 1-5	1500	1000	0.2	0.08	
2	Optigreen Nature Roof 1 (filter mat) 3-5	83	840	0.035	50E-4	
3	PU (heat cond.: 0,025 W/mK)	40	1500	0.025	0.16	
4	dena EPS (heat cond.: 0.03 W/mK - density: 30kg/m³)	30	1500	0.029	0.084	
5	vapor retarder (1perm)	130	2300	2.3	10E-4	
6	Concrete, C12/15	2200	850	1.6	0.26	
7	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	

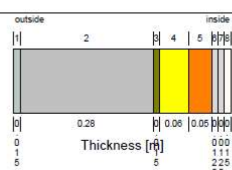
Assembly (Id.3): Exterior Walls

Homogenous layers

Thermal resistance: 10.096 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.097 W/m²K

Thickness: 0.46 m



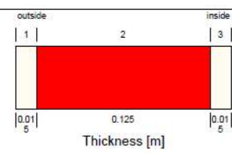
Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	FERMACELL Gypsum-Fibreboard	1153	1200	0.32	0.015	
2	Cellulose Fibre Insulation	30	1880	0.036	0.28	
3	OSB plate	593	1500	0.0964	0.015	
4	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	0.06	
5	Plywood	560	1500	0.13	0.05	
6	Interior Gypsum Board	625	870	0.16	0.013	
7	Interior Gypsum Board	625	870	0.16	0.013	
8	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	

Assembly (Id.6): Interior Walls

Homogenous layers

Thermal resistance: 0.358 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 1.617 W/m²K



Thickness: 0.155 m

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	
2	Solid Brick Masonry	1900	850	0.6	0.125	
3	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	

Window type (Id 1): Window

Basic data

Uw -mounted [W/m²K]	0.6
Frame factor	0.8
Solar energy transmittance hemispherical	0.55
Long wave radiation emissivity (mean glazing/frame)	0.8

Solar radiation angle dependent data

Angle [°]	Total solar trans.
0	0.55

Annex L: WUFI ®PLUS Report Base Case, Lightweight Construction

WUFI®Plus

Assemblies/window types/solar protection

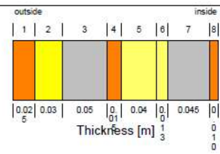
Assembly (Id.1): Floor

Homogenous layers

Thermal resistance: 3.062 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.306 W/m²K

Thickness: 0.228 m



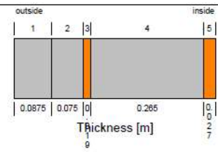
Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Plywood Board	500	1400	0.1	0.025	
2	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	0.03	
3	generic gravel	1400	1000	0.7	0.05	
4	Softwood	400	1400	0.09	0.015	
5	ISOVER ISOCONFORT 032 (Switzerland)	33	850	0.031	0.04	
6	ISOVER ISOCONFORT 032 (Switzerland)	33	850	0.031	0.013	
7	Anhydritestrich	2100	850	1.2	0.045	
8	Hardwood	650	1400	0.13	0.01	

Assembly (Id.2): Ceiling

Homogenous layers

Thermal resistance: 10.048 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.098 W/m²K



Thickness: 0.474 m

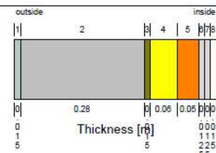
Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	generic gravel	1400	1000	0.7	0.088	
2	Flumroc-Dämmplatte 1	42	830	0.035	0.075	
3	Spruce, radial	455	1400	0.09	0.019	
4	Cellulose Fibre Insulation	30	1880	0.036	0.265	
5	Plywood	560	1500	0.13	0.027	

Assembly (Id.3): Exterior Walls

Homogenous layers

Thermal resistance: 10.096 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0.097 W/m²K



Thickness: 0.46 m

WUFI®Plus

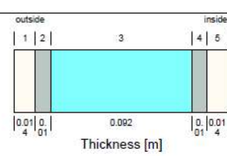
Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	FERMACELL Gypsum-Fibreboard	1153	1200	0.32	0.015	
2	Cellulose Fibre Insulation	30	1880	0.036	0.28	
3	OSB plate	593	1500	0.0964	0.015	
4	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	0.06	
5	Plywood	560	1500	0.13	0.05	
6	Interior Gypsum Board	625	870	0.16	0.013	
7	Interior Gypsum Board	625	870	0.16	0.013	
8	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.015	

Assembly (Id.6): Interior Walls

Homogenous layers

Thermal resistance: 0.358 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 1.617 W/m²K



Thickness: 0.14 m

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.014	
2	FERMACELL Gypsum-Fibreboard	1153	1200	0.32	0.01	
3	Air Layer 100 mm	1.3	1000	0.59	0.092	
4	FERMACELL Gypsum-Fibreboard	1153	1200	0.32	0.01	
5	Interior Plaster (Gypsum Plaster)	850	850	0.2	0.014	

Window type (Id 1): Window

Basic data

Uw -mounted [W/m²K]	0.6
Frame factor	0.8
Solar energy transmittance hemispherical	0.55
Long wave radiation emissivity (mean glazing/frame)	0.8

Solar radiation angle dependent data

Angle [°]	Total solar trans.
0	0.55

Annex M: WUFI ®PLUS Report Combined Cases, Heavyweight Construction

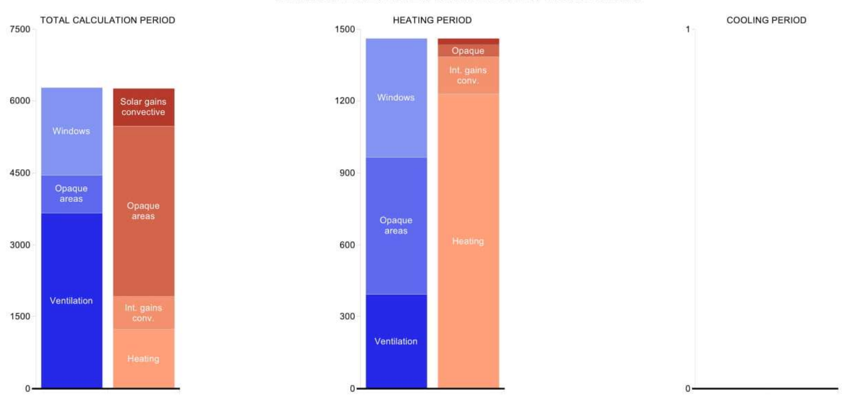
WUFI®Plus

Results

Zone 1: Main results

Setting			Value
Heating period [d]			65.7
Cooling period [d]			0
Heating demand [kWh]			1229.3
Cooling demand [kWh]			0
Humidification demand [kg]			0
Dehumidification demand [kg]			0
Min/Max/Mean values			
Setting	Min	Max	Mean
Inner temperature [°C]	19.6	25.3	22.8
Inner relative humidity [%]	29.4	76.3	44.6
Heating load [kW]	0	1.9	0.1
Cooling load [kW]	0	0	0
Humidification [kg/h]	0	0	0
Dehumidification [kg/h]	0	0	0

ENERGY BALANCE / CONVECTIVE FLOWS kWh/a



Energy balance [kWh/a]

Setting	Total period	Heating period	Cooling period
Ventilation	6.8	0	0
Solar gains total	7816.1	241.8	0
Solar gains convective	781.6	24.2	0
Windows	6.4	0	0
Opaque areas	3540.3	51.7	0
Int. gains rad.	525.6	115.6	0
Int. gains conv.	700.8	154.1	0
Heating	1229.3	1229.3	0
Windows	1820.6	494.5	0
Opaque areas	782.9	569.8	0
Ventilation	3675.9	395.1	0

Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	37	26	7	30
Thermal environment	I	II	III	IV

Percentage	47	53
Indoor air quality	I	II

Zone 1: Heat gain/loss - Total calculation period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: Floor	1575	56
2	Component 2: Ceiling	683	1224
3	Component 3: Exterior Walls	236	901
4	Component 4: Window Front	6461	1472
5	Component 5: Window Side	1049	245
6	Component 6: Window Back	312	103

Zone 1: Heat gain/loss - heating period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: Floor	129	19
2	Component 2: Ceiling	1	381
3	Component 3: Exterior Walls	1	362
4	Component 4: Window Front	197	400
5	Component 5: Window Side	33	67
6	Component 6: Window Back	12	28

Zone 1/Component 1: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
Interior Plaster (Gypsum Plaster)	1.5	19.9 (0)	25.2 (0)	22.9
Concrete, C12/15	29	19.9 (0.167)	25.1 (0.167)	22.9
EPS (heat cond.: 0.04 W/mK - density: 15 kg/m³)	5.5	19.9 (5.333)	25.2 (5.333)	22.9
ISOVER ISOCONFORT 032 (Switzerland)	4	19.8 (3.833)	25.3 (3.833)	22.9
CaSO4 Screed, top layer	7.3	19.8 (7.133)	25.4 (7.133)	23
Hardwood	1	19.8 (1)	25.4 (1)	23
Water content [kg/m³]				
Interior Plaster (Gypsum Plaster)	1.5	2.128 (0)	6.269 (1.375)	3.318
Concrete, C12/15	29	23.481 (0.167)	53 (9.604)	46.167
EPS (heat cond.: 0.04 W/mK - density: 15 kg/m³)	5.5	0.46 (5.333)	1.815 (5.333)	0.843
ISOVER ISOCONFORT 032 (Switzerland)	4	0.041 (3.833)	0.152 (0.167)	0.057
CaSO4 Screed, top layer	7.3	3.237 (7.133)	7.324 (0.167)	4.123
Hardwood	1	30.613 (1)	97.988 (0.2)	50.754

Zone 1/Component 1: U-effective [W/m²K] (theoretical value 0.307)

Orientation (area)	Total calc. time	Heating period	Cooling period
horizontal (A0°, 192.5 m²)			

Zone 1/Component 1: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Inner surface (including radiant source)				
horizontal (A0°, 192.5 m²)	8091.7	0	9.2	0.9

Zone 1/Component 1, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
horizontal (A0°, 192.5 m²)	0	0	-2.62	0	1.82	-4.45	-4.44

Zone 1/Component 2: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
Optigreen Nature Roof 1 (grasses) 1-5	8	-5.7 (0)	42 (0)	12.6
Optigreen Nature Roof 1 (filter mat) 3-5	0.5	-3.9 (0.083)	34.6 (0.083)	12.9
PU (heat cond.: 0,025 W/mK)	16	-3.3 (0.216)	34.2 (0.216)	16.4
dena EPS (heat cond.: 0.03 W/mK - density: 30kg/m³)	8.4	13 (0.216)	27 (0.216)	21.1
vapor retarder (1perm)	0.1	19.2 (0.017)	25.1 (0.017)	22.5
Concrete, C12/15	26	19.2 (0.216)	25.2 (25.784)	22.6
Interior Plaster (Gypsum Plaster)	1.5	19.6 (0.188)	25.2 (1.5)	22.7
Water content [kg/m³]				
Optigreen Nature Roof 1 (grasses) 1-5	8	0.724 (0)	51.278 (0)	5.939
Optigreen Nature Roof 1 (filter mat) 3-5	0.5	0.503 (0.417)	0.7 (0.083)	0.595
PU (heat cond.: 0,025 W/mK)	16	0.481 (0.216)	1.973 (8.774)	1.12
dena EPS (heat cond.: 0.03 W/mK - density: 30kg/m³)	8.4	0.652 (8.184)	1.792 (3.04)	1.079
vapor retarder (1perm)	0.1	0.001 (0.017)	0.002 (0.083)	0.001
Concrete, C12/15	26	23.888 (25.784)	53 (1.22)	46.621
Interior Plaster (Gypsum Plaster)	1.5	2.15 (1.5)	6.264 (0.188)	3.354

Zone 1/Component 2: U-effective [W/m²K] (theoretical value 0.098)

Orientation (area)	Total calc. time	Heating period	Cooling period
horizontal (A0°, 192.5 m²)	0.026	0.067	

Zone 1/Component 2: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
horizontal (A0°, 192.5 m²)	1131693	0	948	129.2
Absorbed				
horizontal (A0°, 192.5 m²)	452677.2	0	379.2	51.7
Inner surface (including radiant source)				
horizontal (A0°, 192.5 m²)	8091.7	0	9.2	0.9

Zone 1/Component 2: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
horizontal (A0°, 192.5 m²)	1	1	1

Zone 1/Component 2, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
horizontal (A0°, 192.5 m²)	0	1.05	-1.95	0	2.57	-3.42	-3.46

Zone 1/Component 3: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
Exterior Plaster A - layer 1 of 4 (exterior)	0.4	-6.1 (0)	31.2 (0)	10.3
Exterior Plaster A - layer 2 of 4	0.1	-6 (0.017)	31.2 (0.017)	10.4
Exterior Plaster A - layer 3 of 4	1.4	-5.9 (0.233)	31 (0.233)	10.4
Exterior Plaster A - layer 4 of 4 (interior)	0.1	-5.4 (0.017)	30.5 (0.017)	10.4
Monobrick	73	-5.2 (0.273)	30.1 (0.273)	16.5
Interior Plaster (Gypsum Plaster)	1.5	19.3 (0.3)	25.3 (1.5)	22.7
Water content [kg/m³]				
Exterior Plaster A - layer 1 of 4 (exterior)	0.4	1.877 (0)	62.776 (0)	15.994
Exterior Plaster A - layer 2 of 4	0.1	9.656 (0.017)	57.408 (0.017)	17.395
Exterior Plaster A - layer 3 of 4	1.4	15.653 (0.233)	24.062 (0.233)	18.319
Exterior Plaster A - layer 4 of 4 (interior)	0.1	15.875 (0.083)	22.571 (0.017)	18.666
Monobrick	73	1.429 (72.727)	14.779 (0.273)	9.536
Interior Plaster (Gypsum Plaster)	1.5	2.156 (1.5)	6.27 (0.3)	3.337

Zone 1/Component 3: U-effective [W/m²K] (theoretical value 0.098)

Orientation (area)	Total calc. time	Heating period	Cooling period
East (A90°, 21.58 m²)	0.04	0.082	
South (A180°, 41 m²)	0.04	0.082	
West (A270°, 25.38 m²)	0.04	0.082	
North (A0°, 62.2 m²)	0.04	0.082	

Zone 1/Component 3: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
East (A90°, 21.58 m²)	791411	0	844.2	90.3
South (A180°, 41 m²)	936495.2	0	881.6	106.9
West (A270°, 25.38 m²)	804971.6	0	810.9	91.9
North (A0°, 62.2 m²)	564158.7	0	348.2	64.4
Absorbed				
East (A90°, 21.58 m²)	0	0	0	0
South (A180°, 41 m²)	0	0	0	0
West (A270°, 25.38 m²)	0	0	0	0
North (A0°, 62.2 m²)	0	0	0	0
Inner surface (including radiant source)				
East (A90°, 21.58 m²)	8091.7	0	9.2	0.9
South (A180°, 41 m²)	8091.7	0	9.2	0.9
West (A270°, 25.38 m²)	8091.7	0	9.2	0.9
North (A0°, 62.2 m²)	8091.7	0	9.2	0.9

Zone 1/Component 3: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
East (A90°, 21.58 m²)	0.5	0.5	1
South (A180°, 41 m²)	0.5	0.5	1
West (A270°, 25.38 m²)	0.5	0.5	1
North (A0°, 62.2 m²)	0.5	0.5	1

Zone 1/Component 3, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
East (A90°, 21.58 m²)	0	2.73	-2.63	0	1.67	-1.54	-1.57
South (A180°, 41 m²)	0	2.73	-2.63	0	1.67	-1.54	-1.57
West (A270°, 25.38 m²)	0	2.73	-2.63	0	1.67	-1.54	-1.57
North (A0°, 62.2 m²)	0	2.73	-2.63	0	1.67	-1.54	-1.57

Zone 1/Component 4: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
South (A180°, 22.8 m²)	861701.2	0	843.2	98.4
Inner surface (including radiant source)				
South (A180°, 22.8 m²)	8091.7	0	9.2	0.9

Zone 1/Component 4: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
South (A180°, 22.8 m²)	0.451	0.5	0.903

Zone 1/Component 5: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
East (A90°, 3.8 m²)	791411	0	844.2	90.3
Inner surface (including radiant source)				
East (A90°, 3.8 m²)	8091.7	0	9.2	0.9

Zone 1/Component 5: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
East (A90°, 3.8 m²)	0.5	0.5	1

Zone 1/Component 6: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
North (A0°, 1.6 m²)	564158.7	0	348.2	64.4
Inner surface (including radiant source)				
North (A0°, 1.6 m²)	8091.7	0	9.2	0.9

Zone 1/Component 6: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
North (A0°, 1.6 m²)	0.5	0.5	1

Annex N: WUFI ®PLUS Report Combined Cases, Hybrid Construction

WUFI®Plus

Results

Heat gain/loss through components [kWh]

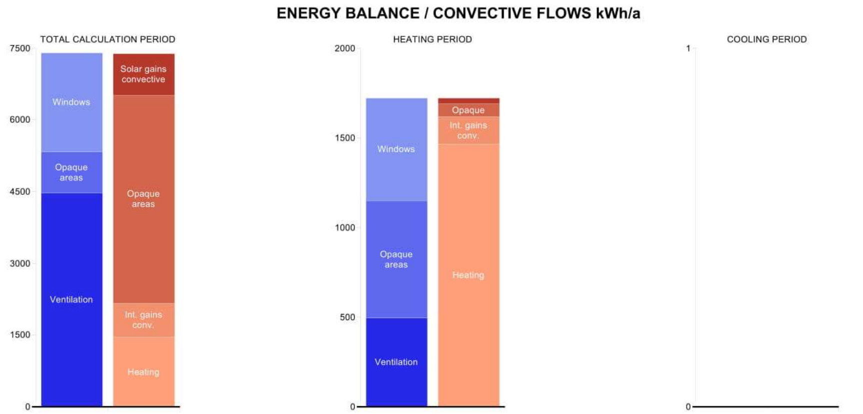
Nr.	Component group	Gain	Loss
1	Outer walls	372	900
2	Flat roof	822	1204
3	Ceiling to conditioned zone	1741	60
4	Inner wall	2798	96
5	Windows	8647	2057

Case 1/Zone 1: Main results

Setting	Value
Heating period [d]	66.7
Cooling period [d]	0
Heating demand [kWh]	1462.6
Cooling demand [kWh]	0
Humidification demand [kg]	0
Dehumidification demand [kg]	0

Min/Max/Mean values

Setting	Min	Max	Mean
Inner temperature [°C]	19.6	25.4	22.8
Inner relative humidity [%]	27.5	75.3	43.3
Heating load [kW]	0	1.9	0.2
Cooling load [kW]	0	0	0
Humidification [kg/h]	0	0	0
Dehumidification [kg/h]	0	0	0



Energy balance [kWh/a]

Setting	Total period	Heating period	Cooling period
Ventilation	8.2	0	0
Solar gains total	8639.4	302.7	0
Solar gains convective	863.9	30.3	0
Windows	7.3	0	0
Opaque areas	4346	74.9	0
Int. gains rad.	525.6	116	0
Int. gains conv.	700.8	154.7	0
Heating	1462.6	1462.6	0
Windows	2057.5	571.9	0
Opaque areas	873.3	656.9	0
Ventilation	4461	494	0

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	38	26	5	32
Thermal environment	I	II	III	IV

Percentage	65	35
Indoor air quality	I	II

Case 1/Zone 1: Heat gain/loss - Total calculation period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: Floor	1741	60
2	Component 2: Ceiling	822	1204
3	Component 3: Exterior Walls	372	900
4	Component 4: Window Front	6291	1466
5	Component 5: Window Side	1029	244
6	Component 6: Window Back	304	103
7	Component 7: Window West	1023	244

Case 1/Zone 1: Heat gain/loss - heating period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: Floor	145	21
2	Component 2: Ceiling	2	378
3	Component 3: Exterior Walls	0	461
4	Component 4: Window Front	222	407
5	Component 5: Window Side	36	68
6	Component 6: Window Back	13	29
7	Component 7: Window West	32	68

Case 1/Zone 1/Component 1: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
Interior Plaster (Gypsum Plaster)	1.5	19.9 (1.375)	25.3 (0)	22.9
Concrete, C12/15	29	19.9 (0.167)	25.2 (0.167)	22.9
EPS (heat cond.: 0.04 W/mK - density: 15 kg/m³)	5.5	19.9 (5.333)	25.3 (5.333)	22.9
ISOVER ISOCONFORT 032 (Switzerland)	4	19.8 (3.833)	25.4 (3.833)	22.9
CaSO4 Screed, top layer	7.3	19.8 (7.133)	25.5 (7.133)	22.9
Hardwood	1	19.8 (1)	25.5 (1)	22.9
Water content [kg/m³]				
Interior Plaster (Gypsum Plaster)	1.5	1.993 (0)	6.262 (1.375)	3.22
Concrete, C12/15	29	23.011 (0.167)	53 (9.604)	45.929
EPS (heat cond.: 0.04 W/mK - density: 15 kg/m³)	5.5	0.45 (5.333)	1.811 (5.333)	0.827
ISOVER ISOCONFORT 032 (Switzerland)	4	0.041 (3.833)	0.15 (0.167)	0.056
CaSO4 Screed, top layer	7.3	3.192 (7.133)	7.329 (0.167)	4.075
Hardwood	1	28.681 (1)	97.986 (0.2)	49.552

Case 1/Zone 1/Component 1: U-effective [W/m²K] (theoretical value 0.307)

Orientation (area)	Total calc. time	Heating period	Cooling period
horizontal (A0°, 192.5 m²)			

Case 1/Zone 1/Component 1: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Inner surface (including radiant source)				

Case 1/Zone 1/Component 1, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
horizontal (A0°, 192.5 m²)	0	0	-2.68	0	1.86	-4.55	-4.54

Case 1/Zone 1/Component 2: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
Optigreen Nature Roof 1 (grasses) 1-5	8	-5.7 (0)	42 (0)	12.6
Optigreen Nature Roof 1 (filter mat) 3-5	0.5	-3.9 (0.083)	34.6 (0.083)	12.9
PU (heat cond.: 0,025 W/mK)	16	-3.3 (0.216)	34.2 (0.216)	16.4
dena EPS (heat cond.: 0.03 W/mK - density: 30kg/m³)	8.4	13 (0.216)	27 (0.216)	21.1
vapor retarder (1perm)	0.1	19.2 (0.017)	25.2 (0.017)	22.5
Concrete, C12/15	26	19.2 (0.216)	25.2 (25.784)	22.6
Interior Plaster (Gypsum Plaster)	1.5	19.5 (0.188)	25.3 (1.5)	22.7
Water content [kg/m³]				
Optigreen Nature Roof 1 (grasses) 1-5	8	0.724 (0)	51.3 (0)	5.939
Optigreen Nature Roof 1 (filter mat) 3-5	0.5	0.503 (0.417)	0.7 (0.083)	0.595
PU (heat cond.: 0,025 W/mK)	16	0.481 (0.216)	1.973 (8.774)	1.12
dena EPS (heat cond.: 0.03 W/mK - density: 30kg/m³)	8.4	0.649 (8.184)	1.792 (3.04)	1.077
vapor retarder (1perm)	0.1	0.001 (0.017)	0.002 (0.083)	0.001
Concrete, C12/15	26	23.42 (25.784)	53 (1.22)	46.408
Interior Plaster (Gypsum Plaster)	1.5	2.014 (1.5)	6.256 (0.188)	3.255

Case 1/Zone 1/Component 2: U-effective [W/m²K] (theoretical value 0.098)

Orientation (area)	Total calc. time	Heating period	Cooling period
horizontal (A0°, 192.5 m²)	0.018	0.065	

Case 1/Zone 1/Component 2: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
horizontal (A0°, 192.5 m²)	1131693	0	948	129.2
Absorbed				
horizontal (A0°, 192.5 m²)	452677.2	0	379.2	51.7
Inner surface (including radiant source)				
horizontal (A0°, 192.5 m²)	8944	0	9.5	1

Case 1/Zone 1/Component 2: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
horizontal (A0°, 192.5 m²)	1	1	1

Case 1/Zone 1/Component 2, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow

Case 1/Zone 1/Component 3: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
FERMACELL Gypsum-Fibreboard	1.5	-5.6 (0)	30.9 (0)	10.5
Cellulose Fibre Insulation	28	-5.3 (0.164)	30.5 (0.164)	15.2
OSB plate	1.5	13.6 (0.125)	25.8 (0.125)	19.9
Mineral Wool (heat cond.: 0,04 W/mK)	6	14.1 (0.164)	25.8 (0.164)	20.9
Plywood	5	17.6 (0.164)	25.7 (0.164)	22.1
Interior Gypsum Board	1.25	18.7 (0.156)	25.6 (0.156)	22.4
Interior Gypsum Board	1.25	19 (0.156)	25.5 (0.156)	22.6
Interior Plaster (Gypsum Plaster)	1.5	19.2 (0.125)	25.5 (0.125)	22.7
Water content [kg/m³]				
FERMACELL Gypsum-Fibreboard	1.5	7.216 (0)	28.404 (0)	15.235
Cellulose Fibre Insulation	28	1.105 (27.836)	69.484 (0.164)	3.093
OSB plate	1.5	34.01 (0.125)	86.997 (1.375)	52.018
Mineral Wool (heat cond.: 0,04 W/mK)	6	0.321 (5.836)	2.675 (0.164)	0.632
Plywood	5	46.97 (4.836)	96.5 (0.885)	60.345
Interior Gypsum Board	1.25	2.951 (1.094)	8.65 (0.156)	4.084
Interior Gypsum Board	1.25	2.781 (1.094)	8.648 (0.156)	3.976
Interior Plaster (Gypsum Plaster)	1.5	2.037 (1.5)	6.281 (0.125)	3.251

Case 1/Zone 1/Component 3: U-effective [W/m²K] (theoretical value 0.097)

Orientation (area)	Total calc. time	Heating period	Cooling period
East (A90°, 21.58 m²)	0.033	0.105	
South (A180°, 41 m²)	0.033	0.105	
West (A270°, 21.58 m²)	0.033	0.105	
North (A0°, 62.2 m²)	0.033	0.105	

Case 1/Zone 1/Component 3: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
East (A90°, 21.58 m²)	791411	0	844.2	90.3
South (A180°, 41 m²)	936495.2	0	881.6	106.9
West (A270°, 21.58 m²)	804971.6	0	810.9	91.9
North (A0°, 62.2 m²)	564158.7	0	348.2	64.4
Absorbed				
East (A90°, 21.58 m²)	0	0	0	0
South (A180°, 41 m²)	0	0	0	0
West (A270°, 21.58 m²)	0	0	0	0
North (A0°, 62.2 m²)	0	0	0	0
Inner surface (including radiant source)				
East (A90°, 21.58 m²)	8944	0	9.5	1
South (A180°, 41 m²)	8944	0	9.5	1
West (A270°, 21.58 m²)	8944	0	9.5	1
North (A0°, 62.2 m²)	8944	0	9.5	1

Case 1/Zone 1/Component 3: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
East (A90°, 21.58 m²)	0.5	0.5	1
South (A180°, 41 m²)	0.5	0.5	1
West (A270°, 21.58 m²)	0.5	0.5	1
North (A0°, 62.2 m²)	0.5	0.5	1

Case 1/Zone 1/Component 3, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
East (A90°, 21.58 m²)	0	0.71	-2.75	0	2.02	-4.05	-4.07
South (A180°, 41 m²)	0	0.71	-2.75	0	2.02	-4.05	-4.07
West (A270°, 21.58 m²)	0	0.71	-2.75	0	2.02	-4.05	-4.07
North (A0°, 62.2 m²)	0	0.71	-2.75	0	2.02	-4.05	-4.07

Case 1/Zone 1/Component 4: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
South (A180°, 22.8 m²)	861701.2	0	843.2	98.4
Inner surface (including radiant source)				
South (A180°, 22.8 m²)	8944	0	9.5	1

Case 1/Zone 1/Component 4: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
South (A180°, 22.8 m²)	0.451	0.5	0.903

Case 1/Zone 1/Component 5: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
East (A90°, 3.8 m²)	791411	0	844.2	90.3
Inner surface (including radiant source)				
East (A90°, 3.8 m²)	8944	0	9.5	1

Case 1/Zone 1/Component 5: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
East (A90°, 3.8 m²)	0.5	0.5	1

Case 1/Zone 1/Component 6: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
North (A0°, 1.6 m²)	564158.7	0	348.2	64.4
Inner surface (including radiant source)				
North (A0°, 1.6 m²)	8944	0	9.5	1

Case 1/Zone 1/Component 6: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
North (A0°, 1.6 m²)	0.5	0.5	1

Case 1/Zone 1/Component 7: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
West (A270°, 3.8 m²)	804971.6	0	810.9	91.9
Inner surface (including radiant source)				
West (A270°, 3.8 m²)	8944	0	9.5	1

Case 1/Zone 1/Component 7: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
West (A270°, 3.8 m²)	0.5	0.5	1

Annex O: WUFI ®PLUS Report Combined Cases, Lightweight Construction

WUFI®Plus

Results

Heat gain/loss through components [kWh]

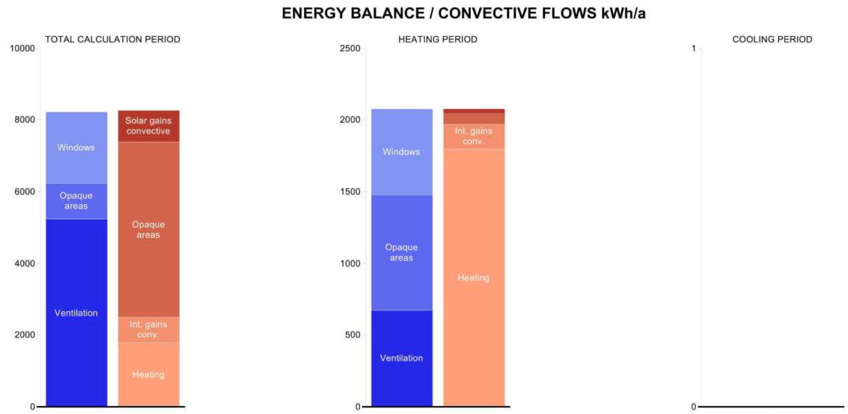
Nr.	Component group	Gain	Loss
1	Outer walls	553	1043
2	Flat roof	801	981
3	Ceiling to conditioned zone	2152	452
4	Inner wall	2895	35
5	Windows	8607	1993

Case 1/Zone 1: Main results

Setting	Value
Heating period [d]	71.1
Cooling period [d]	0
Heating demand [kWh]	1799.9
Cooling demand [kWh]	0
Humidification demand [kg]	0
Dehumidification demand [kg]	0

Min/Max/Mean values

Setting	Min	Max	Mean
Inner temperature [°C]	18	26.2	22.4
Inner relative humidity [%]	25.2	75.3	41.8
Heating load [kW]	0	1.9	0.2
Cooling load [kW]	0	0	0
Humidification [kg/h]	0	0	0
Dehumidification [kg/h]	0	0	0



Energy balance [kWh/a]

Setting	Total period	Heating period	Cooling period
Ventilation	9.1	0	0
Solar gains total	8599.9	309.4	0
Solar gains convective	860	30.9	0
Windows	7	0	0
Opaque areas	4889.6	76.4	0
Int. gains rad.	525.6	127.9	0
Int. gains conv.	700.8	170.6	0
Heating	1799.9	1799.9	0
Windows	1993.3	598.3	0
Opaque areas	1000.6	808.2	0
Ventilation	5235.2	671.2	0

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	31	22	8	40
Thermal environment	I	II	III	IV
Percentage	100			
Indoor air quality	I			

Case 1/Zone 1: Heat gain/loss - Total calculation period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: Floor	2152	452
2	Component 2: Ceiling	801	981
3	Component 3: Exterior Walls	553	1043
4	Component 4: Window Front	6270	1420
5	Component 5: Window Side	1037	237
6	Component 6: Window Back	302	100
7	Component 7: Window West	998	237

Case 1/Zone 1: Heat gain/loss - heating period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: Floor	195	18
2	Component 2: Ceiling	1	607
3	Component 3: Exterior Walls	0	454
4	Component 4: Window Front	226	426
5	Component 5: Window Side	38	71
6	Component 6: Window Back	13	30
7	Component 7: Window West	33	71

Case 1/Zone 1/Component 1: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
Plywood Board	2.5	18.7 (0)	26.3 (0)	22.5
Mineral Wool (heat cond.: 0,04 W/mK)	3	19.3 (1.739)	26.2 (0.081)	22.5
generic gravel	5	19.3 (4.919)	26 (4.919)	22.5
Softwood	1.5	19.3 (1.061)	26 (1.419)	22.5
ISOVER ISOCONFORT 032 (Switzerland)	4	19.3 (0.081)	26.1 (3.919)	22.5
ISOVER ISOCONFORT 032 (Switzerland)	1.3	19.4 (0.081)	26.2 (1.219)	22.6
Anhydritestrich	4.5	19.4 (4.419)	26.2 (4.419)	22.6
Hardwood	1	19.3 (1)	26.2 (1)	22.6
Water content [kg/m³]				
Plywood Board	2.5	20.175 (0)	75.143 (2.419)	41.076
Mineral Wool (heat cond.: 0,04 W/mK)	3	0.296 (0.081)	1.851 (2.919)	0.562
generic gravel	5	0.95 (2.9)	5.222 (0.081)	1.643
Softwood	1.5	23.342 (1.419)	60 (0.439)	33.382
ISOVER ISOCONFORT 032 (Switzerland)	4	0.03 (0.081)	0.14 (3.919)	0.043
ISOVER ISOCONFORT 032 (Switzerland)	1.3	0.03 (1.219)	0.141 (1.219)	0.042
Anhydritestrich	4.5	0.003 (4.419)	0.019 (4.419)	0.005
Hardwood	1	26.182 (1)	98.073 (0.081)	48.027

Case 1/Zone 1/Component 1: U-effective [W/m²K] (theoretical value 0.306)

Orientation (area)	Total calc. time	Heating period	Cooling period
horizontal (A0°, 192.5 m²)			

Case 1/Zone 1/Component 1: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Inner surface (including radiant source)				
horizontal (A0°, 192.5 m²)	8903	0	9.5	1

Case 1/Zone 1/Component 1, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
horizontal (A0°, 192.5 m²)	0	0	-0.89	0	1.59	-2.52	-2.48

Case 1/Zone 1/Component 2: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
generic gravel	8.75	-5.7 (0)	41.5 (0)	12.5
Flumroc-Dämmplatte 1	7.5	-4.9 (0.169)	38.5 (0.169)	13.6
Spruce, radial	1.9	2.3 (0.158)	30 (0.158)	14.7
Cellulose Fibre Insulation	26.5	2.9 (0.169)	29.6 (0.169)	18.5
Plywood	2.7	18.3 (2.7)	26.5 (0.169)	22.3
Water content [kg/m³]				
generic gravel	8.75	0.333 (0)	19.405 (0)	2.513
Flumroc-Dämmplatte 1	7.5	0.004 (7.331)	0.098 (7.331)	0.007
Spruce, radial	1.9	43.174 (0.158)	96.753 (1.742)	59.289
Cellulose Fibre Insulation	26.5	1.016 (26.331)	107.844 (0.169)	2.74
Plywood	2.7	33.956 (2.7)	96.535 (0.169)	53.8

Case 1/Zone 1/Component 2: U-effective [W/m²K] (theoretical value 0.098)

Orientation (area)	Total calc. time	Heating period	Cooling period
horizontal (A0°, 192.5 m²)	0.009	0.1	

Case 1/Zone 1/Component 2: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
horizontal (A0°, 192.5 m²)	1131693	0	948	129.2
Absorbed				
horizontal (A0°, 192.5 m²)	452677.2	0	379.2	51.7
Inner surface (including radiant source)				
horizontal (A0°, 192.5 m²)	8903	0	9.5	1

Case 1/Zone 1/Component 2: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
horizontal (A0°, 192.5 m²)	1	1	1

Case 1/Zone 1/Component 2, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
horizontal (A0°, 192.5 m²)	0	0	-0.91	0	2.15	-3.04	-3.06

Case 1/Zone 1/Component 3: Min/Max/Mean values

Layer	Thickn. [cm]	Min. (dist.[cm])	Max. (dist.[cm])	Mean
Temperature [°C]				
FERMACELL Gypsum-Fibreboard	1.5	-5.6 (0)	30.9 (0)	10.5
Cellulose Fibre Insulation	28	-5.3 (0.164)	30.5 (0.164)	15
OSB plate	1.5	13.3 (0.125)	26.2 (1.375)	19.6
Mineral Wool (heat cond.: 0,04 W/mK)	6	13.8 (0.164)	26.3 (5.836)	20.6
Plywood	5	17.1 (0.164)	26.3 (2.758)	21.7
Interior Gypsum Board	1.25	18.2 (0.156)	26.3 (0.156)	22.1
Interior Gypsum Board	1.25	18.4 (0.156)	26.3 (0.156)	22.2
Interior Plaster (Gypsum Plaster)	1.5	18.6 (1.5)	26.3 (1.5)	22.3
Water content [kg/m³]				
FERMACELL Gypsum-Fibreboard	1.5	7.205 (0)	28.555 (0)	15.211
Cellulose Fibre Insulation	28	1.112 (27.836)	69.765 (0.164)	3.093
OSB plate	1.5	34.194 (0.125)	86.88 (1.375)	51.636
Mineral Wool (heat cond.: 0,04 W/mK)	6	0.305 (5.836)	2.662 (0.164)	0.606
Plywood	5	44.879 (4.836)	96.5 (0.885)	59.365
Interior Gypsum Board	1.25	2.768 (1.094)	8.65 (0.156)	3.973
Interior Gypsum Board	1.25	2.587 (1.094)	8.648 (0.156)	3.857
Interior Plaster (Gypsum Plaster)	1.5	1.865 (1.5)	6.281 (0.125)	3.142

Case 1/Zone 1/Component 3: U-effective [W/m²K] (theoretical value 0.097)

Orientation (area)	Total calc. time	Heating period	Cooling period
East (A90°, 21.58 m²)	0.032	0.099	
South (A180°, 41 m²)	0.032	0.099	
West (A270°, 21.58 m²)	0.032	0.099	
North (A0°, 62.2 m²)	0.032	0.099	

Case 1/Zone 1/Component 3: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
East (A90°, 21.58 m²)	791411	0	844.2	90.3
South (A180°, 41 m²)	936495.2	0	881.6	106.9
West (A270°, 21.58 m²)	804971.6	0	810.9	91.9
North (A0°, 62.2 m²)	564158.7	0	348.2	64.4
Absorbed				
East (A90°, 21.58 m²)	0	0	0	0
South (A180°, 41 m²)	0	0	0	0
West (A270°, 21.58 m²)	0	0	0	0
North (A0°, 62.2 m²)	0	0	0	0
Inner surface (including radiant source)				
East (A90°, 21.58 m²)	8903	0	9.5	1
South (A180°, 41 m²)	8903	0	9.5	1
West (A270°, 21.58 m²)	8903	0	9.5	1
North (A0°, 62.2 m²)	8903	0	9.5	1

Case 1/Zone 1/Component 3: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
East (A90°, 21.58 m²)	0.5	0.5	1
South (A180°, 41 m²)	0.5	0.5	1
West (A270°, 21.58 m²)	0.5	0.5	1
North (A0°, 62.2 m²)	0.5	0.5	1

Case 1/Zone 1/Component 3, numerical quality

Component (part of component)	Number of convergence failures	Integral of fluxes [kg/m²]				Balance [kg/m²]	
		cap. outer	diff. outer	cap. inner	diff. inner	water content	moisture flow
East (A90°, 21.58 m²)	0	0.72	-2.64	0	2.22	-4.12	-4.14
South (A180°, 41 m²)	0	0.72	-2.64	0	2.22	-4.12	-4.14
West (A270°, 21.58 m²)	0	0.72	-2.64	0	2.22	-4.12	-4.14
North (A0°, 62.2 m²)	0	0.72	-2.64	0	2.22	-4.12	-4.14

Case 1/Zone 1/Component 4: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
South (A180°, 22.8 m²)	861701.2	0	843.2	98.4
Inner surface (including radiant source)				
South (A180°, 22.8 m²)	8903	0	9.5	1

Case 1/Zone 1/Component 4: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
South (A180°, 22.8 m²)	0.451	0.5	0.903

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Case 1/Zone 1/Component 5: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
East (A90°, 3.8 m²)	791411	0	844.2	90.3
Inner surface (including radiant source)				
East (A90°, 3.8 m²)	8903	0	9.5	1

Case 1/Zone 1/Component 5: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
East (A90°, 3.8 m²)	0.5	0.5	1

Case 1/Zone 1/Component 6: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
North (A0°, 1.6 m²)	564158.7	0	348.2	64.4
Inner surface (including radiant source)				
North (A0°, 1.6 m²)	8903	0	9.5	1

Case 1/Zone 1/Component 6: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
North (A0°, 1.6 m²)	0.5	0.5	1

Case 1/Zone 1/Component 7: Solar radiation

Orientation (area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
West (A270°, 3.8 m²)	804971.6	0	810.9	91.9
Inner surface (including radiant source)				
West (A270°, 3.8 m²)	8903	0	9.5	1

Case 1/Zone 1/Component 7: Shading factors (diffuse radiation)

Name	Sky view factor with shading	Sky view factor no shading	Shading factor (quotient)
West (A270°, 3.8 m²)	0.5	0.5	1